VARNA SCIENTIFIC AND TECHNICAL UNIONS

FIFTEENTH INTERNATIONAL CONFERENCE ON MARINE SCIENCES AND TECHNOLOGIES

Black Sea 2020

PROCEEDINGS

ISSN 1314 - 0957

October 28th, 2020
Varna, Bulgaria, ONLINE

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URL: nts.varna-bg.org
DOI: https://doi.org/10.7546/IO.BAS.2020.7

ISSN 1314 - 0957

Organized by:

VARNA SCIENTIFIC AND TECHNICAL UNIONS (VSTU)

In cooperation with:

TECHNICAL UNIVERSITY - VARNA
BULGARIAN NATIONAL ASSOCIATION OF SHIPBUILDING AND SHIPREPAIR (BULNAS)
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(3) Ship Hydrodynamics

(4) Maritime Transportation and Port Operations

(5) Shipbuilding and Ship Repair

(6) Machinery and Propulsion Systems

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Black Sea 2020

BLUE CAREERS

TRAINING, LEGAL STATUS AND PROFESSIONAL ACKNOWLEDGMENT OF SCIENTIFIC DIVERS - A REVIEW OF THE CURRENT STATE

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Abstract. *The paper presents the survey findings concerning legislation, training framework and professional acknowledgment of the scientific diving across Europe. The survey was carried out in the framework of ScienceDIVER project, co-funded by the EMFF. ScienceDIVER project aims to build solid -long lasting- collaborations between academia and industry, towards standardized training and clear career pathways for the diving scientists. The research reflects the current state of scientific diving, in countries with existing diving regulations and practices both globally and at EU level. The comparative analysis is based on selected methodology, criteria, collected relevant data and experts' standpoints and revealed significant deviations among EU countries. The asymmetries appear in the legal framework, the available training courses and the professional recognition of scientific divers. The outcomes emphasize the necessity of joint efforts aiming at elaboration of a common framework, harmonization and standardization of scientific diving within all in European countries.*

Key words: *blue careers, professional acknowledgment, scientific diving, standardization, training.*

INTRODUCTION

The project "Cross-sectoral skills for the Blue Economy labour market" (ScienceDIVER, www.sciencediver.eu) is co-funded by Executive Agency for Small and Medium-sized Enterprises/European Maritime and Fisheries Fund EASME/EMFF/2018 GA 863674. Seven institutions from various European countries participated the project as follows: Aristotle University of Thessaloniki (Greece), Atlantis Consulting SA (Greece), University of Calabria (Italy), University of Stuttgart (Germany), Envirocom (Germany), Marine Cluster Bulgaria (Bulgaria), Divers Alert Network Europe Foundation (Malta).

Scientific Diving (SD), according to the European Marine Board, is considered as a strategic area for the European community. Particularly, dive-based research is a valuable tool in scientific progress and maritime business growth. In accordance of the substantial growth of the marine scientific sector (estimated 10 € bn value added in 2020) with baseline year 2010 (EC, 2012) [1] and the corresponding opportunities for employment growth, the project ScienceDIVER overall aim is to create a structured/permanent collaboration framework between marine industry and education. The project benefits young scientists involved in underwater diving research activities, such as marine biology, geology, ecology, underwater archaeology, aquaculture, environmental protection/monitoring, oceanography, oil and gas extraction etc. The main objectives include:

- increase visibility of SD as a high quality - well paid profession;
- creation of links between academic institutions and maritime/diving industry;
- development of a job seeking platform, providing insights on market demands (to students/higher institutions), in terms of skills (input from industry);
- raising awareness of policy makers/competent organizations for the promotion, support, development and professional acknowledgement of SD;
- development of sea-basin network of actors of higher education, diving associations/organizations, industry

Marine Cluster Bulgaria (Bulgaria),**Aristotle University of Thessaloniki (Greece),Atlantis Consulting SA (Greece), ****University of Calabria (Italy), ***** University of Stuttgart (Germany), ******envirocom (Germany), *******Divers Alert Network Europe Foundation (Malta)**

and national/European public authorities, professional associations etc.

Although, the project's main aim is to study the status of SD in EU, the consortium partners expanded the scope to global level in order to increase the sustainability of the assessment and to examine the maturity and the potential progress existing in non-EU countries.

The current report is focused on survey findings concerning *legislation, training framework and professional acknowledgment* of the SD across Europe and at global level. The research reflects the current state of SD, in countries with existing diving regulations and practices both globally and at EU level. The comparative analysis is based on selected methodology, criteria, collected relevant data and experts' standpoints in order to identify the corresponding particularities among EU countries. The consistency between legal framework, available training courses and professional recognition of scientific divers is studied. Based on the established gaps in the legislation, training requirements and professional acknowledgement, measures are suggested leading to harmonization and standardization on EU level.

MATERIALS AND METHODS

A series of three surveys, concerning each of the investigated features (legislation, training framework and professional acknowledgment) on EU and at global level were performed in order to obtain relevant information. The principal approach consists of collecting publicly accessible/on-line facts, defining related terminology and/or assessment criteria and ratings, developing reliable system of questionnaires, on-line forms and interviewing mechanisms, performing stakeholder interviews and expert consultations and systematization, analyses and assessment of the collected data. While the studied features are interrelated, they still differ in nature and corresponding specifics in the methodology are applied.

Definition of terms regarding Scientific Diving

In the course of the initial investigation phase in order to support the data systematisation and to prevent any misinterpretations and misunderstanding, the following types of underwater activity were distinguished: 1) Occupational Diving 2) Professional Diving 3) Recreational Diving 4) Commercial Diving 5) Technical Diving 6) Surface-Supplied Diving 7) Off-shore Diving 8) Police Diving 9) Free Diving 10) Scientific Diving. This work was co-ordinated by envirocom with the active contribution of Divers Alert Network (DAN), Aristotle University of Thessaloniki and Atlantis Consulting SA.

On the ground of all existing definitions, leading specialists recommend that SD should be considered and dealt as a different category and not to be part of professional diving (Fig.1).

Fig. 1. Definition of Scientific Diving

Choice of assessment criteria and ratings

In order to provide consistent analyses and assessment it was essential to select relevant criteria. Each of the investigated features requires specific criteria.

Legislation. All legal frameworks are examined for: 1) The legal requirements of a Scientific Diver in order to perform a job; 2) The legal requirements in education regarding SD for professional acknowledgement; 3) The legal requirements in insurance policies regarding a Scientific Diver; 4) The payroll regulations; and 5) The acting practices that are followed regardless of the regulations. In addition, the countries at national level were categorized according to their maturity level on the legal regulations regarding SD into two categories: 1) Countries with clear, mature and advanced regulations regarding SD; and 2) Countries with no maturity level in SD. In the above country categories, it was furthermore assessed what is the legal consideration of the term SD (i.e. it is covered by professional diving, occupational diving, recreational diving regulations, etc.)

Training framework. The search and recording of the existing training courses are done on the basis of four criteria categories, i.e. 1) Prerequisites (input), 2) Technicalities (durations, costs, number of participants, etc), 3) Learning objectives (knowledge and skills) and 4) Certifications (outputs). The above criteria are selected in order to allow the description of the training courses on the context of "pathways", originating from an entry point (Prerequisites), passing through a fulfilment phase (Learning Objectives) and resulting to a destination point (Certification). Technicalities is considered as a complementary set of information for the logistics of each training course. Additionally, this recording of courses was accompanied by a relevance factor index to indicate whether the course was highly related to SD (factor index 3; direct reference to SD in course title and description), was medium related to SD (factor index 2; direct or indirect reference to SD in description) and low related to SD (factor index 1; no reference to SD in description).

Professional acknowledgment. Four groups of criteria are implemented in the assessment: derived by the terminology, substantial (connected to the skills required by legislation and to the working benefits), concerning the remuneration, cross-country recognition practices. The criteria derived by the terminology include: 1) The dive is a part of a scientific research with non-proprietary results; 2) The research is officially recognised; 3) A scientist is in charge of the activity; 4) The diver understands and is capable of implementing scientific technics; 5) The scientific diver instructor is relevantly certified;6) Intra-organisational regulations are developed; 7) SD is an occupational activity; 8) SD is considered professional if the diver is compensated specifically for the current diving. Substantial criteria consist of: 1) Existence of national regulations; 1) Requirement to appliance to national regulations; 2) Exemption from commercial diving regulations option; 3) Scientific Diver certification requirements; 4) General diving certification requirements; 5) First aid and/or CPR certification requirements; 6) Scientific expertise of divers requirements; 7) Organisational internal regulations requirements; 8) Medical examinations requirements; 9) Maximum depth requirements; 10) Insurance requirements; 11) Early retirement benefit. Remuneration related criteria are: 1) Existing national rules to compensate financially scientific divers; and 2) employer practice to compensate financially scientific divers. The cross-country recognition practices are defined by visitor scientific divers' cross-country requirements.

Data collection

At the initial phase of the research publicly accessible sources were used to define the fundamental parameters of the methodology: the terminology and the assessment criteria. The inherent information was collected through reliable system of questionnaires, on-line forms and interviewing mechanisms, performing stakeholder interviews and expert consultations. Correspondents represented either international organisations, national institutions or corporative structures. 5 international organisations and 72 countries altogether are subject of the research, including all EU countries, as well as countries from Europe and all over the world.

RESULTS

Legislation

The analysis of the collected data, based on the selected criteria reveals four distinctive groups of countries: with mature legal framework (orange colour on the map); such following national rules and codes of practice (blue) and countries that have no laws or regulations on SD (purple colour) (Fig.2).

Figure 3 presents the results distributed in following four categories:

G1) *Countries without any regulations concerning SD;* Most of the landlocked countries does not develop legislation concerning diving at all, although there are exclusions, as well there are countries with access to the sea which still do not have SD legislation. (36 % of the surveyed countries)

G2) *Countries in which SD is being practiced according to corporative rules or are candidate ESDP (Eu-*

ropean Scientific Diving Panel) members: These countries represent the largest group of the surveyed countries - 42 %. Legislation concerning diving exists, but SD is not included or is included on unclear terms.

G3) *Countries with partially developed or developing legislation or are ESDP statutory members:* These countries are predominantly EU countries in stable economical state and traditions in both diving, archaeology and marine science area. The share is 17 %.

G4) *Countries with matured legislation:* Special interest appears to be the set of the countries with mature legislation. Although they form the smallest group in the survey (only 6 %), these countries obtain strong economy, advanced industry and strong scientific sector.

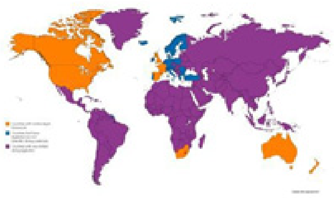

Fig. 2. Global map of countries by level of legislation

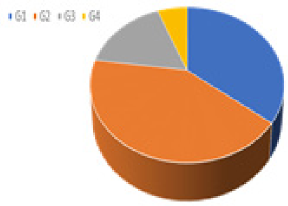

Fig. 3. Distribution by level of legislation

The most mature legal framework is implemented in USA, UK, Canada, Australia/New Zealand and South Africa. The legal strength of the authority follows the scheme [2]:

- *Statutes (laws).* Statutes are at the top of the legal hierarchy and are created by a legal body;
- *Regulations.* A regulation is the second step in hierarchy of law. Regulations have the force of law which is made by an executive authority under powers delegated by primary legislation;
- *Codes of Practices.* Codes of Practices do not have the force of the law. They provide guidance from the regulator on how to comply with requirements and obligations under work health and safety laws and regulations. They are used mainly in UK and Australia and they can influence court proceedings under the health and safety laws and regulations;
- *Standards.* They don't have legal force, but can similarly be used to establish norms for certain classes of diving. These are voluntary consensus documents, which, although not automatically a legal document, may be incorporated into legislation by reference or used in private contracts as a set of specifications and procedures. They are distinct from the American regulatory standards.

Training framework

Training framework survey is based on comparative analysis of 6 recognizable qualification systems, which are directly related to SD: 1) American Academy of Underwater Science (AAUS) / Canadian Association of Underwater Science (CAUS); 2) Australian Diver Accreditation Scheme (ADAS); 3) Confédération Mondiale des Activités Subaquatiques (CMAS); 4) European Scientific Diving (ESDP); 5) Global Underwater Explorers (GUE); and 6) Health and Safety Executive (HSE).

A summary of a comparison of each system to a set of predefined prerequisites, learning objectives and certification details is the core result of this mapping effort. The main comments on the results derived from this summary can be listed as follows:

- Regarding *Prerequisites*, the training system with most identified items is AAUS/ CAUS followed in descending order by ADAS, GUE, HSE, ESD and CMAS;
- Regarding *Learning Objectives*, the training system with most identified items is AAUS/ CAUS followed in descending order by CMAS, ESD, GUE, HSE and ADAS;
- Regarding *Certification Details*, the training system with most identified items are GUE and HSE followed equally by AAUS/ CAUS and ADAS, and then equally by CMAS and ESD.

Hence, it can be said that AAUS/ CAUS system is the most challenging one regarding prerequisites and Learning Objectives, but in terms of certification/ recognition GUE and HSE are the "winning" systems.

Requirements set by the training systems concerning entry level certification, learning objectives, titles attributed to successful trainees and their recognition as well other characteristics are presented in Table 1.

Professional acknowledgment

The survey aims at an evaluation of the degree of professional acknowledgment concerning the SD in both EU and global level. The evaluation is based on selected criteria, collected relevant data and expert standpoints. The survey succeeded in obtaining data form 18 countries: 10 EU-countries and 8 non-EU countries. Following results are obtained through systematisation of the collected data:

Identification of the required skills in becoming professionally acknowledged scientific diver. According to the collected data 33 % of the surveyed countries reported skill requirements on national level and 13 - on organisational level. There are only few countries requiring specific scientific diver certificate. Most of the countries require recreational certificates corresponding to the diving conditions.

Remuneration of scientific divers. The information about scientific divers' remuneration is scarce. In most cases the remuneration practice is not clear; either depends on separate projects capabilities, either on the practice in the specific organisation, or is not applied at all. Significant deviations appear by countries and vary from bonuses to the main salary in the range of 50 - 100 EUR/per diving day or monthly salary of 1000-2000 EUR in EU countries, and in USA were detected rates of 30,000 to 90,000 USD per year according to qualification. We may conclude that there is no consistent general policy in EU countries concerning SD remuneration

Other criteria

- only four countries (Australia, Canada, UK and USA) are reported to have distinct definition of the term "scientific diving". They are non-EU;
- in the legislation of the half of the reported countries (Albania, Australia, Canada, Italy, Poland, Singapore, South Africa, UK, USA) exists the term "scientific diver";
- in most countries which apply their national rules to SD is observed process to exemption from commercial diving regulations option;
- only 22 % of the reported countries require specific SD certificate. Two are EU countries - Germany and Romania (last requires this certification for archaeological purposes only);
- no proper data about scientific expertise of diver's requirements are available, neither on national, nor on organisational level;
- medical examination is commonly applied.

Characteristics of training systems regarding "Scientific Diving"

Table 1

CHARACTERISTICS			AAUS/ CAUS	ADAS	CMAS	ESDP	GUE	HSE
PREREQUISITES	ENTRY LEVEL (CERTIFICATION)		√	√	√	√	√	√
	ENTRY EXAMS		√	√				
	ADMINISTRATIVE		√				√	
	MEDICAL		√	√		√	√	√
	SWIMMING/ WATERMANSHIP		√	√			√	√
	EXPERIENCE		√	√	√	√	√	√
LEARNING OBJECTIVES	DIVE SAFETY		√	√	√	√	√	√
	PROJECT MANAGEMENT		√	√	√	√	√	√
	SCIENTIFIC METHOD		√		√	√	√	√
	DATA RECORDING & HANDLING		√		√	√	√	√
	LEGAL ASPECTS		√	√	√	√	√	√
	DIVE THEORY		√	√	√	√	√	√
	DIVE MODES		√	√	√		√	√
	SEAMANSHIP		√		√		√	√
	SPECIAL CONDITIONS		√					√
	SPECIALIZED EQUIPMENT		√		√	√		√
	OTHER TOPICS		√		√	√	√	
CERTIFICATION	TITLE	Scientific Diver	√		√	√	√	
		Professional Diver						√
		Occupational Diver		√				
	RECOGNITION	Europe			√	√	√	√
		Americas	√				√	
		Asia					√	√
		Africa					√	√
		Australia		√			√	√
	RECIPROCITY		√	√				√
	DISCIPLINES	Oceanography	√	√	√	√	√	√
		Archaeology	√	√	√	√	√	√
		Biology	√	√	√	√	√	√
		Ecology	√	√	√	√	√	√
		Geology	√	√	√	√	√	√
		Engineering	√	√	√	√	√	√
		Media						√

- few of the reported countries (Croatia, Italy, Latvia) limit the SD to a certain depth;
- insurance policy is commonly required where diving certification is required, predominantly on national level;
- visiting foreign scientific divers are generally not treated in the host country legislation; France and Australia reported relevant regulations.

CONCLUSIONS

Legislation

The general conclusion, especially for the EU countries, is that regulations can be found concerning health and safety standards, but SD is not clearly regulated.

A profound difference in legal framework concerning SD was recorded during the present research. Certain countries, mainly USA, UK, Canada, Australia/New Zealand and South Africa have more mature legal framework and SD is exempted from Occupational Diving. In most of the countries of the world, legal framework for SD does not exist at all, whereas Science Dives are performed with requirements that relate to recreational diving. In Europe, certain standards have been followed (such as the Standards from ESDP and CMAS) but they do not have legal enforceability. Most of the organizations that perform SD have their own protocols that are not the same but influenced from Codes of Practice and mature legislations in certain occasions.

The present study proved that very important legal gaps in most countries exist. There is not an acceptable clear international legal framework and certifications that will allow diving activity for scientific purposes in an appropriate way. Recommendations and Standards, such as the ones from ESDP are not fully incorporated in the national legislations whereas the respective certifications are not accepted by all EU members. The previous make the mobility of science divers a complex task and different certifications may be required from country to country. The lack of a legal definition for “scientific diving”, as well as the very complex framework, limits the extent of which SD could be applied for a list of research fields. An important legal gap is the different categorization of SD from occupational diving in some cases that allows the recruitment of occupational instead of science divers.

The first step to the harmonization of the legal framework must be to define what SD is. The legal definition will allow the exemptions from regulations regarding occupational diving. This task, when accompanied with other technical requirements and skills, such as the maximum depth, training of the scientific divers etc will provide the baseline for the legislative part. Harmonization of the legal framework globally speaking would be a difficult task, but it is possible due to the expertise, the efforts and the willingness of many scientific divers and related organizations, such as UNESCO, ESDP and CMAS among others. For the case of EU countries, a unique opportunity exists at present to integrate all the good practices from EU and non-EU countries, harmonize the respective definitions and standards and provide a brand-new legal framework based on all the good work that has been done for decades all over the world. An easier task to standardize legally is the safety regulations regarding SD, which can be based to the existing protocols and mature codes of practice that are followed. Scientific Divers have a very good record regarding safety regulations and very few accidents happened in decades.

Some countries (with matured legislation concerning SD) have managed to make the appropriate legal changes that can be the basis for further discussion, definition and orientation of science diving. At present, an EU directive that will include all the data presented in the present report could regulate all the respective issues concerning SD, allowing scientific divers to legally exist and be able to work in all EU countries after the appropriate training and certifications.

Training framework

Prerequisites. At the phase of the entry certification there are two options 1) Open Water + BLS; and 2) Rescue - CMAS ** (which includes BLS). All of the training courses require a number of logged dives.

Learning objectives. All training courses provide knowledge and skills on diving safety, project management, legal aspects and dive theory. The only one that does not require analysis of the scientific method is ADAS which is oriented on aspects of occupational diving (SD is provided as additional module). Most training schemes cover all diving modes (SCUBA, CCR, mixed gases, Surface supply) ESD has not yet covered all areas. AAUS and CMAS focus also on seamanship, whereas AAUS and HSE provide knowledge about operating in special conditions.

Certification. Besides ADAS (Occupational Diver) and HSE (Professional Diver) the rest of the training schemes deliver the title of "Scientific Diver". Recognition is not easily defined. In some cases, acknowledgement comes through the diver's employer, while in others through the certification agency. As far as regional recognition is concerned it depends on national legislation.
Training in SD covers almost all scientific disciplines.

Professional acknowledgment

On the basis of all material gathered from free sources, personal conversations, interviews and questionnaires several important issues could be defined:

- predominantly, there are not available legislative/official documents concerning the professional acknowledgment at national level. SD is not regulated in a clear manner, even in countries where it has been considered as well developed;

- The institutions set with the aim to promulgate SD (national associations such as AAUS, ADAS) are not nationally recognized by any state administrative act as organization responsible for the professional acknowledgment of scientific divers. In practice, they don't provide training courses and don't issue certificates. Usually they adopt minimum standards for the certification of scientific divers and their members further develop own manuals meeting the minimum requirements and the safety at work regulations applying for underwater work in the relevant country;

- the recognition of divers varies according national rules, but often companies employing divers for scientific research have own rules (at organizational level). The difference between EU countries is significant - some of them recognize ESD/AESD, others require commercial diving certificates, as well as some others - recreational diving certificates. Requirements could depend also on the sea conditions and specifics - low visibility, currents or diving below sea ice, i.e. in North Sea;

- a lot of countries recognize DAN insurance, as well as some others accept national occupational accident insurance. Usually companies pay the insurance for the divers employed, otherwise diver has personal insurance;

- the topic of remuneration seems very sensitive - there is not reliable information obtained. The options vary (in EU) from additional payment to the basic salary of the scientist for diving activities - amount per diving day, or to be based on the time spent underwater and the depth of performed work. Other countries define monthly salaries, the information about UK and USA is on yearly basis. The salaries depend on the organizations hiring the scientific divers, the place, the research site, etc. Additionally, there are scientists practicing diving supporting their researches, without any additional payment. It is remarkable that salary rates are not significantly bound to the minimum/average wages of countries. The scarcity of the information does not allow statistical analysis, but it can be concluded that 1) Scientific diver's labour remuneration is formed considering the ability of divers to migrate in regional or global scale; and 2) In countries with "mature" diving legislation divers, occupied in SD, would be employed permanently with this position, while in the rest of the countries rates would be lower and remuneration would be delivered as an addition/bonus to the salary.

All conclusions above demonstrate the necessity of establishment of common framework. The professional recognition is essential to divers involved in scientific researches. It is important to understand that SD is a particular underwater activity and restricting it within the frame of commercial diving is an obstacle to proper implementation of the tasks and may lead to withdrawal of skilled specialists. In some countries (exmpl. USA) this issue is solved by conditional removal of SD from the general safety legislation and applying appropriate rules developed and controlled by specific agencies.

Summary

The comparative analysis, based on selected methodology, criteria, collected relevant data and experts' standpoints, reveal significant variability both among the EU countries and among countries at the global level. The asymmetries appear either in the legal framework, the available training courses and the professional recognition of scientific divers.

On a EU level, joint efforts are necessary towards elaboration of a common framework, harmonization and standardization of SD within all European countries.

ACKNOWLEDGEMENTS

This paper reports a work developed within the project "ScienceDIVER: Cross sectoral skills for the blue economy market", which is implemented with the contribution of the European Maritime and Fisheries Fund of the European Union, under Grant Agreement Number 863674 - EASME/EMFF/2018

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PSYCHOLOGICAL ASPECTS OF THE PREPARATION AND CONDUCT OF A SEA EXPEDITION ABORA IV

Teodor ROKOV*, Dimitar STAVREV, Rositsa NEDEVA*****

Abstract. *An analysis of a performed experimental voyage with the ship Abora IV through the eyes of one of the participants in the mission is presented in this article. The whole process of the expedition performance is traced, from the ship building, the process of sailing to the return. The analysis is presented in organizational and psychological terms.*

Key words: *experimental archaeology, intercultural communication, personal experience, sailing.*

All great achievements are related to man's leaving the familiar and its zone of comfort. The thirst for adventure, the strive for better acquainting of the world, leads humanity to progress. The achievements of the ancient people and civilizations are increasingly attracting the attention of researchers and enthusiasts. From ancient times people have searched and built roads and ships, following their desire to conquer new territories. More and more researchers are looking for an answer how ancient sailors managed to reach distant lands, using primitive technologies.

Experimental marine archaeology is a branch of science, studying these technologies and the relevant sailing and navigation skills through practical experiments. The present article traces the process of building a replica of an ancient Egyptian ship made of reed, the sailing with it from the Black Sea to the Aegean Sea, the achieved aims and conclusions from the performance of such an experiment, represented by the Bulgarian participant in the voyage of Abora IV Mr Teodor Rokov.

In the past 2019, in the town of Beloslav the reed ship Abora IV was built. Volunteers and members of the crew of Abora IV took part in the building. The head of the building and expedition was Mr Dominique Görlitz - founder of the Association for Experimental Archaeology in Germany. The aim of the mission was to prove that ancient Egyptians carried out commercial contacts by sea with the people, living on the shores of the Black Sea and the Mediterranean Sea. The crew of ship Abora IV was composed of people of five different nationalities and this set an interesting task related to tracing the formation of the crew and the dynamics in it.

***Regional Historical Museum - Varna;**
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In seafaring, there are clear rules and obligations, related to the role and tasks of each member of the crew. In the conditions of an experiment, in which the crew has no special marine education and training, it is important to follow the crew formation, the aims and tasks setting and last but not least the role of the experiment leader and captain of the ship in building and maintaining interpersonal relationships on the ship. One important difference with sailing and standards, imposed in it, is that during the experiments performance, the two roles of head of the experiment and captain of the ship, were performed by one and the same person, who had no marine competencies. The mixing of these two functions is ineffective and may lead to accidents or even failure of the expedition. A vivid example from Bulgaria is the failed experiment with the Thracian ship 'Tsar Rezos' led by TV producer Atanas Dimitrov.

The beginning of the experiment (photo 1) started in Bulgaria, in the town of Beloslav, as the idea was ship Abora IV to be a replica of the ship of Thor Heyerdahl - Ra. 2019 marked 50 years since the voyage of ship Ra. [4]

Photo 1. The crew of Abora IV

The implementation of this ambitious idea met a number of administrative difficulties. Society gets acquainted with the final product, the final result only, as the difficulties overcome on the way to the goal remain concealed. The building of the ship in Bulgaria put Mr Teodor Rokov in the role of coordinator with all institutions and organizations. The heavy bureaucratic system, as well as the great number of required documents, may fail any initiative. The difficulties in the initial stage were caused by a number of mistakes, made by Mr Dominique Görlitz when preparing the documentation, related to the transfer of the necessary for the ship building reed from Bolivia to Bulgaria. This exposed the whole experiment to risk. Each problem has its solution as in this case it refers to one typical Bulgarian feature - 'self-respect'. Proving that this can be done in Bulgaria placing the latter on an equal level with all European countries. The trust in the 'honest word' that the merits of the country and the personal merits will be mentioned after the end of the expedition is enough to arouse enthusiasm, the patriotic spirit and pride, which motivate Bulgarian sponsors to make incredible efforts to overcome all difficulties. The administrative problems with visas, documents for cargo transport, provision of materials for the construction site on the shore, assistants in the ship building (we should note that Nikola Vaptsarov Naval Academy has provided four times a different number of cadets who participated in the ship building), administrative procedures related to the issuance of the necessary documents to permit its launching in the water - all hidden for society problems find their solution thanks to Bulgarian spirit and the desire to prove that we in Bulgaria can cope with everything. This is only a small part of the typical folk psychology of the Bulgarian, which is less and less shown in public life. Interestingly, in the conditions of democracy and market economy, trust in the 'honest word' still exists, but this lesson has a bitter taste. At the end of the mission the head of the project did not keep his promise to announce the role of Bulgaria and the institutions, which helped for the successful mission of Abora IV.

During the building of the ship Abora IV in the town of Beloslav, the mutual acquainting of the crew members began - Germans, Dutch, American, Russian and Bulgarian. [5] The necessity to build a unified and solid team is an important condition for the success of each initiative. The first stage of formation of a successful team is the acquainting of its members. Communication between members of the crew is maintained formally, strictly subject to the daily performed evening discussions (briefings with the aim of discussing the past day), the role of the captain as a head with expressed leadership style begins to emerge. Insufficient informal communication with the aim of personal acquaintance and building of trust may lead to severe accidents. Setting the language of communication in the ship - German, marked the beginning of the formation of 2 conditional groups in the crew - German speaking and others. By becoming acquainted with the stereotypes in the perception of the world and the method of communication, typical of the nationalities of the members of the crew, we can fix differences and possible conflict zones in communication. Knowing the national stereotypes can explain the difficulties or to prevent them. The peculiarities of German nationality: accuracy, punctuality, individual lifestyle, as well as the authority of the head are manifested in the method of communication. The figures of the state, the head and the father and the faith in them are decisive in the existence of Germans. The strive for domination, getting recognition is part of the German culture of communication. In contrast is the Slavic soul, characterized by optimism, expansion of thought, hospitality and commitment to personal and official life. The American business stereotype, which imposes a division of personal and official life, pragmatism, friendliness and patriotism, is strikingly different. During the mission the differences in thinking and perceiving the world, the style of communication played an important role in reaching the goal and achieving personal satisfaction. [2] [3]. The relations in a multinational crew are always a challenge, as their tracing on the ship Abora IV contributes to getting acquainted with the psychological factors, exerting influence over motivation, communication, leadership style and conflicts occurrence.

The directive commanding style, imposed as early as the beginning of the mission Abora IV by the head Mr Dominique Görlitz, developed during the voyage. Imposing German language as a language of official communication, as well as the refusal to use English, additionally created a barrier in the communication of the crew. The personal characteristics of the head of the crew strongly influenced the experiment. The strive to demonstrate power and attract attention, expressed in the sudden changes in the intended route, undermine trust in the head and increase the level of personal anxiety, related to the fear for physical survival. The watch teams (3 teams of four people each, the crew consisted of 12 people) were divided according to nationality and knowledge of the language, which is logical. A factor, complicating the cohesion of the crew, was also the shift of the members of the crew at each port. This led to a continuous process of adaptation to new persons with their peculiarities and to impossibility for formation of a fully functioning crew. The problems aggravated during the voyage due to the developing authoritarian style of the head of the expedition, characterized by increased control over the crew and desire to minimize all personal contacts. After the disembarking in Istanbul of Captain long sailing Aleksandar Aleksandrov, who provided all administrative procedures, related to launching in the water and permitting the expedition voyage to Executive Agency 'Marine Administration', assisted for the successful passing of the expedition through the Bosphorus by acting as a ship agent and implementing the initial contact between the head of the expedition Abora IV and the Turkish consul in Burgas, the attitude towards the other Bulgarian in the crew Mr T. Rokov changed drastically. Communication between the crew members in the person of Mr. Teodor Rokov and Prof. Alexander Bugaev from Russia was minimized to zero as they were relocated to different watch teams. The argument was that the crew shall not be divided into groups. The formation of a new watch team with a German, scarcely fluent in English, led to increase in the level of stress and anxiety. The relations between the members of the crew, who were not of German nationality, were characterized by negligence and at moments with open criticism. The strive to impose authority by exercising control in every field of communication - personal and official, led to lack of trust and aggravation of relations. The extremes in the leader's behaviour occurred in the speech as well. The conditional division of official and personal communication when setting different questions or problems began with the defined expression 'my friend', showing attitude and method of communication - formal or informal. After Istanbul the others were not allowed to address the captain informally, emphasizing on its commanding role. This violates one of the basic leadership rules - to maintain trust in the commander, as well as to perform permanent communication between different levels. In one small crew, which maintains constant control, only direct level of leadership may be developed, which includes immediate communication with the subordinate staff, knowing their problems and solving such personally. [1] The demonstration and desire to control, expressed by the head of the expedition, led to aggravation of relations, creation of prerequisites for conflicts, tolerating representatives of German society and disrespecting the others. Extremes in the captain's behavior were expressed at port Roumelli Hissar at the entrance to the Bosphorus, when the same gave orders for sailing without waiting for the two members of the crew, which were getting late. It is important to note that these are the Dutch and the American, who are not part of the 'privileged' group of the German speaking. With no information on where the subordinates are, what the problem is, the decision is single, as they had to find how to reach the ship on their own. Undoubtedly, national stereotypes influence the method of performing the expedition, defining the style of communication and leadership.

The parallel in the relations during the experimental sailing are obvious for Mr T. Rokov, who has experience in another similar expedition. In 2010 expedition called 'Danube Odyssey', led by Dr. Igor Melnik from Odessa, Ukraine, took place. The voyage began from Belgrade, Serbia along the lower Danube through the Djerdap Locks, the Iron Gates, the artificial water canal Chernavoda - Constanta and from there by sea south to Varna. The voyage was performed by a replica of a prehistoric boat made of carved oak trunk, equipped with a sail and oars. Teodor Rokov participated in its crew (photo 2), comprised of four Ukrainians. The comparison between the two expeditions shows that effective functioning of the crew is predominantly governed by a number of factors: Russian language which is common for all members, the identical mentality and close spirit, the direct communication with the head of the experiment and captain of the voyage (again one and the same person). The individual style of leadership as well as the individual personal characteristics of the head of the expedition and captain of the voyage are especially important for the successful implementation of the expedition.

Photo 2. The crew of 'Danube Odyssey'

After finishing participation in the voyage of Abora IV, the relations with the head of the expedition are limited to strict formal communication. The disappointment from non-fulfilment of the promises and responsibilities taken creates a conflict which is hard to overcome and does not exist in the eyes of the media. Evidently, the goals are reached and the mission is successful. The voyage is performed most of the time with the help of tugboats and a small part of the route is passed on sail, the navigation equipment used is modern which calls into question the ethics of the results achieved.

An important aspect of the performed expedition is tracing the course of the psychological processes on individual level. In the beginning, the responsibility to organize the building of the ship in the town of Beloslav is predominantly taken by Mr Rokov as this fact has psychological and emotional impact. Symptoms of increased stress begin to occur - anxiety, irritability for trifles. The family is a major source of support and maintains the process of stress control. Developing friendly relations with the American participant Tom Murphy also has a favourable influence. The friendly support has a buffer effect in the stress control, supporting coping with situations. Persistence, self-respect, dedication to the goal (idea) are part of the qualities, which characterize personality with a high level of resilience. During the expedition Mr Rokov could rely solely on his own efforts.

The possibilities for solitude, although minimal, compensate to some extent for the lack of cohesion of the crew and the sense of support, which is extremely important in performing voyages. Resilience develops exactly in the fighting with difficulties and their overcoming. Expanding the experience supports personality, enriching its lifestyle repertoire. After returning, thanks to relatives and friends, re-adaptation to normal everyday life takes place within a month.

The conclusions from the performed experiment may be considered in two directions: personal and organizational.

• In personal aspect the participation in such an initiative requires maintaining a high level of motivation, resilience and striving to achieve the goal, which is extremely hard. Facing personal problems - separation from the family (during the ship building and sailing), the lack of empathy on the part of the management body, the changing requirements towards participants in the course of the expedition lead personality to testing its own capabilities;

• The successful overcoming of all difficulties, as well as the rapid recovery indicate high personal resilience. The experience, gained in organizing the expedition, expands the lifestyle repertoire and forms clear and concrete ideas in the participant in the expedition Mr T. Rokov for the necessary means and opportunities for organization of a similar expedition referring to the documentary part and interpersonal relations;

• Trust, faith in the 'honest word' in the relations is necessary to be supported by all means with purely administrative procedures - signing and sealing of documented agreements between partnering countries;

• Mixing the two roles - scientific head of the expedition and captain of the voyage is not always functional;

• The preparation for work at sea, training for work in a team, as well as managing a multinational crew, which captains of ships have to pass, contribute to the successful implementation of the tasks assigned, which refers to voyages of experimental type as well;

• Lessons from practice prove once again the necessity and significance of preparation, which marine experts pass for successful completion of the voyage.

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Black Sea 2020

OCEANOLOGY

WIND WAVES AND THEIR IMPORTANCE FOR THE ECOLOGY OF A SEAGRASS FIELD

Elitsa HINEVA, Valentin PANAYOTOV

Abtsract. *The Sozopol Bay is one of the few coastal areas along the Bulgarian Black Sea that supports shallow water seagrass habitats. The area is remarkable for having two small islands which impact the local wave climate and consequently the ecological conditions within the bay. In the northern part of the bay there is a clear exposure gradient which impacts both the boundaries and the diversity of the seagrass meadow. The statistical modelling has shown that discriminating ability of the relationships varies from poor to satisfactory, indicating that the meadow is relatively protected from wave action.*

Key words: *biodiversity, the Black Sea, seagrass, wave climate.*

INTRODUCTION

Seagrass meadows are one of the most productive ecosystems on our planet [1]. They possess high ecological value due to the ecosystem services they provide [2]. The study on the ecological factors which impact seagrass communities is a primary task in the sustainable coastal zone management. One of the main ecological factors limiting spatial distribution of the wave sensitive seagrass species is the hydrodynamic one. In micro tidal seas like the Black Sea [3] wind waves are the main factor which limits the persistence of the seagrass communities in exposed coastal areas. The Bulgarian Black Sea coast is predominantly exposed to wave action [4]. There are few coastal areas where the wave climate favors the settlement of seagrasses and they are mostly concentrated in the Burgas Bay. One of the persistent shallow water seagrass meadows is located in the Sozopol Bay.

The aim of the present study is to assess the importance of the wind waves for the spatial boundaries of the "Gradina" meadows and to assume the possible consequences for the local ecology of the region.

MATERIAL AND METHOD

The methodology of wind regime, wave exposure and wave parameters calculation as well as statistical modelling and seagrass distribution are presented in detail [5] in Hineva (in press) and [6] Hineva, 2020. For estimation of the average wave height, length and period under the "deep water" conditions modelled data of wind speed and azimuth in front of the Burgas Bay [7] and wave fetches [8] were used. The CMS v. 2.5 (University of Cantabria) modeling software was used for wave parameters calculation under "shallow water" conditions. The bottom orbital velocity was estimated according to Hunt's method [10]. A generalized linear modelling [11] was used for search for a relation between the bottom orbital velocity and the seagrass shallow water boundary. It is assumed that if the model for a given direction was well-fitted, with large area under the ROC curve (AUC) and high percent of correct forecasts [11], [12], waves coming from that direction limit the seagrasses, while the opposite is true when the model showed a bad discriminative ability.

Seagrass boundaries were delineated after scanning the bottom with single beam echosounder (Garmin Chirp 42 CV) [5], during the summer season of 2018.

Sozopol Bay is a part of the greater Burgas Bay and is open towards northeast, well protected from south and southeast and relatively well protected from the north direction (fig. 1). A peculiarity of this bay is the presence of two small islands - Sveti Ivan and Sveti Petar, which create a specific wave climate in this area. There are two seagrass meadows identified within the bay: Gradina to the north and Sozopol-south to the south. (Fig. 1).

RESULTS AND DISCUSSION

The results from the statistical modeling have shown that the upper boundary of "Gradina" meadow is

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predominantly wave limited. There are two zones that can be easily distinguished in this area: smaller internal part which is wave protected and a bigger one whose exposure gradually increases as does the withdrawal of upper boundary towards greater depth. The waves approaching from northeast (azimuths 40°, 50°, 60°, 70°) impact the second area of the meadow (table 1).

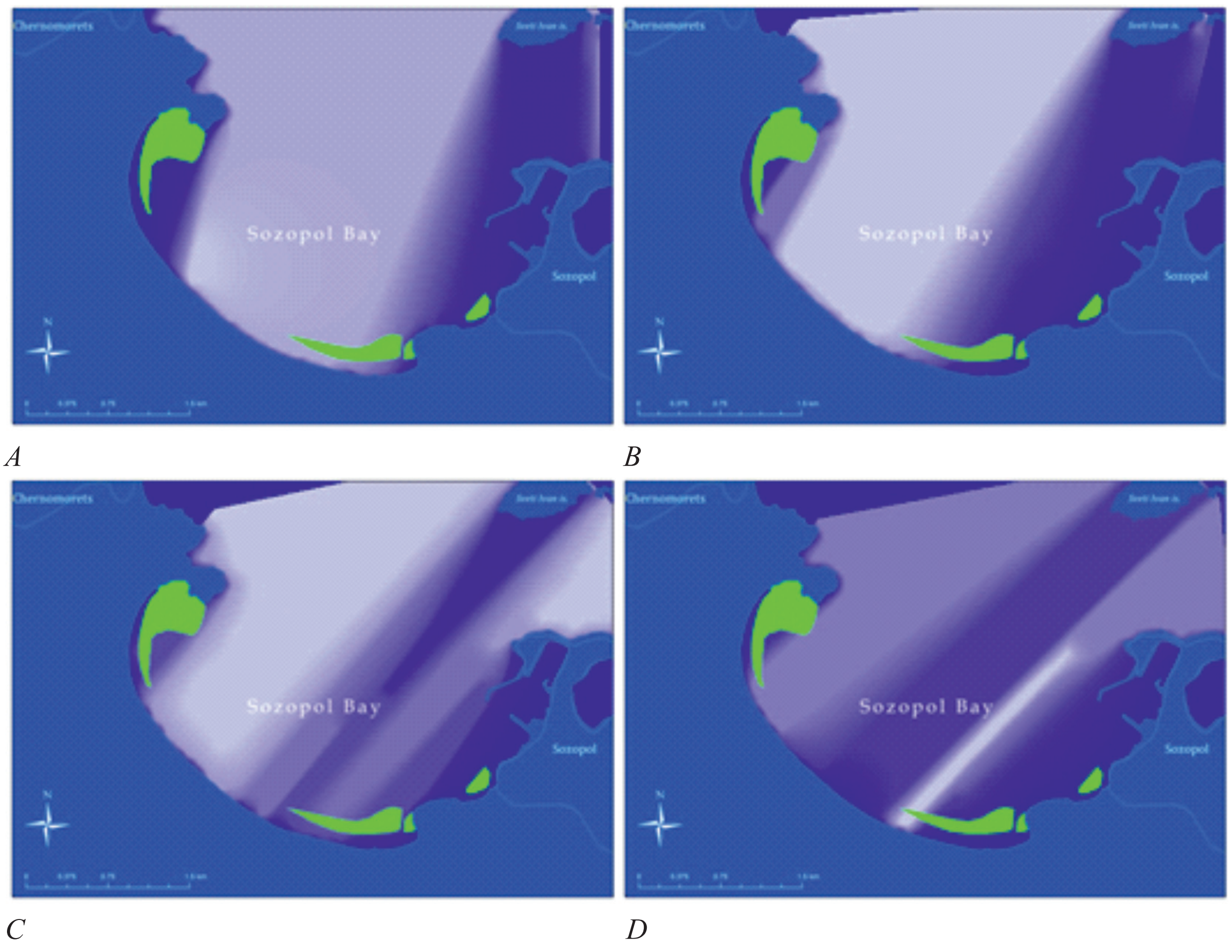
Results from statistical modeling between the bottom orbital velocity and the shallow boundary of the seagrass meadow

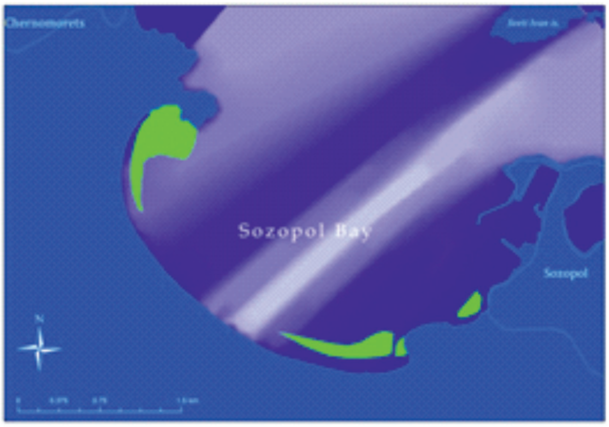
Table 1.

№	Azimuth, degrees	Coefficient b0	Coefficient b1	Correct Forecasts, %	AUC	Discriminating ability acc. [13]
1	20	0,81	-38,9	68	0,50	poor
2	30	1,24	-41,9	75	0,61	poor
3	40	1,95	-55,5	79	0,75	satisfactory
4	50	1,43	-209,9	75	0,76	satisfactory
5	60	1,56	-68,2	80	0,75	satisfactory
6	70	2,04	-25,8	82	0,70	satisfactory
7	80	1,43	-6,17	72	0,62	poor
8	90	0,02	6,33	63	0,62	poor

When waves come from azimuths 20°, 30°, 80° and 90° the spatial distribution of bottom orbital velocity cannot explain the spread of the seagrass in this meadow, because the area is protected from cape Chervenka and Sozopol peninsula (Fig. 1 A, B and G, H).

The islands Sveti Ivan and Sveti Petar have limited ability to shadow the bay. As they are two small they cannot protect the whole Sozopol Bay area. This is the most probable reason why there have formed two seagrass meadows and not only one along the whole coast.





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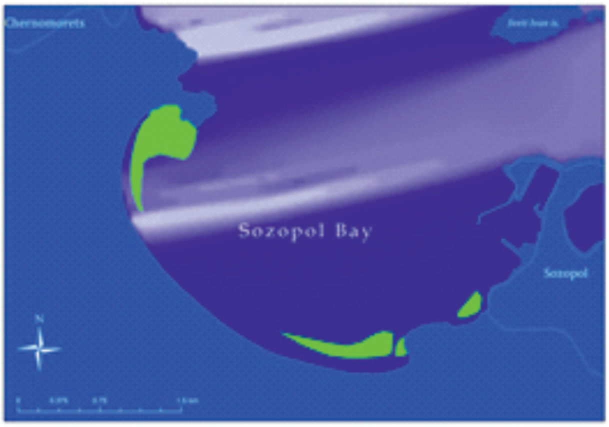

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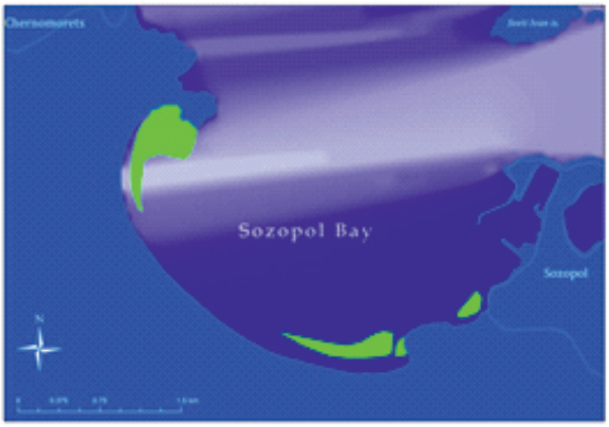

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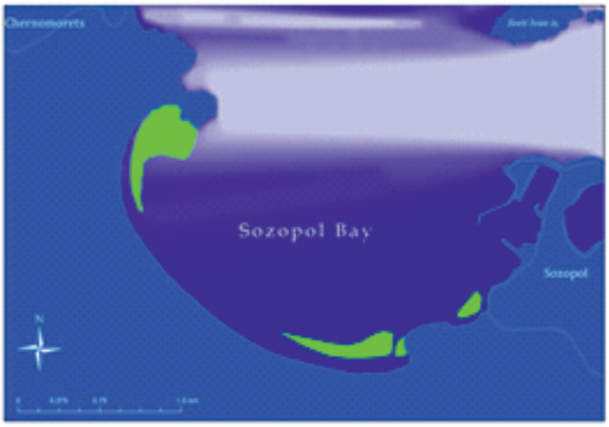

H

Fig. 1.
Distribution of the wave height in the Sozopol Bay when wave approaching from different azimuths: A - 20 °, B - 30 °, C - 40 °, D - 50°, E - 60 °, F - 70 °, G - 80 °, H - 90 °. The maximum wave height is in light shade and the minimum - in dark shade

The comparison with other studied coastal bays has shown that the Gradina meadow is more wave protected than the meadows located along the north coast of Nesebar Bay, Lachna Bay and Vromos Bay but is more wave limited that the meadows located in the most sheltered parts of the Bulgarian coast: Chengene Bay and Foros Bay.

Not only the boundaries of the "Gradina" seagrass field are wave limited but the dominant macrophyte species could be related with the local hydrodynamic conditions. There is obvious gradual change in the dominant species of the seagrass community along the wave exposure gradient. In the most protected area up to the 1.5 m depth the community consists of the tolerant species *Z. pallustris* L. and *Stuckenia pectinata* (L. (Borner) in combination with *Z. noltei*, Hornemann. At a greater depth only the second one is dominant. In the most exposed area the upper limit lays at a 4 m depth and the community is dominated by the more sensitive Z. marina L. This species distribution can be related with the different sensitivity of the dominant species towards nutrients and the heterogeneity in their spatial distribution caused by the different water retention time. Although direct measurement of the water retention time in the different areas are currently lacking, based on the well-known relation between the coastline openness and water exchange one can suppose the most protected parts have more stagnate conditions than the more exposed one. In the most protected area the nutrients are accumulated and retain longer thus affecting the plant community - the sensitive *Z. marina* is absent but more tolerant species are present. Their leaves and stems are heavily covered by epiphytes, including well developed macroalgal ones. The longer living above ground stems of *Z. pallustris* and *S. pectinata*, offer more permanent substrate for epiphytes colonization. Thus not only the tendency to accumulate and retain nutrients but the longer available substrate are acting together to sustain rich and abundant epiphyte community. The opposite is true about the most exposed area which has a better water exchanges the meadow is dominated by *Z. marina*. Here the water dynamic is more intensive and all the nutrients are quickly exported from the area. The epiphyte cover on seagrass leaves is scarce although as a bigger species Z. marina leaves have longer life [14], [15] and suppose more abundant epiphytes [16]. Obviously here the importance of seagrass substrate longevity is masked by the wave exposure effect.

The wave action can impact epiphytes directly causing their easier sloughing from the substrate surface e.g. [17]. The intensive hydrodynamic can affect periphyton indirectly, as well. This is done through its impact on the top-down control, supporting lower abundance of the grazing pressure [18] or through the impact on the bottom – up control via fast dilution and export of nutrients from the shallow water towards the open sea [19], thus sustaining low nutrient concentration or contributing to inflow of nutrients via water mass "renewing" [20].

CONCLUSION

The present study has shown that seagrass fields in the Sozopol Bay area are impacted by wind waves. The small natural protection (Sveti Ivan and Sveti Petar islands) cannot completely shadow the bay, and that is why there have formed two seagrass meadows in both most protected bay areas. In the middle of the bay, where the waves approach more or less unaffected by obstacles, the bottom up to 6 m depth is lacking permanent seagrass cover but only small separate spots are present. The wave climate is an important factor for the local ecology and can be used both understand the specific macrophyte biodiversity and to plan human pressure sources in way that minimizes their negative effect on seagrass meadows. Further research is recommended in order to understand more in detail changes observed at a community level along the exposure gradient.

ACKNOWLEDGEMENTS

This study was partially financed by the Bulgarian Ministry of Water and was partially been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № Д01-322/18.12.2019.

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MICROPLASTIC POLLUTION OF POMORIE LAKE, BULGARIAN BLACK SEA COAST

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Abstract. *Microplastics are ubiquitous across ecosystems and there are growing concerns about potential threats to the ecosystems and humans. Microplastic pollution assessment is a pioneer activity in the Bulgarian part of the Black Sea. To expand the understanding of microplastics in the marine environment, we performed a case study at four stations in the Pomorie Lake, considering abundance and spatial distribution of microplastics in the surface layer of the water column and sediments. The investigation was in the frame of BioLEARN BSB142 Project activity. For the analysis, density separation was implemented. The identification of microplastics was performed under a microscope examination. The abundance of microplastic particles varies between 61 and 333 in samples or between 31 and about 14000 microplastic particles per cubic meter of water. Fibres were the most abundant and occurred at all stations. A long-term microplastic litter assessment program is required in the Bulgarian Black Sea area.*

Key words: *Bulgarian Black sea, fibres, marine litter, ultra-saline littoral lagoon.*

INTRODUCTION

Recently marine environment, ecosystem goods and services have been adversely affected by the expansion of coastal and marine human activities. The last generate considerable quantities of waste contaminating the marine environment. Much of this litter persists in the environment for years, decades or even centuries. The occurrence of litter has been demonstrated worldwide: in oceanic gyres, on shorelines, in sediments and the deep sea [1]. Additionally, transitional water ecosystems are largely affected by human pressures as well. Plastic input in coastal ponds, lagoons, river deltas and estuaries, could be driven by a wide range of human activities such as agriculture, waste disposal, municipal and industrial wastewater effluents, aquaculture, fishing and touristic activities and urban impacts [2]. Thus, marine litter, particularly microplastics, is now a global challenge. Research on microplastic (MP) waste has grown rapidly over the last decade, gaining recognition as an "emerging problem of international concern" [3], but lacking standardization in sampling methods, laboratory analysis and data reporting [4].

Microplastics categorized as plastic fragments, pellets, fibres, plastic films, granules and foamed plastic. Microplastic fibres can be carried by watercourses and sewage systems, before being deposited in the seas and oceans via discharge outlets [5], [6]. Moreover, large amounts of microplastics have been observed to be able to pass straight through collection filters at municipal sewage treatment plants [7]. Aside from fibres, wastewater often contains large amounts of other plastics, such as microbeads (small spherical particles of plastic less than 1 mm to 1 μm in size) and nanoplastics.

Although marine plastic waste is recognized as a global problem, there is insufficient data on the extent of microplastic pollution in the Black Sea. In this study, the composition and density of coastal microplastics in Lake Pomorie were analyzed as indicators of marine micro-waste pollution. The sampling area (Pomorie Lake) is an ultra saline natural lagoon, separated from the sea by a sandbank and an artificial dike. In its southern part, there is a connecting channel through which part of the inflow of seawater takes place. Pomorie Lake is about 6-7 km long (in the NS direction) with a maximum width of 2 km. It covers an area of some 7-8.5 sq.km. and its waters are relatively shallow, of an average depth of 0.6 m. The bottom of the lake is covered with black mud, rich in minerals and trace elements. The northern part of the lake is used for 20 centuries for salt yield. The

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salinity varies from 1 to 140‰, mainly 50 - 70 ‰. Pomorie Lake and the adjacent territories have been declared a Protected Site under Bulgarian law (2001) and a Ramsar site within the meaning of the Ramsar Convention for the Protection of Wetlands and Waterfowl.

MATERIAL AND METHODS

All samples were taken in April 2020 at four stations (Fig.1): Bank, Mud deposit, Healing mud and Saltworks museum. The first two samples were taken by a horizontal zooplankton net, mesh size 150 µm. The net was drawn about 100 m distance with 2 km/h speed on the water surface. The southward samples the Healing mud and the Salt museum were taken with glass containers respectively from the mud and salt. The wind speed was below 10 km/h with east direction.

In the laboratory, samples were treated with saturated sodium chloride (NaCl) solution for density separation. The organic matter was removed with 30% hydrogen peroxide for 1-3 days. The filters were examined under a stereomicroscope Olympus SZX10 and each particle was categorized according to shape and colour. Each filter was reviewed by another person. Blank controls were made, with NaCl solution and H2O2.

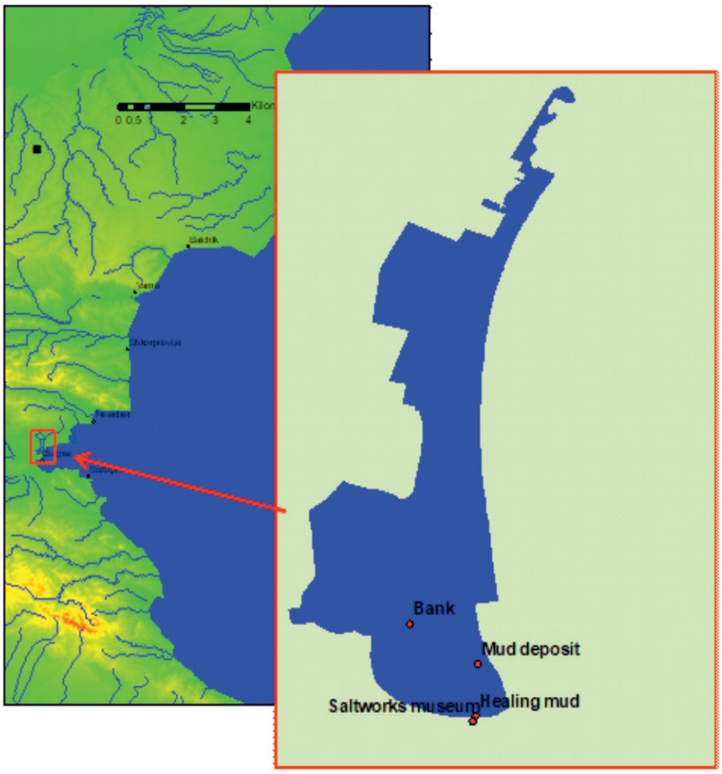


Fig. 1. Location of sampling stations in spring 2020

RESULTS AND DISCUSSION

A total of 550 microplastic particles were found in the 4 samples (2 water, 1 lye and 1 mud sample). The concentration of MPs differs significantly among 4 stations. Fig. 2 shows that the MPs abundance ranges from 61 to 333 items or 31 to 14355 items/m³, which is represented in the size of pie charts in Fig. 3. The abundance results were recalculated for square and cubic meters for comparability between stations. The highest abundance was detected at station Mud deposit in the water surface and the lowest at Bank. When the items were recalculated per area and volume the highest concentrations were established for sediment and lye because of the lower sampling volume and area. Despite the large range of the data, the difference between sampling stations and different colored fibres is not statistically significant (ANOVA test $p>0.05$).

A wide spectrum of colors was observed for the MPs during the field survey. Fig. 2 indicates that the dominant color of MPs in the Pomorie Lake is blue (~36.2%), followed by transparent (29%), grey (27%), brown (11%), black (~9) and so on.

The difference in distribution could be related to water dynamics and to a greater extent to different environments. Microplastics tend to accumulate in low-dynamic areas, commonly sandbars and the inner part of the lagoon; while low microplastic levels are recorded in sediments from zones characterized by a water current > 1 m/s [8]. Lake Pomorie has no constant currents. During the spring season, the lake water level is usually higher than sea level [9] and probably the direction of the current is from the lake to sea. The accumulation expressed per square and cubic meter is higher in the southern part, where the connection to the sea is. The prevailing north - northeast winds in the spring could affect the higher concentrations in the south. The samples there were taken from lye and mud.

Types of microplastics found in the study were mainly fibres (90.16-100%) - Fig. 4 A, B. Microfibres are among the most prevalent type of microplastics observed in the marine environment [10]. A recent study reported that transitional water ecosystems could be more affected by fibre pollution than marine ecosystems [11]. The fibres denser than seawater like cellulosic and polyester are more likely to sink and accumulate in sediments [12].

Most of the Black Sea microplastics studies also reported fibres as most common microplastic [13], [16], [17] , [18], [19], [20], [22] but microfibres abundance identified in Pomorie lake is higher compared with results of cited papers [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24] - Table 1. There is a lack of consistency in sampling and extraction techniques used to quantify microplastics. Because of the large variety in techniques applied, a comparison of reported microplastic concentrations between studies is difficult and often requires additional calculations based on assumptions [25]. On the other hand, higher concentrations can be attributed to the higher vulnerability of transitional waters [11] and the location of the lake in an area under the strong anthropogenic influence, exposed to the direct or indirect influence of industrial and municipal discharges, port operations, tourism development and inputs from diffuse sources.

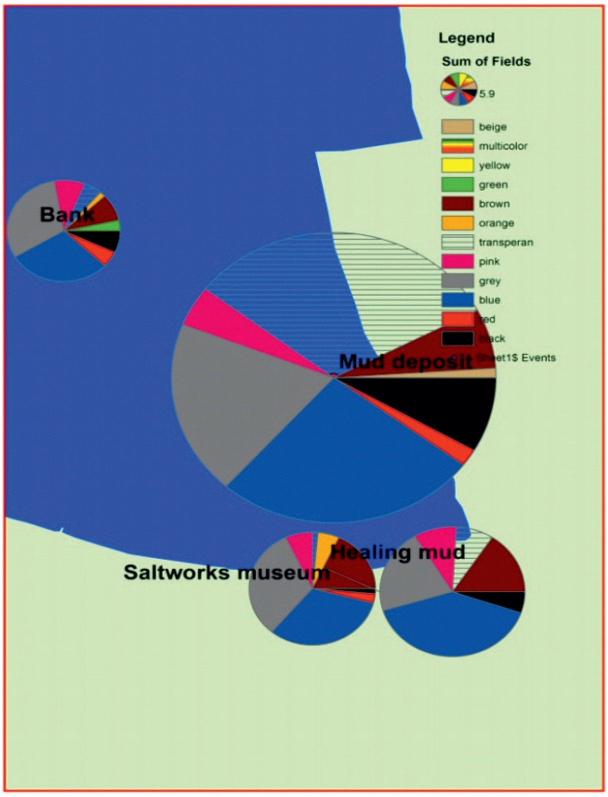


Fig. 2.
Abundance of microfibers in Pomorie Lake

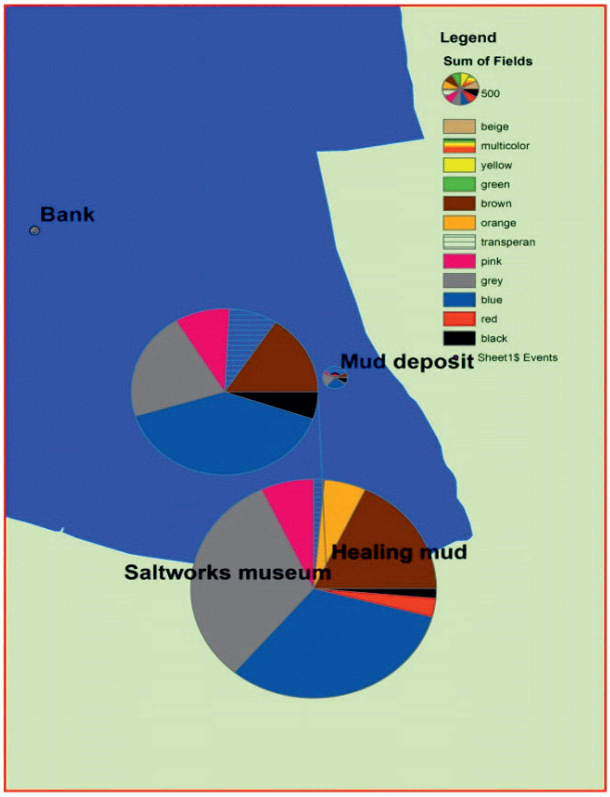


Fig. 3.
Distribution of microfibres items/m3

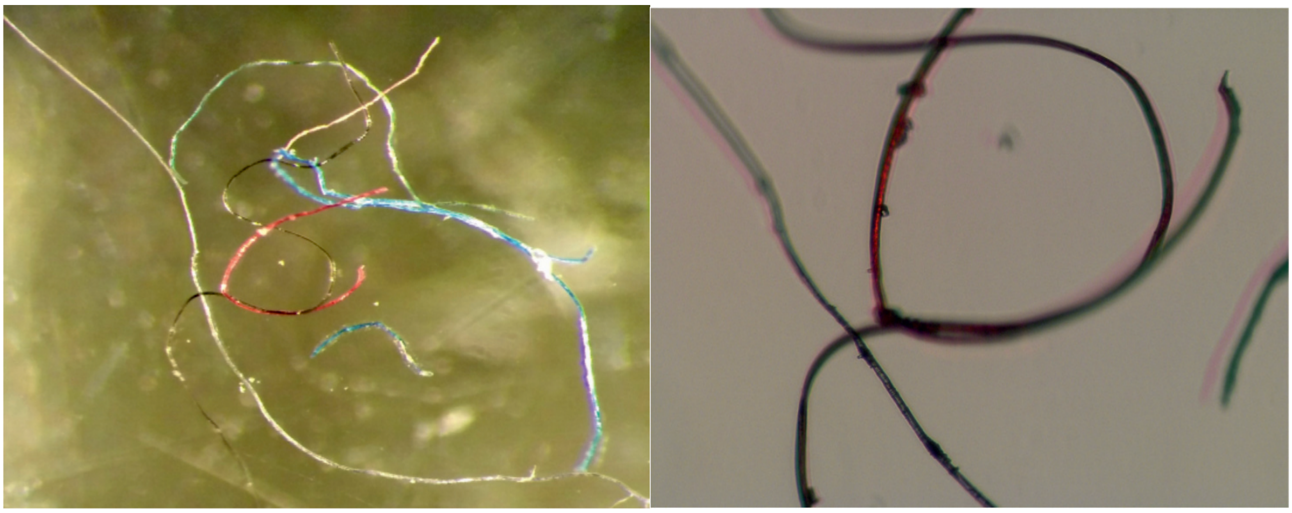
Comparison of investigated microplastics abundance with other Black Sea studies (N- northern, NW - northwestern, W - western, S - southern, SW - southwestern)

Table 1

	Dominating shape	Items/kg	Per m³	Per m²		Source
NW Black Sea	fibres		9		water	[13]
W Black Sea	fragments		0.15-2.54	0.014-0.19	water	[14]
Southern Black Sea	ship paint, fibers		2.67-26.15		water	[15]
W Black Sea	fibres		$3.11x10^{1}$-$1.66x10^{2}$	3.66-$1.96x10^{1}$	water	This study
W Black Sea	fibres		$7.96x10^{3}$-$1.44x10^{4}$	$1.01x10^{3}$-$1.25x10^{3}$	mud and lye	This study
Black Sea	fibres	0 - 390			sediment	[16]
W Black Sea	fibres	102			mud	This study
W Black Sea	fibres	286			lye	This study
SE Black Sea	fibres		$0.16x10^{3}$-$3.28x10^{3}$		water	[17]
NW Black Sea	fibres	36 - 64			sediment	[18]
Southern Black Sea	fibres	6 - 14			sediment	[19]
NW Black Sea	fibres			(Σ per area) 29-541	sediment	[20]
N Black Sea	fragments				sediment	[21]
NW Black Sea	fibres		3 - 650		water	[22]
Southern Black Sea	fibres	8 - 102			lake salt	[23]
W Black Sea	fragments	12			sea salt	[24]

Sources of plastic litter in the transition water ecosystem are wide as these ecosystems are largely impacted by agricultural, industrial and municipal effluents [26], [2].

The fibres are mostly discharged into wastewater from domestic washing machines [27], each garment producing between 1,900 and 700,000 fibres [28] [10], [12], [25], [29].



A **B**

Fig. 4.
A, B - Images of microfibres identified in spring 2020 in Pomorie lake

CONCLUSION

The study presents preliminary results but first in the Bulgarian transition water ecosystem and the second in the Bulgarian Black Sea zone. They reveal the fibre microplastics pollution in the coastal Black Sea zone. Further studies are needed to identify the amount and spatial distribution of this type of effluence in the Black Sea and the adjacent area.

ACKNOWLEDGMENTS

This work has been carried out in the framework of the BioLEARN BSB142 Project "Eco-Conscious Minds to Stop Pollution in the Valuable Wetlands of Black Sea Basin" funded by ENI CBC Joint Operational Programme BLACK SEA BASIN 2014-2020. The study was supported by Project National Geoinformation Centre, Contract D01-161/28.08.2018 (Ministry of Education and Science).

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SPATIAL DISTRIBUTION OF CYST MORPHOTYPES OF SCRIPPSIELLA ACUMINATA COMPLEX IN THE BLACK SEA SURFACE SEDIMENTS IN RELATION TO ENVIRONMENTAL FACTORS

Ivelina ZLATEVA*, Nina DZHEMBEKOVA*, Fernando RUBINO, Nataliya SLABAKOVA*, Violeta SLABAKOVA* and Snejana MONCHEVA***

Abstract. *The present research aimed to disclose a link between the spatial distribution and abundance of different cyst morphotypes of Scrippsiella acuminata and in situ environmental variables. Surface sediment samples collected at 30 sites in the Black Sea, were screened for Scrippsiella acuminata cyst morphotypes presence during spring and summer. The cysts data were analyzed along with environmental in situ sampling site variables (temperature, salinity, water transparency, Chlorophyll a, ammonia, nitrates and phosphates concentrations). Canonical correspondence analysis (CCA) was employed to the in situ data to expand our understanding of specific morphotypes traits/environment relationships and niche breadth. The analysis highlighted statistically significant model, linking Scrippsiella acuminata cysts morphotypes distribution with temperature, salinity and eutrophication.*

Key words: *Black sea, CCA, cyst distribution, environmental variables, Scrippsiella acuminata.*

INTRODUCTION

Resting cysts are a common part of the life cycle of many dinoflagellates [1] that accumulate in sediments and remain alive for long periods affecting the dynamics of the pelagic population [2]. Dormant propagules have been considered an adaptive strategy of phytoplankton to survive adverse environmental conditions [3], while intraspecific morphological variability among cysts produced by some species have been associated to variations of the environmental conditions [4].

The cosmopolitan dinoflagellate *Scrippsiella acuminata* (Ehrenberg) Kretschmann, Elbrächter, Zinssmeister, S.Soehner, Kirsch, Kusber & Gottschling, 2015 is one of the dominant microalgae in the Black Sea reported as bloom-forming species [5]. Furthermore, the cysts of this species are amongst the most abundant resting stages recorded in surface Black Sea sediments [6,7]. Interestingly, a high intraspecific morphological variability of *Scrippsiella acuminata* cysts has been observed in the Black Sea [8].

The aim of this study was to investigate if there is a link between *Scrippsiella acuminata* morphotypes spatial distribution and environmental factors. Sea surface temperature (SST), sea surface salinity (SSS), nitrates (NO3), ammonia (NH4) and phosphates (PO4) concentrations in the water column, water transparency/ Secchi depth (WT), Chlorophyll a (Chl a), and the sediment substrate were analyzed as plausible drivers of morphotypes spatial distribution.

MATERIALS AND METHODS

The present study covered Romanian, Bulgarian, Turkish, Ukrainian and Georgian territorial waters. Surface sediment samples (N=38) were collected during different surveys conducted in spring-summer months by using a multicorer (the top 0-5 cm of the core) or a Van-Veen Grab sampler, by a 10 x 10 cm frame at a total number of 30 stations as follows: in April 2008, June 2008, April 2009, July 2013 and May-June 2016. All sediment samples were stored in the dark without preservatives at 4°C until processing.

For cysts morphological identification the sediment samples were treated and analyzed as described in [8]. Cyst morphotypes produced by *Scrippsiella acuminata* complex were distinguished on the basis of their size

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and wall features. To confirm the taxonomic identification germination experiments were performed on single cysts isolated into Nunclon MicroWell plates (Nalge Nunc International, Roskilde, Denmark) containing ≈1 ml of natural sterilized seawater. Cysts were incubated at 20°C, equinotial photoperiod and 80 μE m^{-2} s^{-1} irradiance and examined daily until germination [9].

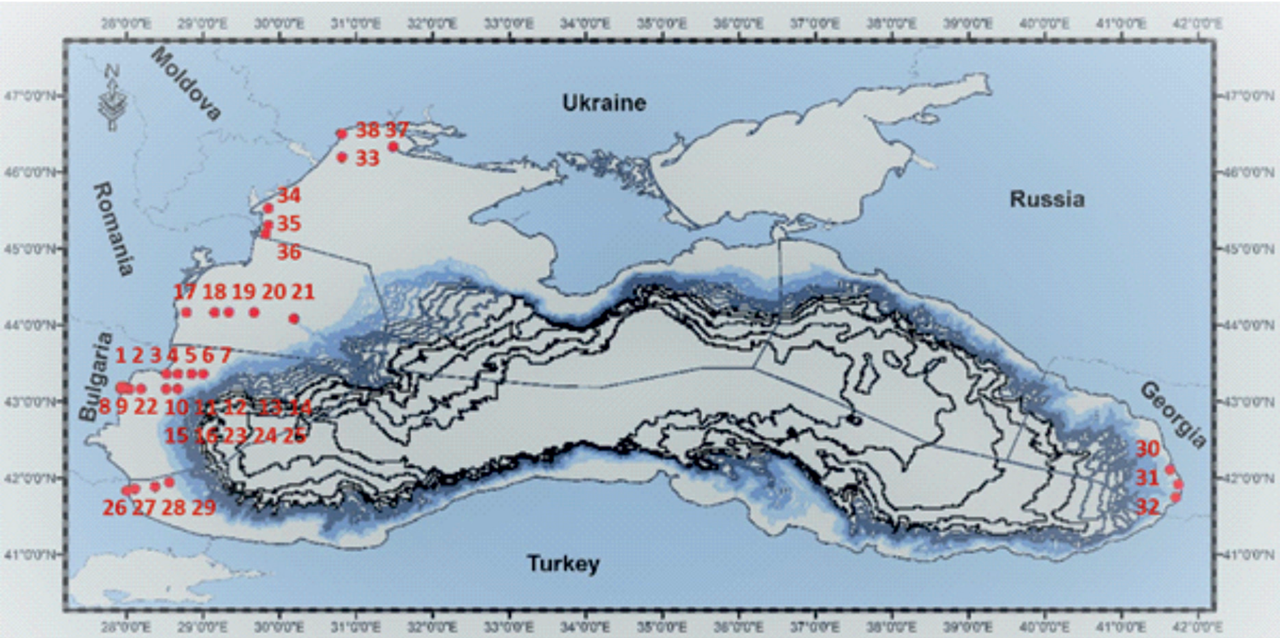

Fig. 1. Map of sampling stations (the map was produced using ArcGIS software version 10.2.2)

An *in situ* environmental data set was composed by environmental data collected during the sampling campaigns. Water samples were collected through the water column at discrete depths with a 12-Go Flo bottle CTD rosette sampler system (SBE-911 CTD) outfitted with a fluorimeter for measuring fluorescent profiles. Temperature and salinity were measured with SBE-911 CTD system. Nutrients were analyzed using standard methods [10,11]. For Chlorophyll a measurements water samples were filtered through GF/F Whatman filters with vacuum pump (Millipore) at < 0.2 atm pressure. The filters were stored at -20°C until lab analysis. The pigments from the filters were extracted in 90% cold acetone and measured spectrophotometrically (Nova 400, Merck Spekol 11). Jeffrey and Humphrey's equations were used for the calculations [12]. The precision of the method is 0.1 [mg.m-3] and the error does not exceed 10% [13]. *In situ* dataset was constructed only using data for the upper homogeneous layer (0-25 m). The water transparency (WT) was measured by Secchi disk (m). The selection of those environmental parameters was based on previous knowledge of reliable variables to influence encystment of phytoplankton active stages.

Cysts morphotypes abundance matrix was constructed by using the morphotypes' abundance measured at each data point during every single survey. Correspondence canonical analyses (CCA) was applied to link *Scrippsiella acuminata* cyst morphotypes abundance per station to *in situ* environmental data. Regardless of the homogeneity of data CCA can be considered an option without significant concern, if the underlying model is linear or unimodal in case CCA focuses on relative abundance, rather than overall trends in abundance [14,15,16]. Variables variance inflection factors were calculated as a diagnostic tool for multicollinearity of data. Analysis of variance (ANOVA) was used as permutation test to assess the overall CCA model, axis and explanatory variables significance. All analyses and graphic representations were performed using the statistical and programming software R 3.6.2 [17], package 'vegan', available through the CRAN repository (www.r-project.org) [18].

RESULTS AND DISCUSSION

Cyst densities of *S. acuminata* complex were highly variable, ranging between 2 cysts g^{-1} (Bulgarian waters, sample 4 /11.06.2008) and 2740 cysts g^{-1} (Ukrainian waters, sample 33/24.05.2016) for viable cysts and between 8 cysts g^{-1} (Bulgarian waters, station 4/10.06.2008) and 888 cysts g^{-1} (Bulgarian waters sample 25/24.05.2016) for empty cysts. Viable cysts proportion exceeded 50% (up to 100% - sample 6 (Bulgarian waters)/12.06.2008) of the total cyst abundance in 51% of the samples, with equal share found for the empty cysts.

Five cysts morphotypes of *Scrippsiella acuminata* were observed in the sediment samples. Generally, more than two different morphotypes co-occurred in all samples. The most abundant cyst morphotypes were *Scrippsiella acuminata* medium type (SAM) (59% of total *S. acuminata* viable cyst density) and S*crippsiella acuminata* small type (SAS1) (30% of total *S. acuminata* viable cyst density) whereas the abundance of *Scrippsiella acuminata* large type (SAL) was negligible (only 2% of the total *S. acuminata* full cyst). Cysts of *Scrippsiella acuminata* rough type (SAR) and *Scrippsiella acuminata* smooth type (SAS) type were present across the sampling sites (SAR found in 57 % and SAS in 67 % of the samples) in varying concentrations (Fig. 2).

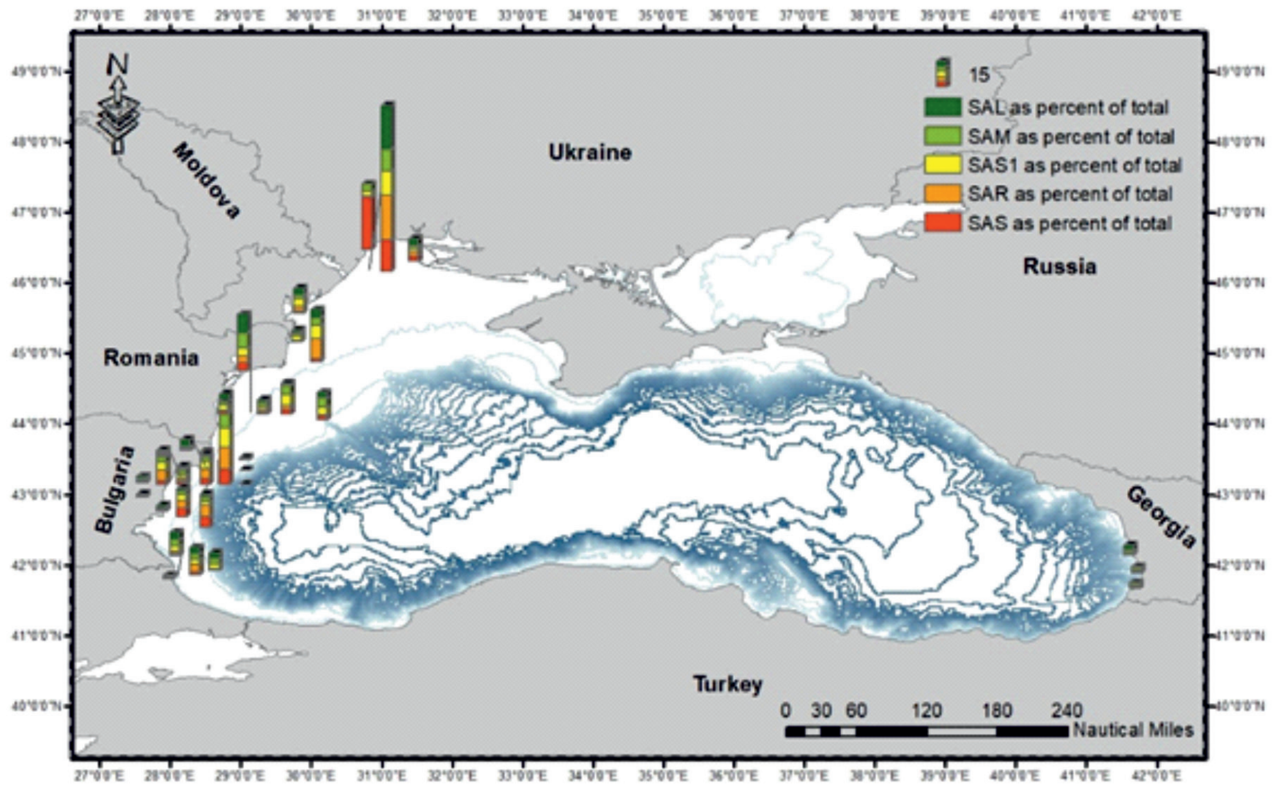

Fig. 2. *S. acuminata* morphotypes distribution in the Black Sea (% in the total abundance of viable cysts by sampling stations)

Statistical summary of environmental variables (min-max values) of the *in situ* environmental dataset and *S. acuminata* morphotypes cysts concentrations ranges per cluster are provided in Table 1 and Table 2. Non-metric multidimensional scaling (NMDS) was employed to outline specific clusters of sampling stations in respect to environmental data (Fig. 3).

Statistical summary of *in situ* environmental variables

Table 1

Value	Temperature (°C)	Salinity (ppt)	Chl a (mg/m3)	Secchi depth (m)	NH4-N (µmol/l)	NO3-N (µmol/l)	PO4-P (µmol/l)
Max	26.35	18.23	24.38	15	11.5	20.52	1.76
Min	9.62	6.03	0.25	0.9	0	0	0
Avg	19.03	15.55	2.96	5.61	0.98	1.82	0.2

***S. acuminata* morphotypes concentrations ranges per cluster**

Table 2

Cluster	SAR [min-max cysts g^{-1}]	SAS [min-max cysts g^{-1}]	SAL [min-max cysts g^{-1}]	SAM [min-max cysts g^{-1}]	SAS1 [min-max cysts g^{-1}]
C1	0 - 188	9 - 34	6 - 17	140 - 367	168 - 453
C2	0 - 426	0 - 561	0 - 93	2 - 1074	0 - 815

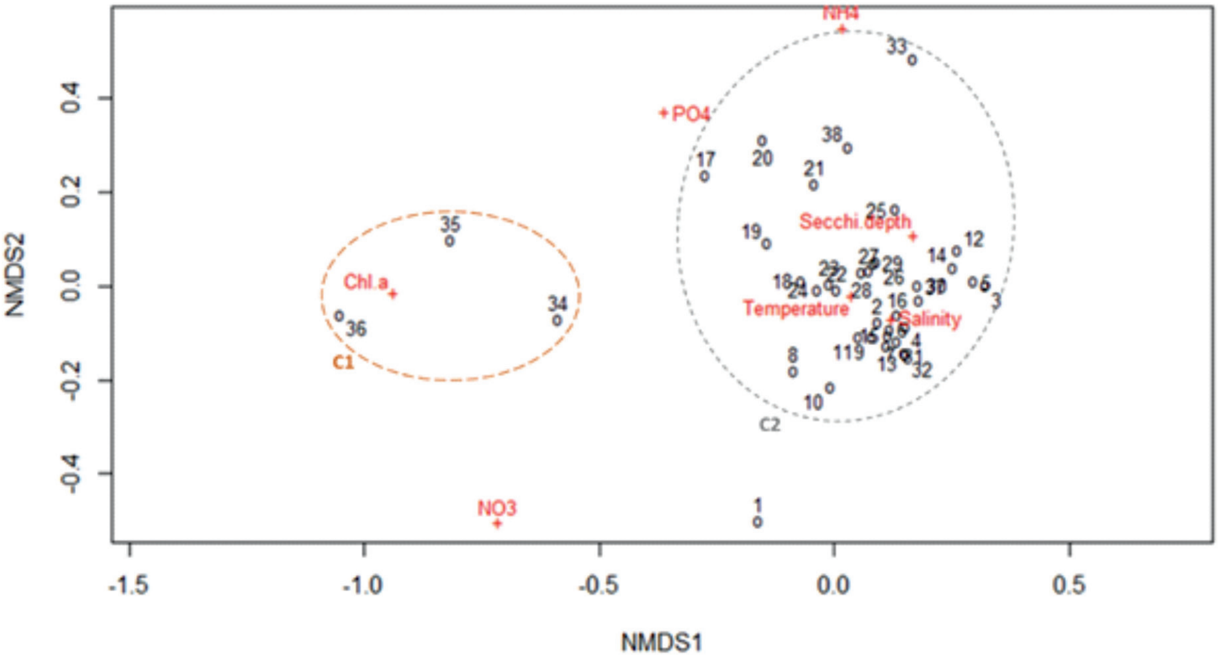

Fig. 3. NMDS of samples (1-38) in respect to *in situ* environmental data

Two explicitly separated clusters are evident in the NMDS representation of the in situ environmental data; the first one differentiated by Chl *a* concentration, and the second one in respect to all of the remaining environmental variables. Cluster 1 (Ukrainian stations - samples 34-36) is characterized by the following ranges of environmental variables: SST (15.7-17.09°C), the lowest salinity (SSS 6.03-11.08 ppt), the highest concentrations of Chl *a* (14.30-23.95 mg/m^3), the lowest water transparency (WT, i.e. Secchi depth) (0.9-4.5 m), and high nutrients (NH4 - 0-1.19 µmol/l, NO3 3.20-10.64 µmol/l, PO_4 0.19-0.38 µmol/l). Cluster 2 which encompass all the remaining sampling sites is rather heterogeneous with high variables ranges (SST 9.62-26.35°C, SSS 7.62-17.83 ppt, Chl *a* 0.35-3.39 mg/m^3, WT 2-15 m, NH_4 0-1.84 µmol/l, NO3 0-5.29 µmol/l, PO_4 0-0.28 µmol/l). The slight differentiation of samples 17, 19, 20, 21 (Romanian stations) and 38 (Ukrainian stations) is associated to the relatively high PO_4 concentrations (0.88-1.76 µmol/l) and the segregation of sample 1 (Bulgarian station) is due to the highest NO_3 concentration measured (20.52 µmol/l).

CCA was applied to model a link between *in situ* environmental data (explanatory dataset) and cysts concentrations (response matrix). VIF were used as a diagnostic tool for multicollinearity of data calculated as follows: SST - 2.11, SSS - 2.67, Chl *a* - 2.43, WT - 1.78, NH_4 - 1.73, NO_3 - 1.61, PO4 - 1.15 - <5. Overall CCA model significance was tested with ANOVA $p=0.001$ The first two CCA axes were statistically significant (CCA1 - $p=0.001$ and CCA2 - $p=0.004$) and explained 73% of the total variance, (CCA1 58% and CCA2 - 15%); 5 out of the 7 variables were found statistically significant: Chl a, SST, WT (Secchi depth), SSS, and NH4 (respectively with 48%, 16%, 14%, 11% and 9% of the total variance explained by the model).

According to CCA biplot outcome (Fig. 4), SAL distribution is preferably linked to environment with mid to high Chl *a* and NH_4 concentrations and mid-levels of WT, SSS and SST (within the given range of variations of *in situ* environmental variables in Table 1). SAS1 most likely is aligned to conditions of mid Chl *a*, WT, SSS and NH_4 values; SAM to mid to low Chl *a* and NH_4 concentrations and mid SST, SSS and WT. SAR apparently requires high WT levels and NH4 concentrations and mid to low SST and SSS; SAS seems to prefer low Chl *a* concentration, SST and SSS and mid to high NH_4.

Our results suggest that the overall distribution of different cyst morphotypes of *S. acuminata* complex is regulated by a complex interaction of environmental variables, including salinity, temperature and eutrophication (NO_3, NH_4, PO_4, Chl *a* and WT) which is quite in conformity with other findings. Salinity, temperature and nutrients were found to be among the main factors that influence dinoflagellate cyst morphology and distribution [20]. However, none of the morphotypes alone could be associated to a firm range of any environmental variable, e.g. a well-defined environmental niche. On the one hand the structure of resting-stage assemblages can be regarded as a time- and space-integrated response of a subset of phytoplankton species to environmental conditions, including the physical oceanographic dynamics that favor or prevent sedimentation of resting stages [19]. Thus the momentum *in situ* measurements of the environmental variables does not necessarily correspond to the thresholds conditions that may trigger encystment. On the other hand, the high cryptic diversity within the complex [21] as well as the fact that morphotypes may fall along gradients between described taxa [22] call for further research resolving the morphotypes/cryptic species paradigm [22].

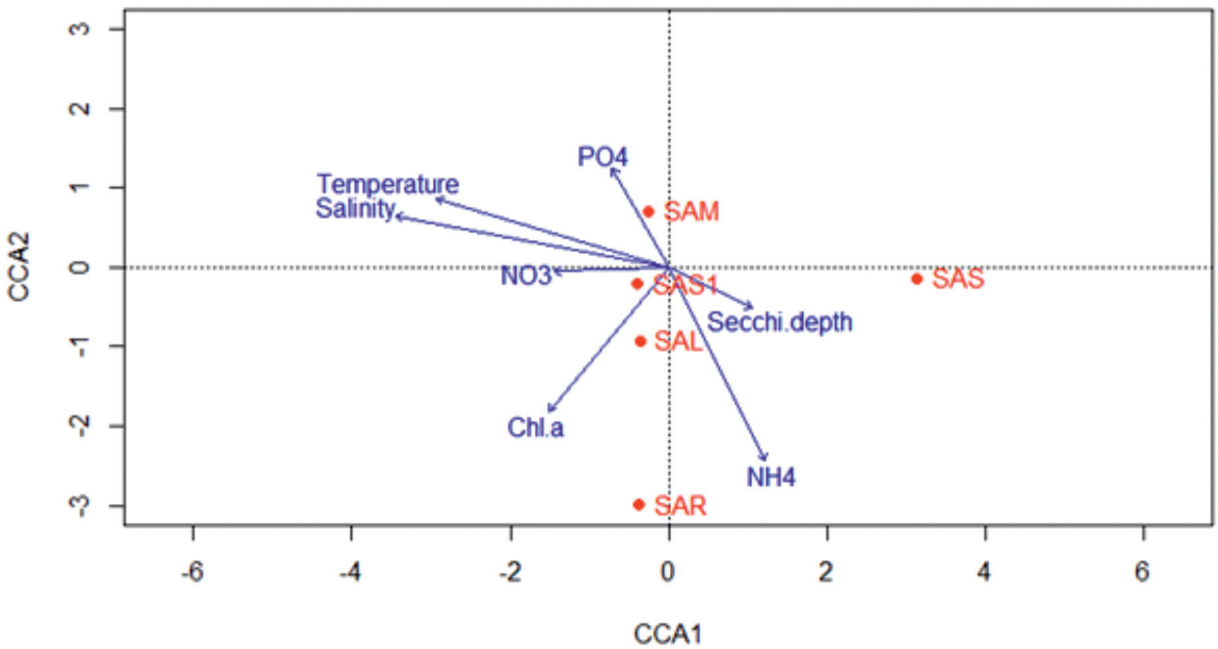

Fig. 4. Biplot of CCA - Scaling 2 - species scores
(*in situ* environmental explanatory dataset and cyst response matrix)

We found out that the Black Sea sediments harbor phenotypically diverse seed banks of *S. acuminata* complex as described also in other geographic areas [21,23,24,25]. In addition, *S. acuminata* morphotypes dominated in the sediment samples, confirming the high efficiency of the species complex in cyst production [26,27,28], most likely playing a significant role in its bloom dynamics.

CONCLUSIONS

The present study represents one of the largest basin-scale surveys of *Scrippsiella acuminata* cyst distribution in the Black Sea conducted to this date.

Our results show that all *S. acuminata* cysts morphotypes relative abundances were found to correlate significantly to a combination of environmental factors, confirming that cysts beds are repositories of ecophysiological diversity.

The applied multivariate analysis highlighted overall statistically significant models linking *Scrippsiella acuminata* cysts morphotypes distribution with temperature, salinity and eutrophication. The lack of niche speciation however poses the need for both targeted studies of en/excystment conditions along with further research resolving the morphotypes/cryptic species paradigm.

ACKNOWLEDGEMENTS

This study was supported by the National Science Fund, Ministry of Education and Science (MES), Bulgaria the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № D01-230/06.12.2018) and Project National Geoinformation Centre, Contract D01-161/28.08.2018 (Ministry of Education and Science).

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EFFECTS OF KAMCHIA RIVER INPUT ON THE ECOLOGICAL STATUS OF COASTAL BLACK SEA ECOSYSTEM

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Abstract. *Rivers play a major role in the delivery of nutrients to coastal ecosystems which are essential for ecosystem productivity. The Kamchia River is one of the largest and highly anthropogenic loaded river systems in Bulgarian Black Sea basin watershed. It's waters are affected by inputs of industry, agriculture and urbanization with high content of organic matter and nutrients, exerting pressure on the coastal ecosystem ecological quality. The effect of Kamchia River is investigated based on a spring-summer seasonal dataset of short time series (2012-2019) to represent the level of discharge impacts low in the food chain comparing two scenarios of dry (2013, 2019) and wet (2014, 2016) years. Statistical analyses were applied to highlight significant impacts of river discharge on sea water quality variables as well as to study the relationships between environmental data and plankton community metrics as indicators of ecological quality of coastal marine waters.*

Key words: *Coastal ecosystem, plankton community, river - sea interaction*.

INTRODUCTION

Rivers provide the primary link between land and sea, the riverine discharge affecting the physical, chemical and biological processes of coastal marine ecosystems. The Kamchia River, entirely located in Bulgaria, is one of the largest (length of 245 km) and highly anthropogenic loaded river systems in Bulgarian Black Sea basin watershed [1] with a strongly dynamic seasonal regime originally of maximum flow in February/March and minimum in October [2]. The river catchment (5358 km2) covers 40 % of the Bulgarian Black Sea catchment area and contributes to about half the freshwater discharge by national rivers, ranging between 179.3 x 106 m^3 yr-1 and 1475.3 x 106 m^3 yr-1, collecting urban effluents of many settlements, including untreated sewage discharges [3], [4]. Therefore its water is affected by anthropogenic inputs (industry, agriculture and urbanization) with high content of organic matter and nutrients [1], [3], [5], exerting pressure on the coastal ecosystem nutrient regimes [4], [6].

One of the major factors in the dynamic of river runoff and sediment discharge is climate change, intensity of heavy rains and storms and warmer and dry periods. During 2004-2018 strong floods have been registered in 2005-2006, 2007, 2009, 2010 and 2012, the strongest one in the Varna region and Kamchia area observed in 2014 [7], [8]. Riverine nutrients act in concert with local hydrographic conditions to create distinct ecological niches for phytoplankton communities across river-sea continuums [9].

The main objective is to assess the Kamchia river impact on the Black Sea water quality through case study carried out in the coastal marine area in front of the river mouth. The effect of Kamchia River on the ecological status of coastal Black Sea ecosystem is investigated based on a spring-summer seasonal dataset of short time series (2012-2019) to represent the level of discharge impacts low in the food chain comparing two scenarios of dry (2013, 2019) and wet (2014, 2016) years.

MATERIALS AND METHODS

Study Area and Variables

The present study was conducted at a station located in one nautical mile zone in the Kamchia water body (WB) (Fig. 1) within the monitoring campaigns of Bulgarian Black Sea coast under the Water Framework Directive (WFD).

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Seven years spring-summer *in situ* data sets (2012 - 2017, 2019) of physical, chemical and biological (phyto- and zooplankton) variables were analyzed (Table 1), following routine methods. The assessment of the ecological status was based on the classification systems used in the WFD National monitoring program. Pressure data of river nutrient loads and discharge were provided by Black Sea Basin Directorate -V arna. Precipitation data are from www.stringmeteo.com. To assess the impact of the river on the marine ecosystem, two scenarios of well discriminated characteristics were studied by selecting dry (2013, 2019) and wet (2014, 2016) seasons based on precipitation and river discharge data.

Statistical analyses

Pearson correlation analysis was used to highlight statistically significant association of river discharge with sea water nutrient content, while Generalized Additive Mixed Models (GAMM) were employed to study the relationships between the *in situ* environmental variables and phytoplankton and mesozooplankton response metrics. Analysis of Variance (ANOVA) was used to test the models and smooth terms statistical significance. The statistical analyses and graphic representations were undertaken in R 3.6.2 [10] CRAN package [11] and CRAN package [12].

Fig. 1. Location of sampling station Kamchia (red arrow) in front of the river mouth

Pressure, in situ environmental and biological variables and metrics

Table 1

Phytoplankton	**Zooplankton**
Abundance N, cells/l	Mesozooplankton abundance ind/m^3
Biomass B, mg/m^3;	Mesozooplankton biomass, mg/m^3
Chl. *a*, mg/m^3	*Noctiluca scintillans* abundance ind/m^3
IBI - Integrated Biological Index	*Noctiluca scintillans* biomass, mg/m
Environmental variables (*in situ*)	**Pressure (river nutrient loads) & precipitation**
T ^{o}C - water temperature	RNO_3, µM - Nitrate
S ‰ - salinity	RNH_4, µM - Amonia
NO_3, µM - Nitrate	RPO_4, µM - Phosphate
NH_4, µM - Amonia	Pp - Precipitation, mm
PO_4, µM - Phosphate	
TN, µM -Total nitrogen	
TP, µM - Total phosphorous	
Si, µM - Silica	

RESULTS AND DISCUSSIONS

A remarkable rainfall for Bulgaria, particularly in the research area, significantly exceeding the mean norm (approx. 10 folds) was reported in spring 2014, with maximum extremes measured in June (211mm - 458%) [13]. Subsequently, an increase of the river discharge rate was measured in Kamchia watershed (Q_{max} = 200 m^3/s), resulting in salinity lower than 13‰ in the mixing zone of the coastal area (Figure 2 a, b). The precipitation in 2016 (spring, about 4 times higher than the standard rates), was considerably lower compared to 2014, but similar environmental changes were observed. The river discharge due to the intensive rainfall carried substantial nutrients loads (phosphates and Si) with direct impact on the coastal zone (Fig. 2 c, d). Phosphates and silica concentrations varied between 0.02 to 0.38 µM and 1.3 to 7.8 µM respectively, with maximum in spring associated to the higher river run-off. Ammonium concentrations varied from 0.2 to 23.8 µM with the higher values occurring during summer when heterotrophic activity is at its maximum. Phosphate ranged from 0.03 to 0.38 µM with the higher values tending to occur during spring (wet 2012), although high values also occurred in July 2016.

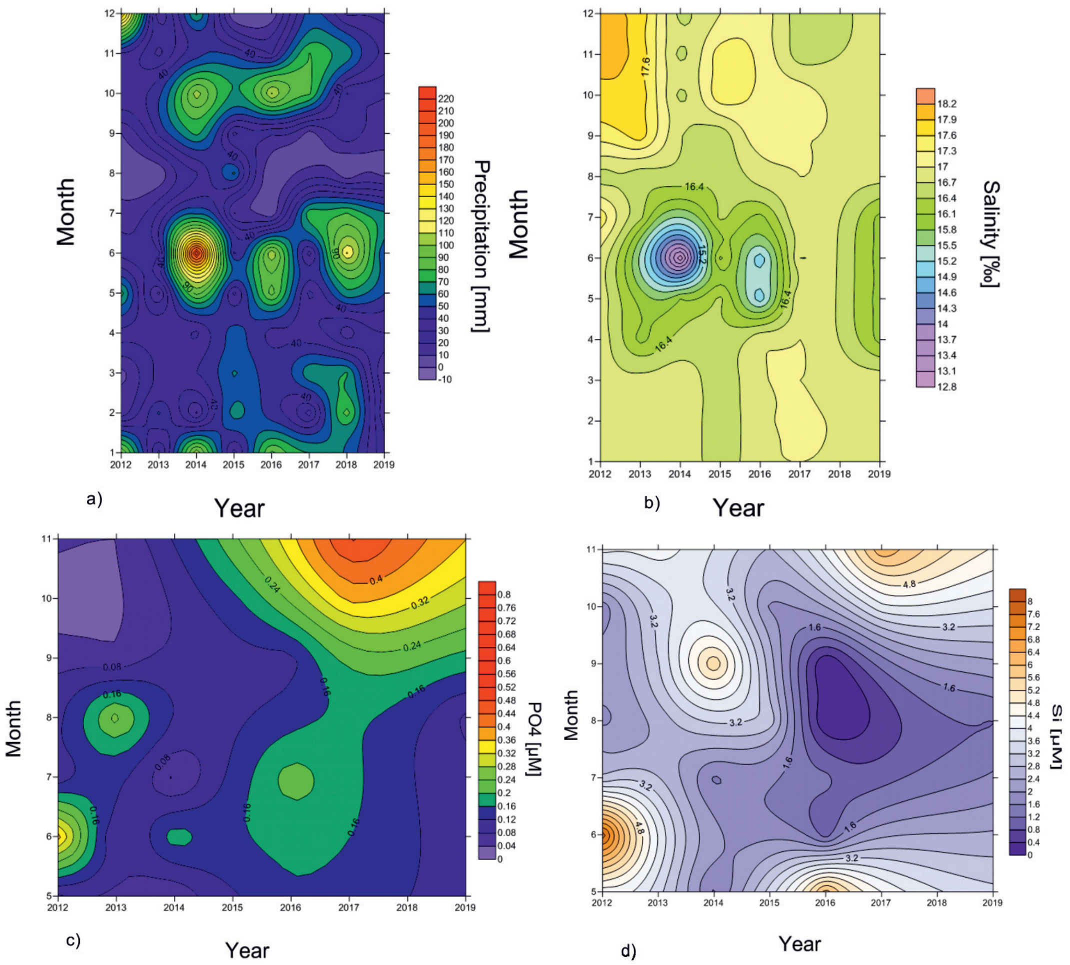


Fig. 2. Environmental variables co-variation (a) precipitation and salinity, b) PO4 and Si at Kamchia monitoring station (Varna region) in the period 2012-2019

Correlation analysis of in situ coastal water nutrients (PO4, PTot, NH4, NO3, NTot, Si) and salinity against river discharge loads (RPO4, RNH4, RNO3) and monthly average precipitation (Varna region) highlighted moderate to strong negative correlation ($r = -0.68$, $p = 0.0003$) of rainfall with sea surface salinity, moderate negative correlation of river discharge phosphates ($r = -0.58$) with salinity and positive moderate correlation of river discharge ammonia concentrations with in situ total nitrates, indicating the association of environmental conditions to riverine pressures (Fig. 3).

During spring-summer 2012-2019 the phytoplankton community of Kamchia WB was featured by high species richness and taxonomic diversity - the number of species fluctuating between 24 and 83 from 18 classes, including a high variety of microflagellates. The total numerical metrics varied in wide ranges depending on the environmental conditions (season, dry-wet scenarios and hydrodynamics), for the abundance between 662.9x103 - 7359x103 cells/l in spring and between $52.1x10^3$ - $2364x10^3$ cells/l in summer and for the biomass between 127.519- 1534.086 mg/m^3 in spring and between 92.596- 717.040 mg/m^3 in summer, respectively. Similarly the chlorophyll a concentration fluctuated greatly, between 0.9-6.6 mg/m3 in spring and 0.2-3.4 mg/m3 in summer. The average spring abundance was 2.4 times higher than that in summer (2.4x106 ± 2.3x106 versus 0.99x106 ± $0.7x10^6$ cells/l), the biomass about 1.7 times (741.85 ± 530 versus 431.331 ± 230 mg/m^3) and chl. a about 2 times (2.6 ± 2.1 versus 1.3 ± 0.9 mg/m^3). It should be noted that the difference between the wet-dry scenario was much higher, about 10 times in the abundance and more than 5 times in the biomass (Fig. 4).

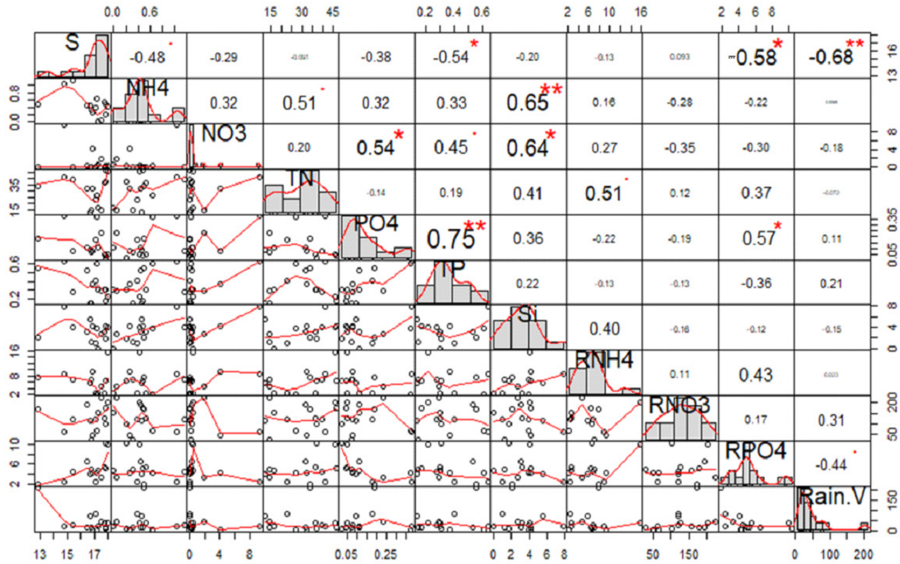
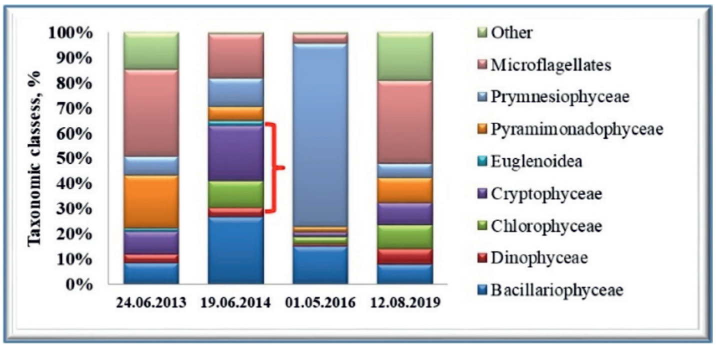


Fig. 3. Correlation matrix plot of in situ environmental and river discharge variables: in situ nutrients, µM (PO4 - PTot, NH4, NO3, NTot, Si) and S - salinity; riverine discharge nutrients, µM (RPO4, RNH4, RNO3) and precipitation in Varna, mm (Rain.V)

Similar to the total abundance and biomass a specific feature in the dynamic of the taxonomic profile of phytoplankton assemblages was of high variability, exhibiting alternating community structure which makes it difficult to extract distinct trends, typical for estuarine/marine coastal mixing zones. A relatively sensible presence of the freshwater/brackish species Pyramimonas sp. (class Pyramimonadophyceae) and microflagellates both in spring (up to 17.1% - 34.5%) and more apparent in summer (up to 34.1% - 40.5% respectively) could be noted over the entire period in the total abundance, with minor contribution in the total biomass due to their small size.

The rainy period (2014) was marked by an increased proportion (~ 34%) of freshwater/brackish species from the classes Chlorophyceae (*Monoraphidium contortum*), Cryptophyceae (*Hemiselmis sp., Plagioselmis sp.*) and Euglenoidea (*Euglena acusformis*), concomitant by an elevated share of diatoms (61.8 % of the total abundance). The max diatom abundance (1.3x106 cells/l) and spring biomass (466.941 mg/m^3) observed in May 2014, was contributed specifically by the indicator species of eutrophication such as *Pseudo-nitzschia delicatissima, Cyclotella choctawhatcheeana, Thalassiosira nordenskioeldii*. For comparison these proportions for the selected dry scenarios were below 18% for the three classes and between 8-8.4 % (61-$63x10^3$ cells/l) for diatoms from the total abundance at much lower total abundance and biomass. Dinoflagellates biomass peak (515.036 - 529.625 mg/m^3), was also measured in 2014 (the rainy year) in June and September after the high diatom development. As riverine waters usually change nutrient loads, resulting in changes of N:P supply ratios and consequent variations in algal communities [14], increased algal growth and development of high biomass as well as shifts in species diversity. Usually the nitrate in this source water exists at sub-Redfield ratios, and hence is quickly drawn down by enhanced growth of coastal diatoms that benefit from the DIP and Si-rich water [15].

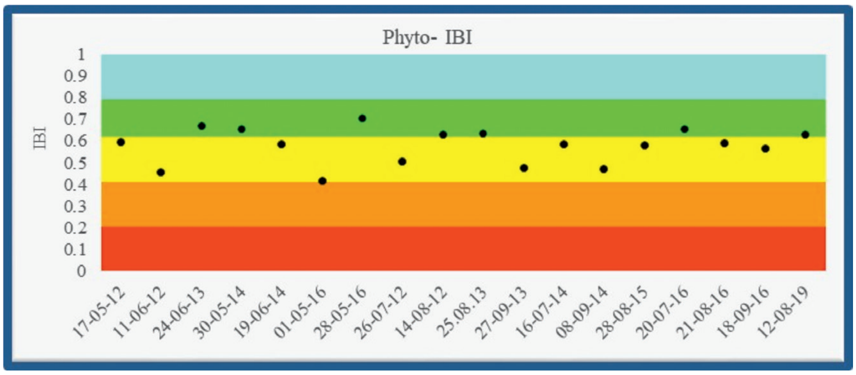
Even if the frequency of total densities exceeding 1x10^6 cells/l was high (>55% of the sampling cases) no monospecific or a 2-3 species cohort outbursts were observed with the exception of the bloom of *Emiliania huxleyi* in September 2013 (abundance 1.3x10^6 cells/l) and especially in May-June 2016, in this case originating from the North-west as a regional bloom and controlled by the basinwide current patterns (Fig.4a). This was a special case in which the bloom density was locally sustained to reach a cell abundance of 5.2x10^6 cells/l more than 3 times higher than that in the northern Bulgarian coastal WBs.



a)

Metric/Date	24.06.2013	19.06.2014	01.05.2016	12.08.2019
N, cells/l	731752	2622784	7359550	790376
B, mg/m3	270.403	1169.515	1534.086	455.500

b)



c)

Fig. 4. Taxonomic profile of phytoplankton communities abundance (in %) under the three different scenarios (a) dry scenario (24.06.2013 and 12.08.2019), wet scenario (19.06.2014) wet scenario + regional bloom (01.05.2016); (b) Total abundance, N (cells/l) and Biomass, B (mg/m^3) and (c) Variation of ecological status of WB Kamchia based on the integrated phytoplankton index Phyto-IBI (spring-summer 2012-2019); color-codes correspond to the WFD classification system

Accordingly based on the phytoplankton integrated index (Phyto-IBI) the ecological status of Kamchia WB associated to the latter event was in category poor (Fig. 4c). During spring-summer 2012-2019 the IBI fluctuated predominantly within the categories moderate-good, however no consistent trend towards achieving good ecological status was observed, most likely modulated by the impact of the Kamchia river as shown by the GAMM approximations (Fig.4c).

GAMM, used to model phytoplankton biomass response to in situ environmental variables, provided statistically significant model approximation ($R2adj = 0.785$), highlighting statistically significant non-linear effects of temperature ($p = 0.05$, $df = 4.61$), NO3 concentrations ($p = 0.009$, $df = 2.56$) and PO4 ($p = 0.005$, $df = 4.56$) and linear patterns of NH4 ($p = 0.00028$, $df = 1$) and Si ($p = 0.0027$, $df = 7$) - Fig. 5. Other runoff-related studies have also noted that variation in salinity, silica, and TN were the main driver of phytoplankton community structure and productivity with potential further implications to the ecological status of the coastal marine environment [16].

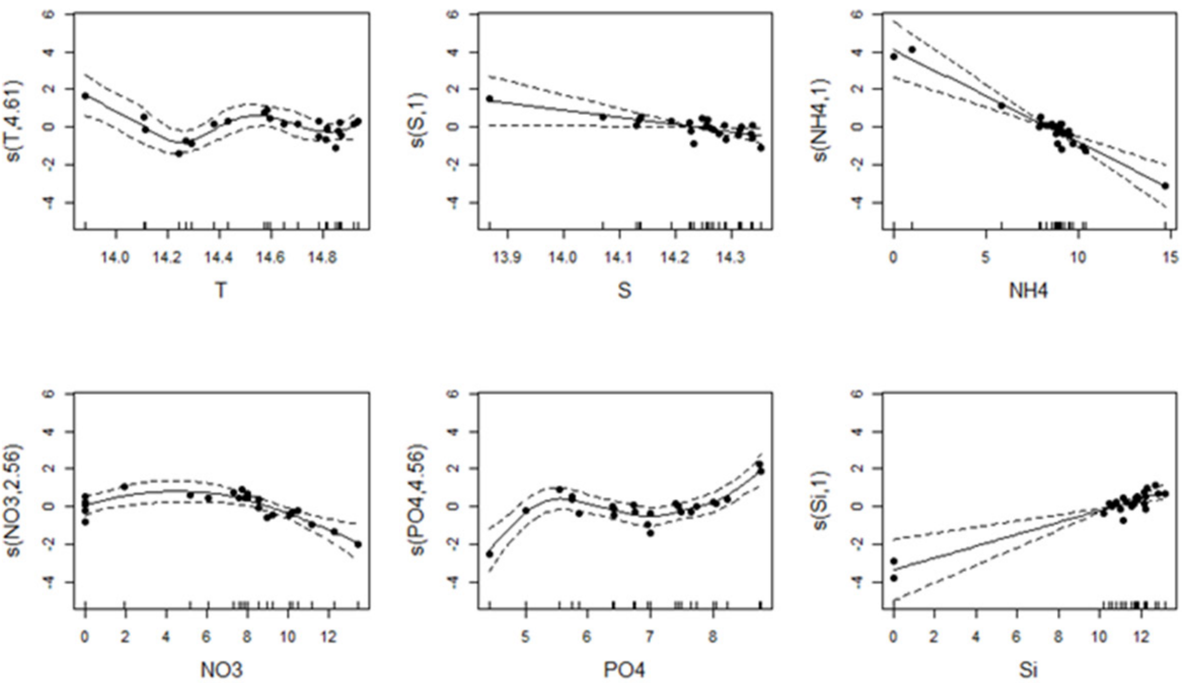


Fig. 5 GAMM fits between phytoplankton biomass and environmental variable (*in situ* data)

Mesozooplankton showed a remarkable variation in density (3271 to 30690 ind.m^3] and biomass (24. 47 to 787.13 mg/m3) during the study period. The variability of abundance and biomass in spring among the years was relatively small about 2-4 folds while the summer is characterized with huge numerical metrics deviation (min - 3864 ind/m^3, max - 30690 ind/m^3 and between 156.86 mg/m^3 - 787.13 mg/m^3 respectively). The lowest abundance/biomass and species number observed during the study (June 2014) coincided with a large rain event in the watershed. The zooplankton community was composed of 22 species/taxa (15 classes), varying from 14 to 22 - poor species richness and taxonomic diversity. Freshwater/brackish species were not registered. Copepoda were the richest species group (11 species), followed by Cladocera (5 species) and Meroplankton (8 taxa), Ctenophora (3 species) and Sciphozoa (1 species) - Fig. 6 (left panel). The frequency of the different species/taxa did not show any major changes between environments (scenarios). *Acartia clausi* prevailed in both wet and dry seasons with 32% and 17 %. The species that contributed to the period differences were *Pleopis polyphemoides* (15% in wet and 10% in dry), *Penilia avirostris* (dry scenario - 14%), Cirripecia larvae (13 % - wet season). Development of *N. scintillans* in spring and *M. leidyi* in summer reflected indirectly on mesozooplankton biomass, since both negatively correlated with the biomass of planktonic fauna.

During the wet period, the abundance and biomass of *N. scintillans* overwhelmed the other-zooplankton abundance/biomasses with more than 80%. Statistical analysis confirmed negative correlation of mesozooplankton abundance with Noctiluca density in spring well pronounced in wet season. Similar to the phytoplankton community pattern in May 2016, Noctiluca was affected positively by regional and local river discharge. The same phenomenon of appearance of *N. scintillans* during the flood season was found by [17] concluding that the mass development of Noctiluca was a result of freshwater input.

N. scintillans is recognized to play an important role in the population dynamics of zooplankton community by feeding on their eggs and competing for food resources [18]. Therefore its response to environmental factors was also modeled aiming to provide statistically significant patterns in its abundance variations, associated with single or a multiplex of environmental variables. GAMM of *N. scintillans* abundance provided statistically significant model approximation (R^2adj = 0.652), showing statistically significant negative linear effects of temperature (p = 4.00e-7, df = 1), salinity (p = 3.36e-7, df = 1) and PO4 concentrations (p = 0.006, df = 1) (Fig. 6) confirming the importance of river flow in Noctiluca development.

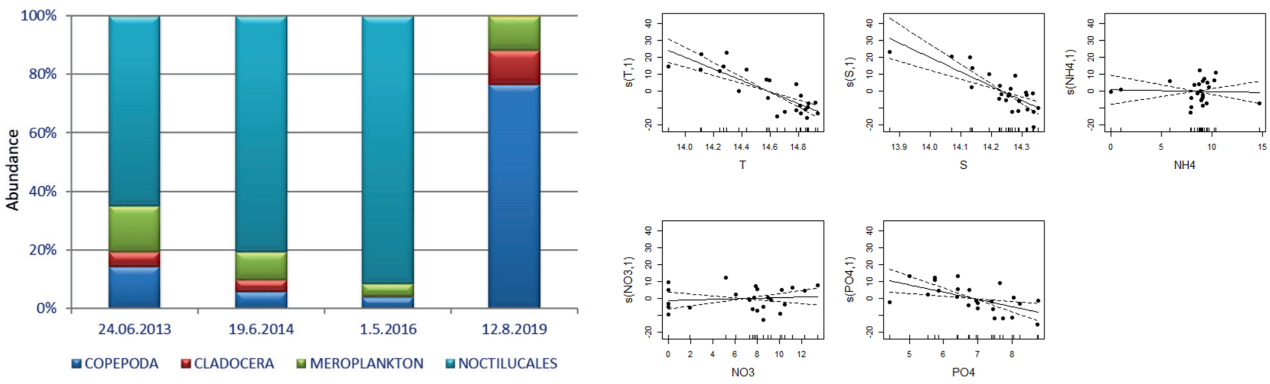


Fig. 6. Zooplankton community structure (left panel) and GAMM fits between *N. scintillans* abundance and environmental variable (*in situ* data) - right panel

Although water discharge of Kamchia River is low compared to the big rivers discharging into NW Black Sea, its influence on coastal water quality could not be ignored. Generally, the majority of fluvial runoff and the related discharge of its suspended and dissolved constituents on a regional scale are provided by the largest local rivers, and small rivers (i.e., rivers with small drainage basins and small annual discharges) usually play an insignificant role [19]. They have little annual runoff and affect adjacent coastal waters to a limited extent under average climatic conditions. However, under certain climatic conditions, the cumulative discharge from small rivers can increase in response to precipitation events and heavy rains [20].

The Kamchia river discharge directly influenced the coastal waters near the mouth, as most of the main parameters, such as suspended solids, nitrite and ammonia nitrogen and phosphates, measured at majority of monitoring points along the stream of the river were reported to exceed the ecological standards before entering into the Black Sea [21]. Our results suggest that the high input of land-sourced nutrients appeared to enhance biological activity near the river mouth (increased total phytoplankton abundance and biomass), increased opportunistic species abundance (*N. scintillans*), sustaining higher local bloom densities in the case of regional blooms (the case of *E. huxleyi* bloom) and causing alteration of phytoplankton taxonomic structure.

The results emphasize that the nutrient condition in the river - coastal gradient was decisively dependent on the extent of the river discharge (dry-wet scenario), the interaction of the riverine inflow with the waters of marine origin, and the topography of mixing and current patterns. What is noteworthy is the marked interannual variability in the wet-dry conditions and consequent phytoplankton community structure, modulated by the extent of the Kamchia River and its inputs. The zooplankton has not shown a clear community pattern in the discrete scenarios, most likely because of lagging behind response to the phytoplankton development. Apart from the peak flow events, the River Kamchia impact is traceable throughout the inner coastal area only, located mainly in the one mile coastal zone, as documented by previous studies [21], [22].

CONCLUSIONS

● Effect of Kamchia river input on the ecological status of coastal Black Sea ecosystem is better expressed in lower levels of food webs - nutrients and phytoplankton;

● Kamchia river impact depends on flow intensity and duration and the associated nutrients import and salinity changes;

● An adequate sampling strategy needs to be implemented in case of an event (conditional monitoring) in order to further quantify and assess the intensity, duration and spread of the river's impact on the marine ecosystem.

ACKNOWLEDGEMENTS

The study was funded under ENI CBC JOP Black Sea Basin 2014-2020, project „Assessing the vulnerability of the Black Sea marine ecosystem to human pressures (ANEMONE), Contract №83530/20.07.2018, eMS BSB319 and the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № Д01-322/18.12.2019).

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MONITORING OF MACROPHYTOBENTHIC COMMUNITIES, ACCORDING TO WATER FRAMEWORK DIRECTIVE, FOR ASSESSMENT OF WATER QUALITY STATUS ALONG THE BULGARIAN BACK SEA COAST

Kristina DENCHEVA

Abstract. *Macroalgae are important biological element in Water Framework Directive and some indexes were developed and applied for ecological quality status assessment. Macrophytobenthos communities as primary producers are very important elements of coastal water communities and are good indicators of ecological status because directly penetrate nutrients with their surface from sea water. The main goal of this paper is to apply some methods for assessment of coastal ecosystems ecological status for the aims of WFD. From the final results obtained from Ecological quality ratios of different ecological quality states, a high status in South part of Bulgarian coast was established. Lower status was assessed for Varna bay and Burgas bay which are zones with high ecological risk because of strong influence of different contaminants. Strong correlation was established between ecological indexes and Secchi dept as indirect indicator for nutrient enrichment.*

Key words: *ecological indexes, macrophytobenthic communities, sea ecology, WFD.*

INTRODUCTION

The European Water Framework Directive (WFD, 2000/60/EC) establishes a framework to prevent deterioration of aquatic ecosystems and protect them. The main objective of this Directive is to achieve a 'good ecological status' of European Waters. The method in this paper uses the algal component of the benthic community, which is considered to be an excellent indicator of stress and pollution. The main objectives of this paper are to present a new methodology designed to assess the quality of coastal and transitional waters along the Black Sea coasts, tested on hard substrate communities data collected in Bulgarian waters, and to describe the validation process of the proposed index (EI), compliant with the European Water Framework Directive (WFD, 2000/60/EC).

MATERIALS AND METHODS

Sampling design and laboratory analysis

In 2016 year, summer season, samples were collected from 28 polygons of macroalgae. Sampling was carried out according to method of squares [9] in hydrobotanical transects, with help of scuba diving technique [7];[8]; [10];[1].Method of sampling and laboratory analysis is described in details in [6].

Method for estimation of ecological status

The assessment of ecological quality status of coastal waters is realized with Ecological index elaborated in compliance with European Water Framework Directive. High values of the Ecological index establish high and good ecological status and lower values respectively-moderate, poor and bad ecological status. The assessment of ecological status of water bodies is on the base of elaborated classification system [3], revised and supplemented in the process of intercalibration - second phase in frames of GIG Black Sea [4];[5];[6] and approved with Regulation 4 /14.09.2012, [11].

Referent value was revised in last phase of intercalibration [2] and in result of this, the following borders of ecological state classes for ecological index and ecological quality ratio were calculated (Table 1):

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Proportion of biomass of more sensitive species, EI values and EI-EQR values of macrophyte communities for different classes of ecological state

Table 1

Biomass proportion of more sensitive species	EI	Ecological status	EI - EQR
> 0.78 - 1 ESGI	> 7.8 - 10	High	> 0.84 - 1
> 0.6 - 0.78 ESGI	> 6 - 7.8	Good	> 0.64 - 0.84
> 0.4 - 0.6 ESGI	> 4 - 6	Moderate	> 0.43 - 0.64
0 - 0.4 ESGI	> 2 - 4	Poor	> 0.21 - 0.43
1 - 2ESGII(A+B) 1 - 2ESGIICa	> 1 - 2 0 - 1	Bad	> 0.11 - 0.21 0 - 0.11

Common characteristics communities on hard substrate-macroalgae

As a result of investigations in 2016 year, 5 species of brawn algae (Ochrophyta)are established, 20 species of red (Rhodophyta), 11 species of green (Chlorophyta). From them 11 species are sensitive and 25 species are tolerant, generally 36 species.

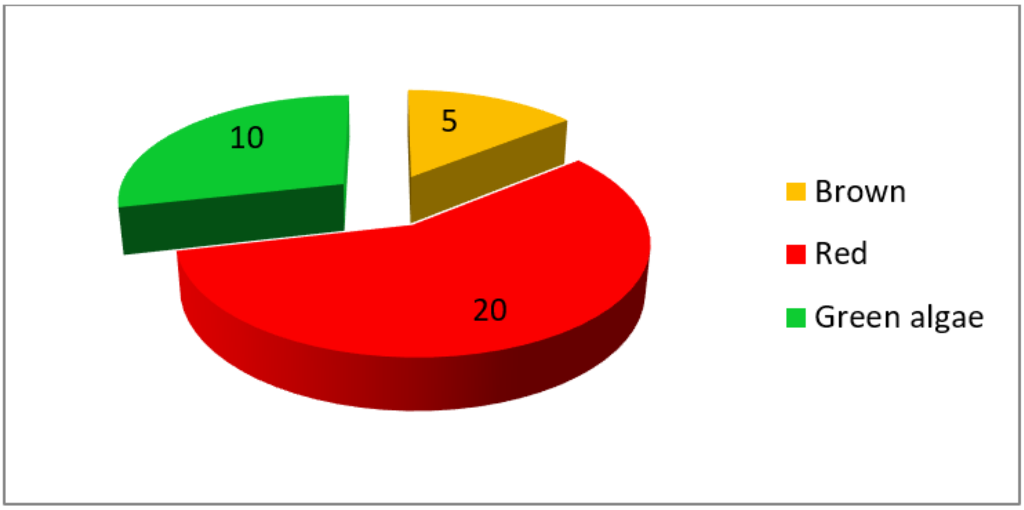

Fig. 1. Number of species from green, brown and red algae

Biomass of sensitive and tolerant species of macroalgae

On figure 2 biomass proportions of sensitive macroalgae species from investigated polygons are presented. *Cystoseira barbata* and *Cystoseira crinita* species basicly form the biomass of sensitive species. In small quantities other sensitive species are present such as *Laurencia coronopus, Gelidium spinosum, Corallina officinallis, Ellisolandia elongata, Cladostephus spongiosus*. Highest values from 0.85 to 0.98 are established in south part of Bulgarian Black Sea coast and lowest one are in Varna and Burgas bay.

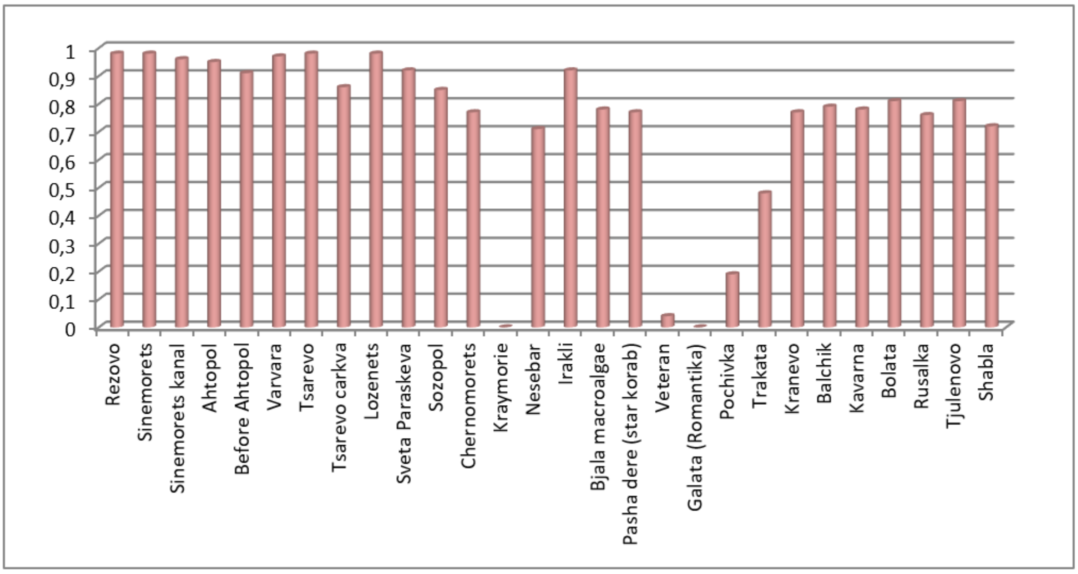

Fig. 2. Biomass proportion of sensitive macroalgae species from investigated polygons, 2016 year

From tolerant species dominant are green algae from *Ulva, Cladophora, Ceramium genus*. In more considerable quantities as accompanying species in communities *Cystoseira spp.*, most often are spread *Poysiphonia subulifera, Geidium crinale, Cladophora spp., Uva spp., Ceramium spp*. Biomass proportion of tolerant macroalgae is highest in Varna (Galata-Romantika, Pochivka, Trakata, Veteran) and Burgas bays (Kraymorie, Nesebar). The lowest biomass proportion of tolerant species is in south part of Bulgarian Black Sea coast-Rezovo, Sinemorets, Ahtopol, Before Ahtopol, Varvara, Lozenets, Sveta Paraskeva, Sozopol (figure 3).

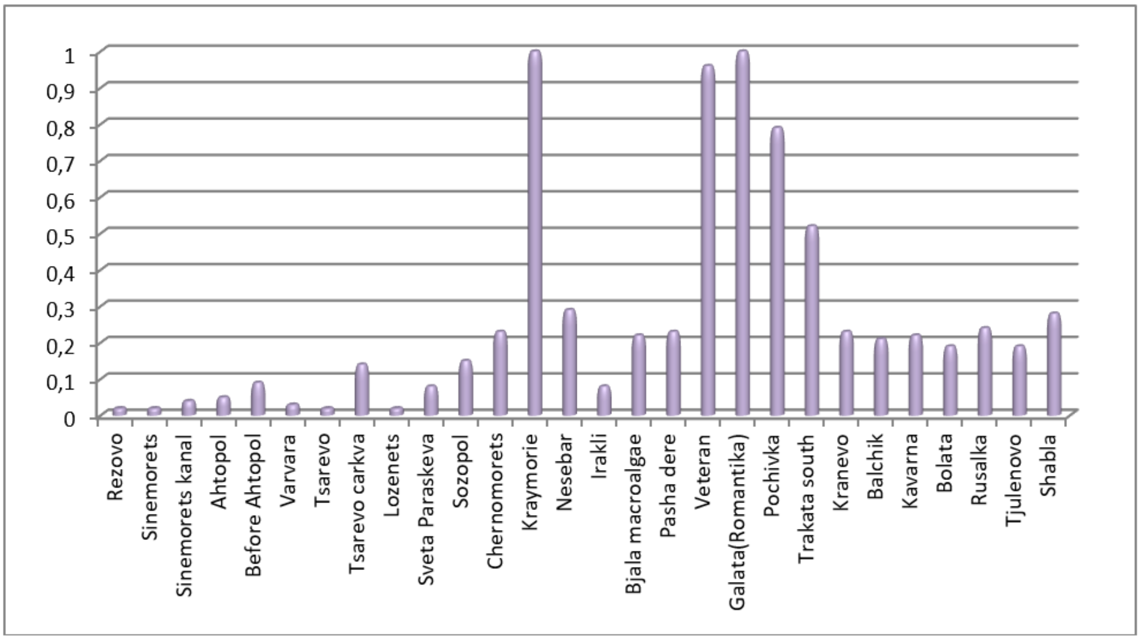

Fig. 3. Biomass proportion of tolerant species of macroalgae from investigated polygons

On dendrogram in figure 4 are distinguished tree basic groups (clusters): I group (Galata, Veteran, Pochivka, and Kraymorie), II group-Bjala, Irakli, Before Ahtopol, Ahtopol, Sveta Paraskeva, Sinemorets, Rezovo, Tsarevo, Arapja, Lozenets, Varvara) and III group (Trakata, Shabla, Kranevo, Rusalka, Kavarna, Sozopol, Tsarevo-carkva, Tjulenovo, Bolata, Pasha dere star korab, Nesebar, Chernomorets (figure 6). This delimitation unequivocally establishes different habitats (associations) of macroalgae, according to Habitats Directive and Marine strategy namely:

I group - *Cystoseira crinite habitat*, when this is dominant (key) species, building the base structure of this community (0-3) м.;

II group - *Cystoseira barbata habitat*, key (dominant) species for the community (association), forming the structure;

III group - habitat of tolerant green and red macroalgae species. Dominant is Ulva spp.

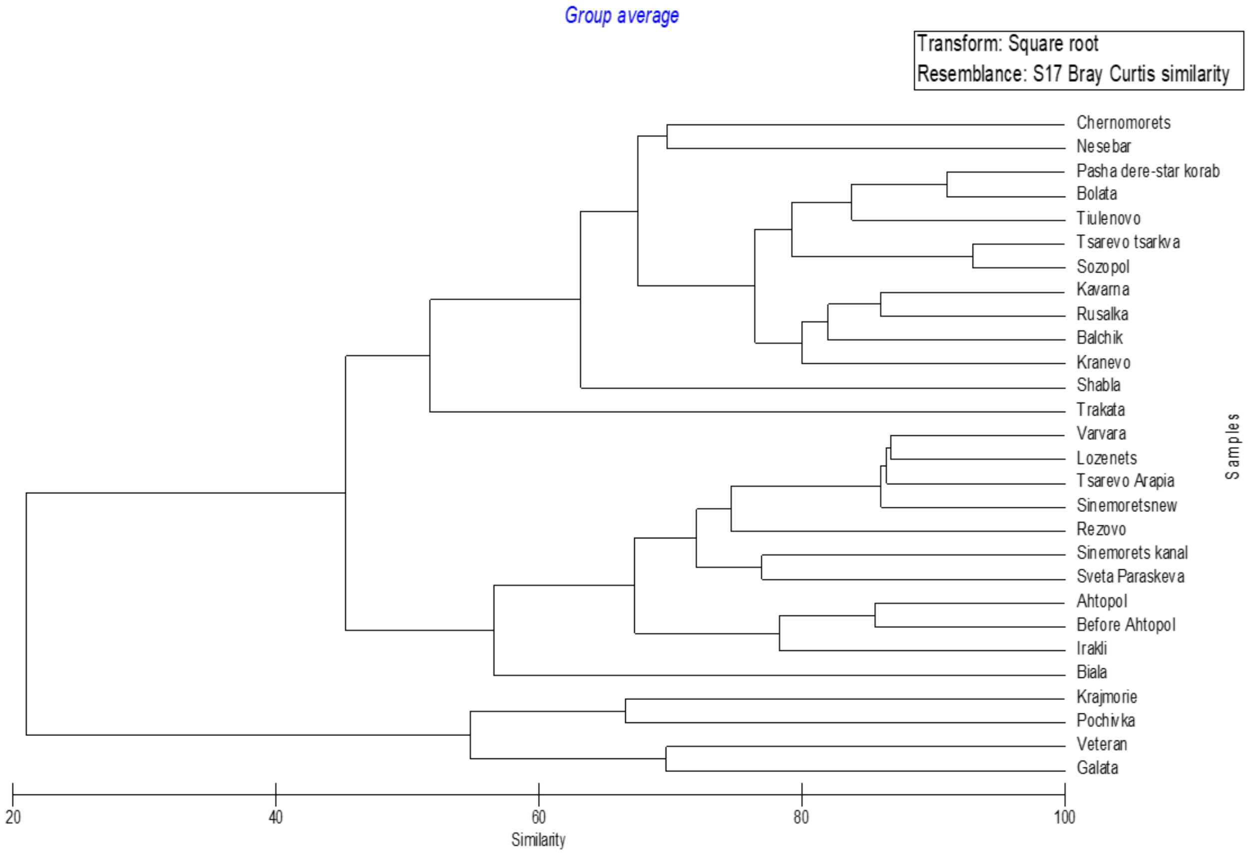

Fig. 4. Similarity dendrogram (cluster) of average species biomass from investigated polygons (Bray Curtis similarity)

The Simper analysis accomplished on the base of the groups f*ormed from the cluster analysis, indicates within groups similarity, mainly due to following species:*

Group I

Average similarity: 69.82

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Cystoseira barbata C. Agardh	61.65	39.58	5.26	56.69	56.69
C. crinita Duby	30.88	16.52	1.98	23.66	80.34
Ulva rigida C. Agardh	9.66	4.87	1.67	6.98	87.33
Gelidium spinosum (Gmelin) Silva	6.10	3.22	2.24	4.61	91.93

Group II
Average similarity: 69.71

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
C. crinita Duby	85.79	52.59	5.80	75.44	75.44
Polysiphonia subulifera (C. Agardh) Harv	8.12	4.07	2.49	5.84	81.28
Gelidium spinosum (Gmelin) Silva	6.56	3.43	2.60	4.92	86.20
Gelidium crinale (Turner) Lamour	5.33	3.03	4.62	4.35	90.55

Group III
Average similarity: 59.21

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Ulva rigida C. Agardh	18.61	26.58	7.99	44.89	44.89
Ulva intestinalis L.	9.88	11.88	4.39	20.07	64.96
Ceramium virgatum Roth	6.59	7.91	1.73	13.35	78.31
Ulva linza L.	8.17	7.89	0.91	13.32	91.63

Groups dissimilarity between I and III groups is 73.28% and is mainy due to species *Cystoseira barbata C. Agardh* with 37.67% contribution, *C. crinita Duby* - 20.93% contribution and *Ulva rigida C. Agardh* with 6.33% contribution. Groups dissimilarity between I and II groups is 54.66% and is mainly due to *C. crinita Duby* - 35.35% contribution, *Cystoseira barbata C. Agardh* - 29%, Ulva rigida *C. Agardh* - 4.93%.

Groups dissimilarity between II and III group-85.67% is mainly due to the same species with 48.41%, 10.01% и 7.85% contribution respectively.

Ecological status of macrophytobenthic communities in summer season of 2016 year

In summer season, highest values of ecological quality ratio are calculated for Rezovo, Sinemorets, Ahtopol, Before Ahtopol, Tsarevo, Sveta Parskeva, Irakli, Sozopol-macroalgae. Lowest values are estimated for Galata (Romantika)(0.09), Pochivka (0.3), Veteran (0.25), Kraymorie (0.11), situated in Varna and Burgas bays. The lowest ecological status in Varna bay is established for Galata and Pochivka polygons, due to many years anthropogenic press in Varna region and coming in the bay contaminated waters from Varna lake through the channels[12;[13]; [15];[3]. Poor status is established for Trakata-south, probably due to the influence of sewage point sources of pollution. In the last years because of intensive buiding and enhancement of population, the ecological status worsening of macrophytobenthic communities is observed. *Cystoseira barbata quantity decreases and epiphytes quantity increase.* This year in spring, high concentrations of ammonia (62µg/l, total nitrogen (398µg/l, total phosphorus (93µg/l), and low oxygen content (4.99ml/l) are registered.

Polygon Kraymorie is in bad condition. Here established status is explained with influence of sources from anthropogenic character : inner Burgas bay and Mandra lake, Oil complex Burgas and outflowing point sources of pollution.

As a whole, in high status are 15 polygons with marine macrophytes, as 9 of them are in water body BG-2BS000C1012, in good status are 8 polygons, in moderate-1, poor-2 and in bad-2 polygons.

Ecological quality ratio of the Ecological index (EQR_EI) and ecological status of investigated polygons, summer season, 2016 year

Table 2

№	Water body code	Polygon	EQR_EI	Ecological status
1	BG2BS000C002	Shabla	0.77	Good
2	BG2BS000C002	Tjulenovo	0.87	High
3	BG2BS000C003	Rusalka	0.8	Good
4	BG2BS000C003	Bolata	0.86	High
5	BG2BS000C004	Kavarna macroalgae	0.84	Good
6	BG2BS000C1013	Balchik-Tuzla	0.85	High
7	BG2BS000C1013	Kranevo	0.82	Good
8	BG2BS000C005	Trakata south	0.52	Moderate
9	BG2BS000C005	Pochivka	0.3	Poor
10	BG2BS000C005	Galata (Romantika)	0.09	Bad
11	BG2BS000C1113	Veteran	0.25	Poor
12	BG2BS000C1113	Pasha dere star korab	0.83	Good
13	BG2BS000C007	Bjala macroalgae	0.84	Good
14	BG2BS000C007	Irakli	0.99	High
15	BG2BS000C1108	Nesebar	0.76	Good
16	BG2BS000C1308	Kraymorie	0.13	Bad
17	BG2BS000C1011	Chernomorets	0.83	Good
18	BG2BS000C1011	Sozopol macroalgae	0.91	High
19	BG2BS000C1011	Sveta Paraskeva	0.99	High
20	BG2BS000C1012	Lozenets	1	High
21	BG2BS000C1012	Tsarevo Arapja	1	High
22	BG2BS000C1012	Tsarevo tsarkva	0.92	High
23	BG2BS000C1012	Varvara	1	High
24	BG2BS000C1012	Before Ahtopol	0.97	High
25	BG2BS000C1012	Ahtopol	1	High
26	BG2BS000C1012	Sinemorets channel	1	High
27	BG2BS000C1012	Sinemorets new	1	High
28	BG2BS000C1012	Rezovo	1	High

CONCLUSIONS

In Bulgarian Black Sea coast. all the ecological state classes were established. From table 2 is obvious that the highest ecological quality ratio are estimated for water bodies BG2BS000C1012 (0.92;0.97;0.99;1), BG2BS000C007 (0.99), BG2BS000C002 (0.87), BG2BS000C003 (0.86) because of little or no sources of anthropogenic pressure in these regions. Probable pressures, which provoke the observed poor and bad ecological status of macrophytobenthic communities could be due to contaminants, which came from rivers in South part of Burgas town, Provadiiska river and through the system Beloslav - Varna lake in coastal waters and direct flows from waste water treatment plants, from sewerage waters and underground waters.

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Black Sea 2020

SHIP HYDRODYNAMICS

CASE STUDY OF THE FEASIBILITY OF WIND-ASSISTED SHIP PROPULSION

Deyan KRASTEV*, Stefan KYULEVCHELIEV*

Abstract. *The paper studies the feasibility of utilizing the power of wind for improving the energy efficiency of ships. The case study involves a real ship design. A mathematical model of the ship motion under varying wind conditions was developed based on models tests, empirical and CFD data. Soft-sail configuration was designed and applied. A specific route in the Black Sea was considered with real weather data along the route. The results prove the feasibility of wind-assisted propulsion in terms of fuel oil consumption.*

Key words: *energy efficiency, renewable energy resources, wind propulsion.*

INTRODUCTION

The increased environmental concerns of the society initiated the introduction of strict measures for improving the energy efficiency of shipping in order to reduce the GHG emissions. As a consequence, number of methods for improving energy efficiency were developed and/or revived.

Among the multitude of options to reduce the emissions from shipping, wind propulsion seems to be an obvious solution. Wind propulsion is a technique that has been studied and developed for centuries but has made great progress also in the last decades mainly due to sports and leisure applications. The physical reason for the attractiveness of wind propulsion lies in the fact that the wind power is utilized directly without energy conversions and losses thereof.

The idea of commercial shipping with hybrid motor/sailing propulsion started in the 1980's with its developments following the trends in oil prices since.

There are several shortcomings of sailing such as: low speed, imprecise ETA, need for large crews of skilled sailors, excessive heel angles, limited mechanical power on board and high maintenance costs. Many of these competitive disadvantages can be overcome by means of the modern mechanical, electronic and IT technologies. This will make auxiliary wind propulsion a viable solution for today's commercial shipping.

The study reported here was aimed at proving the feasibility of wind-assisted propulsion not just in principle but in a specific practical case.

1. METHOD OF ANALYSIS

1. 1. Equations of ship motion in the X-Y plane

The present analysis follows the basic lines of the method described in [1].

The equations of motion of a ship moving in clam water with constant forward speed and no angular velocity were solved accounting for the external hydrodynamic and aerodynamic forces.

Figure 1 is a sketch of the coordinate system, wind parameters and wind forces and some relevant geometrical parameters. Z-axis is directed upwards and all angles are considered positive when in counter-clockwise direction with respect to the corresponding axis..

The equations of motion in the x-y plane express the balance of the X and Y forces and yawing moments N:

(1) $$\sum X_i (V_s, AWS, AWA, \beta, \delta) = 0$$

(2) $$\sum Y_i (V_s, AWS, AWA, \beta, \delta) = 0$$

(3) $$\sum N_i (V_s, AWS, AWA, \beta, \delta) = 0$$

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The arguments in the equations are:

V_s	-	Ship speed
AWS	-	Apparent wind speed
AWA	-	Apparent wind angle
β	-	Leeway angle
δ	-	Rudder deflection angle

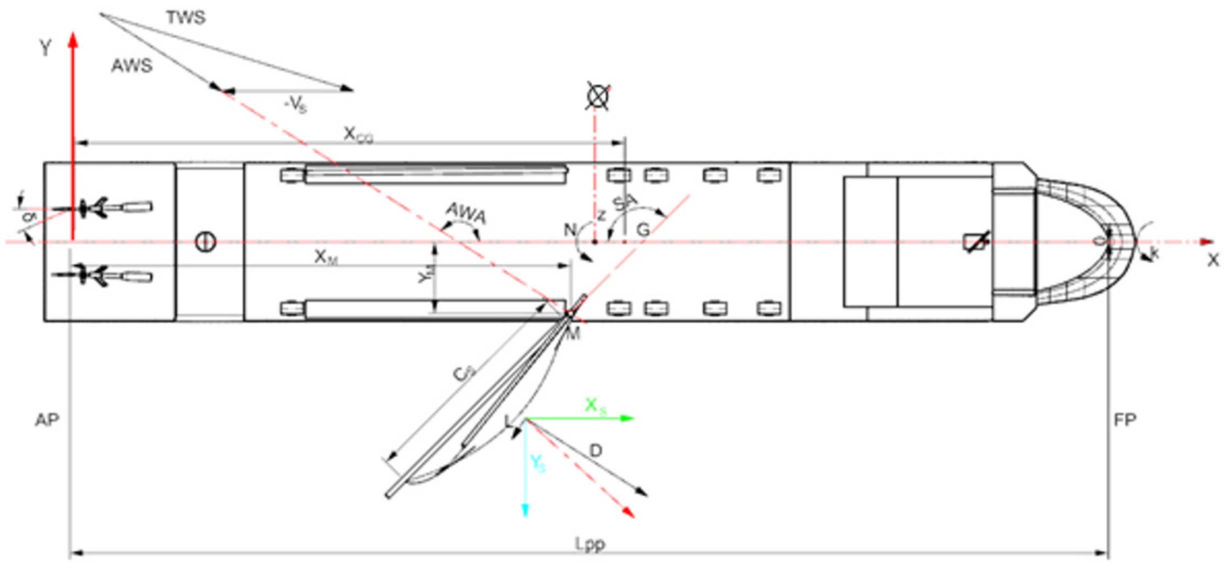

Fig. 1. Problem set-up

Equations (2) and (3) are solved first with respect to leeway angle β and rudder angle δ for specified ship speed and wind parameters.

With the found β and δ equation (1) is solved than to find the resistance of the ship under the action of the external effects.

The updated resistance and the propeller open water characteristics determine the delivered power, the brake power and the fuel-oil consumption (FOC).

A collateral result is the inclining moment and the heel angle.

1. 2. Estimation of forces and moments

The forces and moments involved in the equations can be determined in a number of different ways:

- Model tests in a towing tank or wind tunnel (for ship top side and sails);
- Empirical data;
- CFD simulations.

2. SUBJECT OF ANALYSIS

2. 1. Ship

A ferry-boat was chosen for the simulation. It was deemed suitable for wind-assisted propulsion for the following reasons:

- Foreship location of the navigation deck not to be obstructed by sails;
- Relatively clear deck;
- Regular trip destination and schedule.

The considered ship is based on an existing ship - main particulars, full form and general arrangement. The propulsion system was changed. Instead of the two ducted propellers, two open propellers and two rudders were designed.

Figure 2 presents the general arrangement of the investigated ship.

2. 2. Sails

A system of two soft sails was improvised.

The sails (785 m^2 each) were located at the both sides about the midship (Fig. 2). The sails control system is sketched on Fig. 3. It was designed having in mind the possibility of mechanizing the control of the sails.

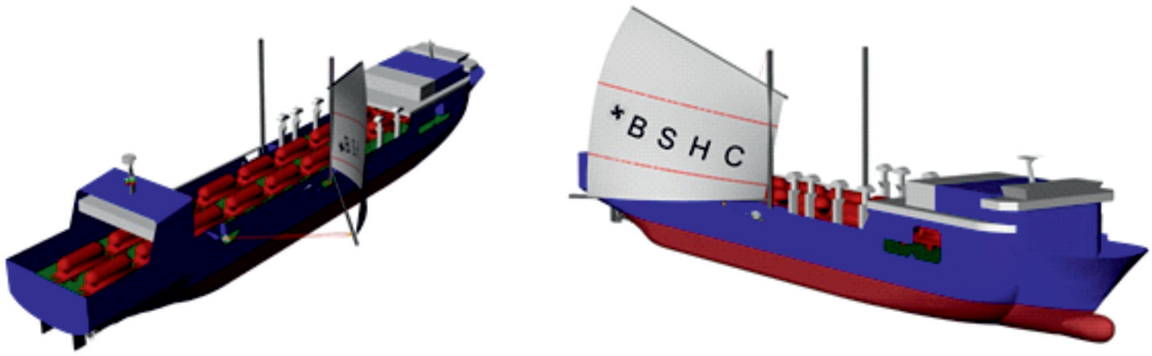

Fig. 2. General view of the investigated ship

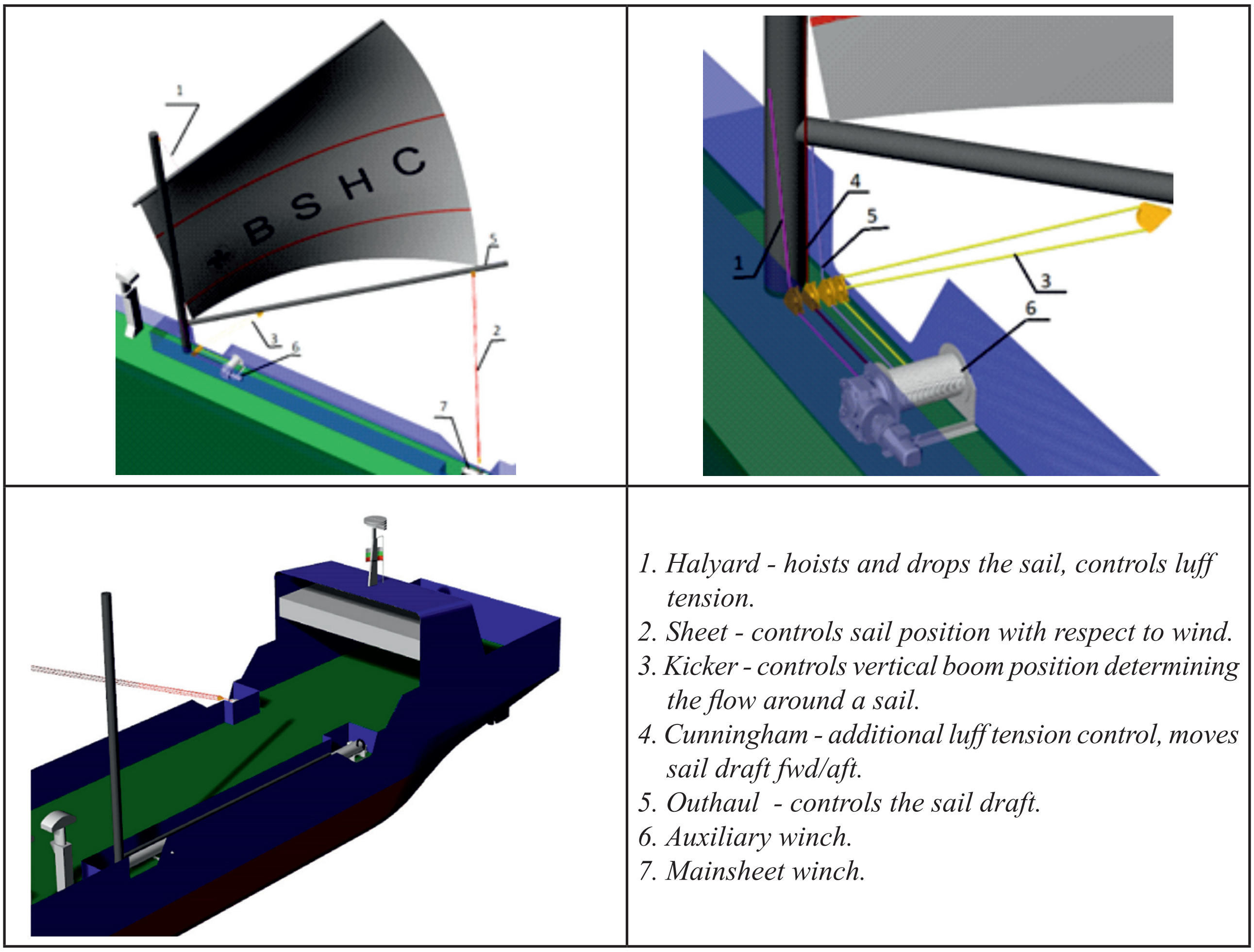

Fig. 3. Sail control system

The presence of vehicles on the deck does not allow deflecting the sail inwards. That is why the idea is using the sails alternatively, one at a time, depending on the apparent wind direction. In principle, at running wind directions it is possible to use both sails [8] but in the simulations here only a single sail was employed alternatively.

2. 3. Route

It was decided to study the feasibility of wind-assisted propulsion specifically in the Black Sea. The route Varna - Poti - Varna was selected. It is not the regular destination of the prototype ship but the route is considered promising in view of the trends in Bulgaria-Georgia economic relations.

Actual wind data along the route were taken from [6] (Fig. 4)

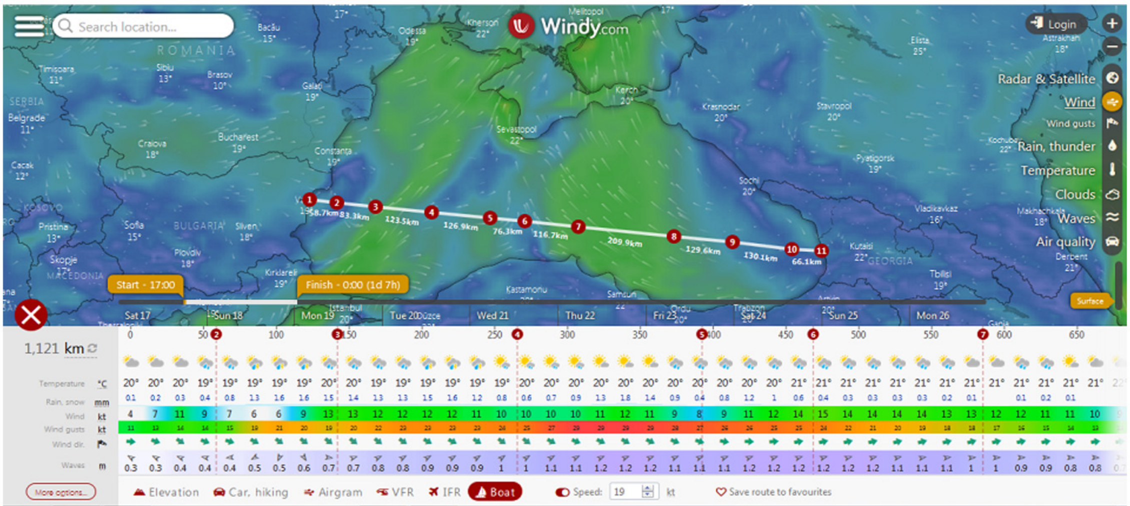

Fig. 4. Screen of the application used to collect the wind data [6]

The route was split in several sections with relatively constant weather conditions. The collected data for a period of time sufficient to cover the targeted distance are presented in Table 1.

Wind data along the route Varna - Poti

Table 1

Section	Latitude	Longitude	Bearing	Distance, nm	TWS, kn	TWA, deg
1	43.19	28.00	95	31.70	13	0
2	43.14	28.72	96	45.00	15	10
3	43.06	29.74	95	66.70	15	10
4	42.94	31.25	95	68.50	12	10
5	42.83	32.80	96	41.20	13	10
6	42.76	33.73	95	63.00	10	0
7	42.65	35.15	95	113.40	14	0
8	42.46	37.70	95	70.00	12	280
9	42.34	39.27	96	70.30	13	270
10	42.20	40.84	94	35.70	15	270

3. ANALYSIS

In this initial conceptual study the forces and moments in equations (1) to (3) are estimated by simple approximate methods.

The hydrodynamic straight-course resistance, RHYD, was taken from model test results carried out for the prototype ship.

The wind loads (X_{TOP}, Y_{TOP}, N_{TOP}) coefficients on the topside of the ship (above-water part of the hull + superstructures) were taken from [4] for a support vessel with similar dimensions and general arrangement.
The rudder forces and moment (X_{RUD}, Y_{RUD}, N_{RUD}) were calculated by empirical formulae from [3, 5] accounting for the influence of the propeller.
The forces and moment due to leeway angle (X_β, Y_β, N_β) were determined by empirical formulae from [2] for the hydrodynamic derivatives using the main particulars of the ship.
The forces on the sail (X_S, Y_S) were calculated by applying the JavaFoil applet [7] on a wing with simplified foil-and-mast section, camber ratio 0.1 and aspect ratio of 1.5.

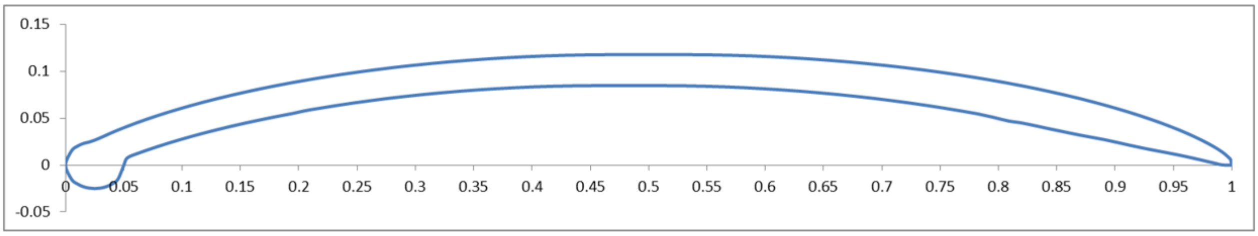

Fig. 5. Calculated foil and mast section

The sail forces are calculated as a function of the angle of incidence. For each apparent wind angle (AWA) there is an angle of the sail w.r.t. centre plane (SA) which provides maximum driving force X_S. This force and the corresponding cross force YS was used for each AWA.

Equations (2) and (3) were solved by means of the EXCEL add-in SOLVER with respect to leeway angle β and rudder angle δ. With β and δ found, ship resistance was calculated by solving equation (1).

The delivered power and revolutions were obtained from the calculated resistance and the propeller open-water characteristics. The fuel-oil consumption is determined knowing the characteristics of the main engine.

4. RESULTS

The energy efficiency of wind-assisted propulsion can be estimated in two ways:

- Comparing attainable speed with and without sails at the same engine power, or
- Comparing the power and FOC at the same speed to be maintained.

The second approach was applied here because the ship mission implies constant speed for keeping the schedule.

Speed of 10 knots was assumed for the whole trip.

Figure 6 shows the delivered power per propeller for each of the sections of the route Varna-Poti-Varna. Three options are compared: no true wind without sails, true wind without sails and true wind with sails. The true wind parameters are those from the weather data base (Table 1.)

Accumulating the FOC of the two engines with the calculated power, speed and time for each section of the route the fuel savings were deduced:

	Varna-Poti	Poti -Varna	Round trip
No wind, no sales	13.6 t	13.6 t	27.2 t
Wind, no sales	13.5 t	12.8 t	26.3 t
Wind, with sales	11.4 t	11.3 t	22.7 t
FOC savings	**16 %**	**12 %**	**14 %**

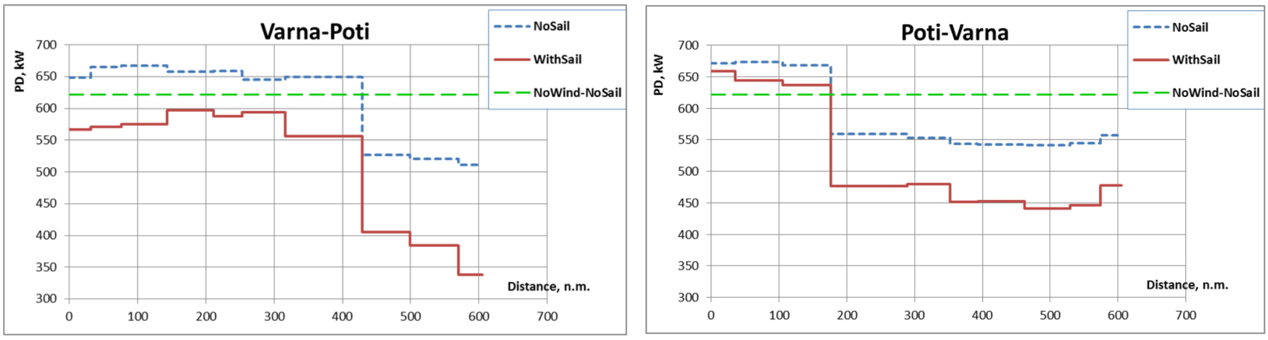

Fig. 6. Delivered power on a round trip Varna-Poti-Varna

Figure 7 presents the variation of leeway angle and figure 8 the necessary rudder angle to keep the ship on course.

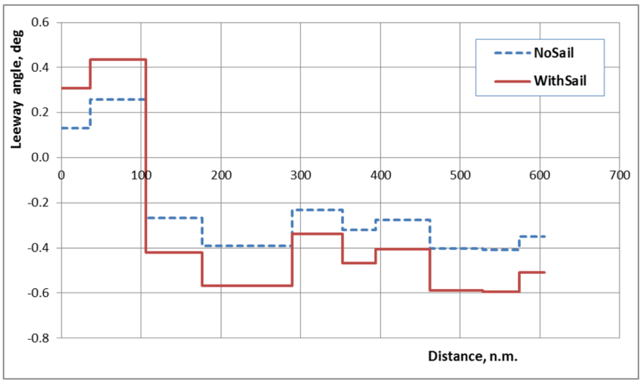

Fig. 7. Variation of the leeway angle on the route Poti -Varna

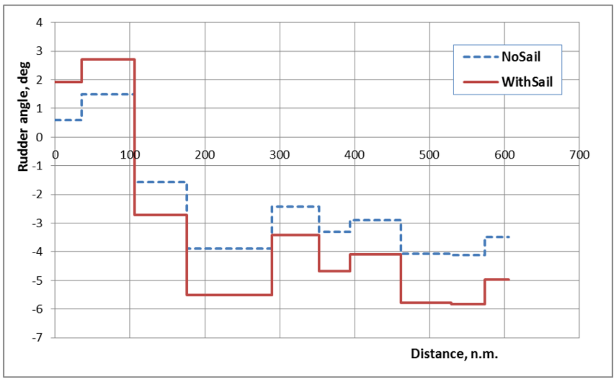

Fig. 8. Variation of the rudder angle on the route Poti -Varna

Figure 9 illustrates the variation of heel. This is a collateral but equally important for the ship operation result.

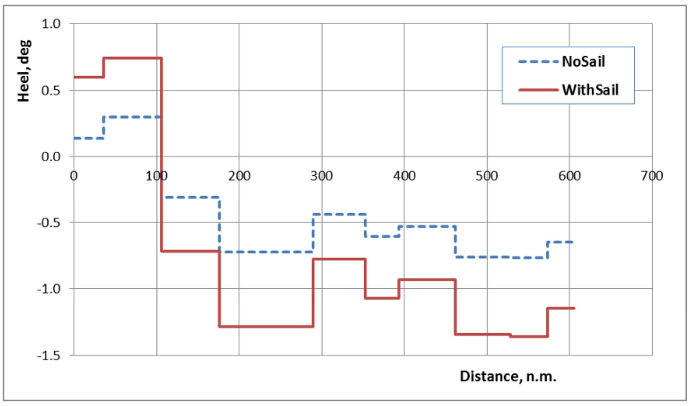

Fig. 9. Variation of heel on the route Poti-Varna

CONCLUSIONS

The results of the study with a specific ship on a specific route and wind conditions prove the energy saving effect of wind-assisted propulsion (WAP). The fuel-oil savings for a round trip Varna-Poti-Varna was estimated as 14%.

This study should be considered as only a simple initial step of a more comprehensive analysis. The further developments on the topic would be:

- Improved mathematical models and data sources on the external loads on the ship used in solving equations of ship motion. These include more sophisticated CFD simulations and systematic model tests.
- Including the wave induced forces and moments in the equations of ship behaviour.
- Development and study of different sail types and configurations.
- Generalized analysis of the effect of WAP on a yearly basis.
- Route optimisation for ships with WAP.

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INVESTIGATION OF THE PROCESS OF TIGHTENING AN ONBOARD TWO-TIERED FLEXIBLE HOVERCRAFT SKIRT WITH A DIAPHRAGM IN A TRANSIENT MODE OF MOVEMENT BY THE SIDE IN WAVES

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Abstract. *A mathematical model is described for determining the shape parameters of an onboard flexible hovercraft skirt with a single-tier flexible receiver with removable elements and a diaphragm. The shape of this flexible skirt is determined by moving the hovercraft sideways at low speed. The study was carried out to take into account the phenomenon of tightening a flexible skirt under the hovercraft hull.*

Key words: *flexible skirt, hovercraft, receiver, removable element, tightening.*

INTRODUCTION

When the hovercraft moves sideways at low speed on rough seas, the water surface is deformed under the influence of the air cushion pressure, the depression under the bottom forms a wave profile.

The wavelength gradually increases as the speed of the hovercraft increases. In particular, with a Froude number of 0.4, tчhe wavelength is equal to the width of the hovercraft over flexible skirts. The hovercraft is on two wave crests, and the hovercraft's center keel is the highest and the vessel's stability is the lowest. This can lead to an emergency heel angle with the Froude number **Fr = 0,4**.

The main external hydrodynamic forces acting on the board flexible skirt (BFS) when it is tightened in a transitional mode under the hull when moving sideways on waves are usually divided into two components: the first component is associated with excess air pressure in the air cushion and in the flexible receiver, the second - with water resistance arising on removable elements as a result of contact with water. As a result of the impact on the removable elements of water resistance, under certain conditions, the BFS is tightened under the hovercraft hull.

The behavior of the BFS in the transient mode depends on its ability to resist tightening, and this ability depends on the shape of the flexible skirt (FS), air pressure and the presence of diaphragms that reduce the possibility of pulling the FS under the hovercraft hull (Fig. 1).

NARRATION

The aim of the study is to determine the parameters of the BFS shape with a single-tier flexible receiver with removable elements and with a diaphragm, which affect the tightening of the BFS in the transient mode under the hovercraft hull when it moves sideways in waves.

In the process of research solved the problem of taking into account the phenomenon of tightening in the transient mode when determining the stress-strain state of a single-tier BFS receiver with removable elements with a diaphragm in the hovercraft sideways motion mode on waves without taking into account the size of the airway cutouts

We study the shell of the BFS receiver (Fig. 1.), consisting of two sections AK_1 and DK_2 of isotropic, inextensible and absolutely flexible material, between which there is a section $K_1 K_2$ for attaching removable elements $K_1 K_3 K_4 K_2$ to the shell of the receiver. FS is fastened to a rigid receiver by two parallel guides A and D on hinges around which the receiver can rotate freely. The AK_1 diaphragm is attached with its upper end to the rigid receiver also on hinges at a short distance from the hinges of the upper mounting of the flexible BFS receiver. The lower end of the diaphragm is attached to the shell of the onboard flexible receiver in the area of the removable element attachment (forming K_1). The section $K_1 K_2$ together with a removable element is considered in the design scheme as a rigid structure in the form of a straight quadrangular prism, which can rotate around the lines passing through the points K_1 and K_2 of attachment to the tissue sections of the receiver shell.

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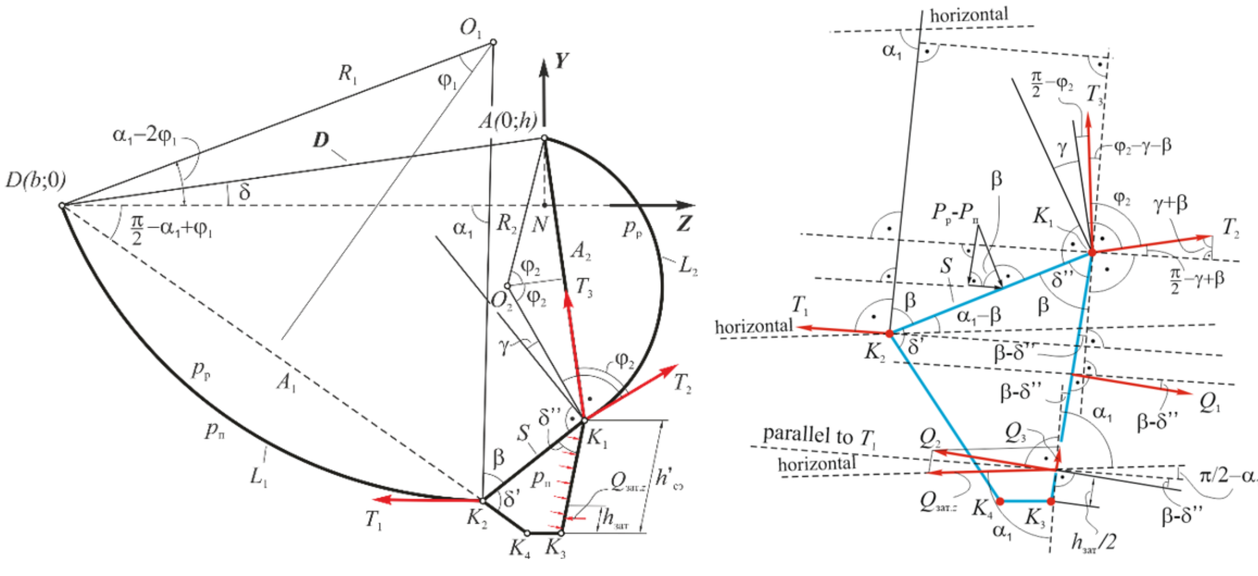
On waves, the ship moves sideways along the ξ axis at a distance dξ (Fig. 2.). In Fig. 2. denoted: ζ0ξ - a fixed coordinate system, the origin of which coincides with the center of gravity of the vessel; $B_П$ - width of the air cushion (AC), m; λ - wavelength, m; G - center of gravity of the vessel, m; ν_Z - sideways speed of the vessel (movement of the hovercraft in the direction of the NZ axis), m/s; $\zeta_Л$, $\zeta_П$ - ordinates of the wave profile, respectively, along the outer edges of removable BFS elements of the left and right sides of the vessel, m.

During the movement of the hovercraft sideways on the starboard side in waves, removable elements (RE) are immersed in the wave to a depth of $h_{ЗАТ}$ as shown in Fig. 2. and Fig. 3., which are marked: $\alpha_П = \alpha_Л + \left(\frac{2\pi B_П}{\lambda}\right)$- the angle of the wave slope in the area of the outer edge of the removable starboard element BFS, $\alpha_Л = \sigma t - \left(\frac{\pi B_П}{\lambda}\right)$ - angle of the wave slope in the area of the outer edge of the removable element of the left side BFS, rad; (where $\sigma = \sqrt{gk}$ - wave frequency, s^{-1}; $k = 2\frac{\pi}{\lambda}$ - frequency of the wave profile, m^{-1}; g - gravitational acceleration, m/s^2); $h_{ЗАТ}$ - depth of RE BFS immersion into the wave, m.



a ***b***

Fig. 1. Design scheme of BFS for studying its tightening in transient when the hovercraft moves sideways in waves:
a - general design scheme; b - diagram of the forces acting on the removable element

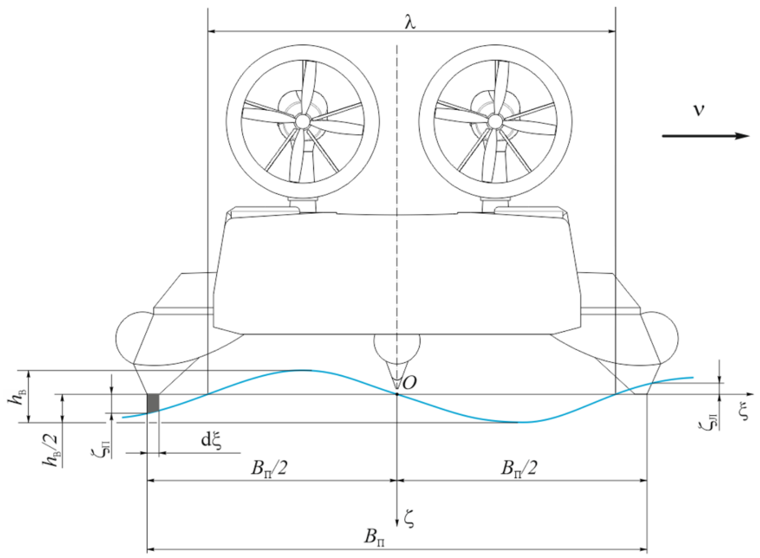


Fig. 2. Scheme of wave propagation through an air cushion and BFS in the hovercraft sideways movement mode

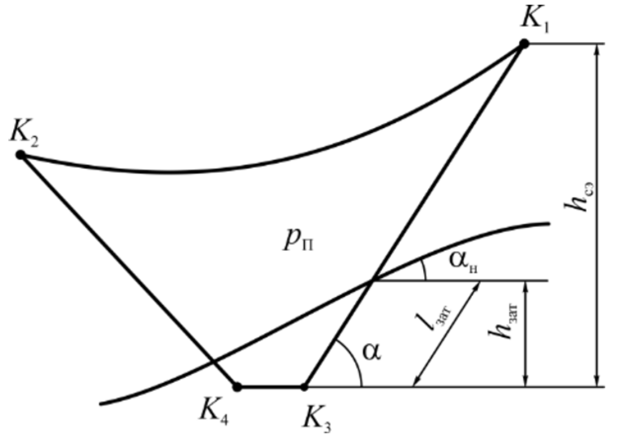


Fig. 3. Scheme of immersing a removable element in water in the hovercraft sideways motion mode on waves

Height of a removable element along its outer edge $\boldsymbol{K_1 K_3}$ - $\boldsymbol{h'_{C.Э}}$. Shell tissue sections $\boldsymbol{AK_1}$ and $\boldsymbol{DK_2}$ of the flat rectangular cut are fixed on two rigid parallel ties. Inner edge $\boldsymbol{K_2 K_4}$ and outer $\boldsymbol{K_1 K_3}$ of outer removable element form with the rigid section of the receiver $\boldsymbol{K_1 K_2}$ respectively angles **δ'** and **δ''**. The ribs of the rigid quadrangular prism (removable element) are parallel to the attachment lines of the receiver shell on the rigid hovercraft hull.

Accepted assumptions. The material of the two sections AK_1 and DK_2 FS - isotropic, inextensible and absolutely flexible; section $K_1 K_2$ together with a removable element is considered in the design scheme as a rigid structure in the form of a straight quadrangular prism, which can rotate around the lines K_1 and K_2 attachment to the tissue sections of the BFS receiver shell; the rigid removable element does not receive longitudinal inclinations and turns in the horizontal plane; the tissue sections of the flexible receiver shell during operation remain cylindrical; there are no normal and tangential forces on the end sections of the FS shell; the loops of the upper mount of the flexible receiver in the design diagram coincide with the loops of the upper mount of the diaphragm AK_1; the shell of the flexible receiver is loaded with staged air pressure.

When a removable element is immersed in a wave, a force of resistance to its movement R_Z (H), arises on it, which can be defined as $R_z = 0{,}5\, C_z\, (\alpha, h_{зат.z})\, \rho_B\, \upsilon_z^2\, A_{хар.z}$ (*here* $C_z\, (\alpha, h_{зат.z})$) - drag coefficient determined by a numerical experiment for a real RE structure, which depends on the values α and $h_{зат.z}$; $\rho_B = 1025$ kg/m^3 - mass density of sea water; $A_{хар.z} = \frac{L_П h_{зат.z}}{\sin\alpha}$ - characteristic area).

External loads: section AK_1 is loaded with pressure in the flexible receiver p_P, Pa; section DK_2 - by the difference in pressure in the air cushion $p_П$ and the receiver p_P, that is, by pressure (p_P - $p_П$), Pa; hard section of the receiver $K_1 K_2$ - pressure (p_P - $p_П$), Pa; outer edge $K_1 K_3$ of the removable element is loaded with pressure $p_П$, the resultant of which Q_1, kN/m, (Fig. 1., *b*) applied in the middle of the height of the removable element, and the resultant tightening load $Q_{зат.z}$, kN/m, applied at a distance $h_{ЗАТ}/2$ from the lower edge of the removable element (here $h_{зат.z}$ - is the height of the part of the removable element that comes into contact with the water surface when moving the hovercraft, m) in the direction and parallel to the NZ axis.

Except pressures and tightening loads as the initial data are the following taken as raw data: (Fig. 1.):

$\boldsymbol{L}$ - cross-sectional length of flexible receiver, m;

$\boldsymbol{A_2}$ - diaphragm cross-section length, m;

$\boldsymbol{D}$ - distance between the mounting points of the receiver, m;

$\boldsymbol{c = L_1/L_2}$ - the ratio of the lengths of the inner and outer parts of the cross-section of the flexible receiver excluding the area of attachment of the removable element;

$\boldsymbol{\delta}$ - the angle between segments AD and ND or the angle of elevation of the outer line of attachment of the BFS to the hovercraft hull in relation to the inner line of attachment of the flexible skirt;

$\boldsymbol{\delta'}$ - the angle formed by the inner edge $\boldsymbol{K_2 K_4}$ of the removable element with the rigid section of the receiver $\boldsymbol{K_1 K_2}$;

$\boldsymbol{\delta''}$ - the angle formed by the outer edge $\boldsymbol{K_1 K_3}$ of the removable element with a rigid section of the receiver $\boldsymbol{K_1 K_2}$;

$\boldsymbol{h'_{C.Э}}$ - height of the removable element along the outer edge $\boldsymbol{K_1 K_3}$ of the removable element, m;

$h_{ЗАТ}$ - the height of the part of the removable element that comes into contact with the water surface when the hovercraft moves, m;

S - length of the rigid section of the receiver $K_1 K_2$, m;

α - the angle of inclination of the removable element to the water surface, degrees (Fig. 3);

v_Z - sideways speed of the vessel (hovercraft movement in the direction of the NZ axis), m/s;

$z_П$ - the applicate of the center of gravity of the air cushion, m;

$L_П$ - length of the air cushion, m;

$B_П$ - air cushion width, m;

θ - hovercraft roll angle in sideways movement on an air cushion, degrees, as a function of trim angle ψ, yaw angle φ, drift angle β, heading angle γ, translational $\vec{V}^T = \begin{pmatrix} V_x & V_y & V_z \end{pmatrix}$ and angular $\vec{\omega} = \begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix}$ velocities of the hovercraft movement, longitudinal a_x, lateral a_y and vertical a_z accelerations of the hovercraft:

$$\theta = f(\psi, \varphi, \beta, \gamma, \vec{V}, \vec{\omega}, \vec{a}).$$

The shape parameters of the board flexible receiver, taking into account its tightening in the hovercraft sideways movement mode on an air cushion, will be found by considering its cross section (Fig. 1.).

Let us write down the equilibrium equations of the removable element $K_1 K_2 K_4 K_3$, Fig. 1.:

(1) $T_1 - Q_1 \cos(\beta - \delta'') + Q_2 \cos(\beta - \delta'') - Q_3 \sin(\beta - \delta'') - T_2 \sin(\gamma + \beta) - S(p_P - p_П)\cos\beta + T_3 \cos(\frac{\pi}{2} - \gamma - \beta + \varphi_2) = 0;$

(2) $T_2 \cos(\gamma + \beta) - Q_1 \sin(\beta - \delta'') + Q_2 \sin(\beta - \delta'') + Q_3 \cos(\beta - \delta'') - S(p_P - p_П)\sin\beta + T_3 \cos(\varphi_2 - \gamma - \beta) = 0;$

(3) $T_1 S \cos\beta - S^2 \frac{(p_P - p_П)}{2} - Q_1 \frac{h'_{С.Э}}{2} + Q_2 \left(h'_{С.Э} - \frac{h_{ЗАТ}}{2}\right) = 0$

(4) $Q_1 = p_П h'_{С.Э}$; $Q_2 = Q_{зат.z} \cos(\frac{\pi}{2} - \alpha_1 + \beta - \delta'')$;

(5) $Q_3 = Q_{зат.z} \sin(\frac{\pi}{2} - \alpha_1 + \beta - \delta'')$;

(6) $T_1 = (p_P - p_П) R_1$;

(7) $T_2 = p_P R_2$;

(8) $Q_{зат.z} = R_z = 0{,}5\, C_z(\alpha, h_{зат.z})\, \rho_B v_z^2 h_{хар.z}$;

(9) $h_{зат.z} = (\frac{B_П}{2} + z_П)\tan\theta + \xi_П$;

(10) $h_{хар.z} = \frac{h_{зат.z}}{\sin\alpha}.$

where

$\xi_П$ - the ordinate of the wave profile in the coordinate system $\zeta 0 \xi$ (see Fig. 2.) in the region of the outer edge of the removable element of the onboard flexible skirt (at time t, the equation of the surface of waves traveling towards the ship $\xi_П = \left(\frac{h_B}{2}\right)\cos\left(\sigma t + \frac{2\pi}{\lambda}\xi\right)$, m: $\xi_П = \left(\frac{h_B}{2}\right)\cos\alpha_П$;

$\alpha_П$ - angle of the wave slope in the area of the outer edge of the removable element on starboard, radians:

(11) $\alpha_П = \alpha_Л + \left(\frac{2\pi B_П}{\lambda}\right)$;

$\alpha_Л$ - the angle of the wave slope in the area around the outer edge of the removable element on port side, radians:

(12) $\alpha_Л = \sigma t - \left(\frac{\pi B_П}{\lambda}\right)$;

λ - wavelength, m:

(13) $\lambda = 30 h_B$;

$\alpha_Л$ - the angle of the wave slope in the area around the outer edge of the port side removable element, radians:

v_z - speed of movement of the hovercraft sideways on an air cushion in the direction of the NZ axis, m/s;

$h_{ГО.\theta=0}$ - height of BFS at a ship's heel angle $\theta = 0°$;

α_P - BFS opening angle (design angle between the cut of the side part of the pontoon and the main plane), degrees (Fig. 4.): $\delta = \alpha_P - \theta$;

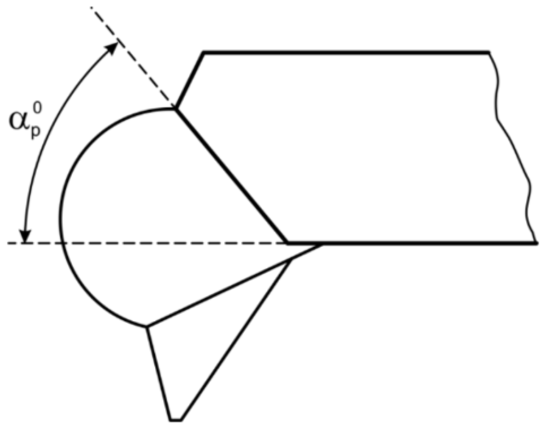


Fig. 4. Opening angle of board flexible skirt

$A_{хар.z}$ - characteristic area of the removable element when tightening the BFS under the hovercraft hull in the direction of the *NZ* axis, m_2;

ρ_B - mass density of seawater, $\rho_B = 1025\ kg/m^3$;

R_z - resistance force (form resistance) of removable BFS elements when moving the hovercraft with a roll on board when tightening the BFS under the hull in a transient mode, *N*;

$C_z\ (\alpha, h_{зат.z})$ - form resistance coefficient, determined by numerical experiment for a real design of removable BFS elements, which depends on the values of α and $h_{зат.z}$;

α - the angle of inclination of the removable element to the water surface, degrees;

Q_2 - component of the resultant tightening load directed perpendicular to the outer edge $K_1 K_3$ of the removable element, *N/m*;

Q_3 - component of the resultant tightening load directed along the outer edge $K_1 K_3$ of the removable element, *N/m*;

T_1 - tension in the sheath of the flexible skirt, acting on the inner section of the flexible receiver DK_2, *N/m*;

T_2 - tension in the sheath of the flexible skirt acting on the outer section of the flexible receiver AK_1, *N/m*;

T_3 - tension in the diaphragm AK_1, *N/m*;

β - the angle between the rigid section $K_1 K_2$ and the direction of the radius $O_1 K_2$ of the inner section of the flexible receiver DK_2;

γ - the angle between the normal to the rigid section $K_1 K_2$ and the direction of the radius $O_2 K_1$ O_2K_1 of the outer section of the flexible receiver AK_1;

R_1 - radius of curvature of the inner section of the receiver DK_2, *m*;

R_2 - radius of curvature of the outer section of the receiver AK_1, *m*.

$z_П$ - applicate of the center of gravity of the air cushion, *m*;

$L_П$ - length of the air cushion, *m*;

$B_П$ - air cushion width, *m*;

θ - hovercraft roll angle in sideways movement on an air cushion, degrees, as a function of trim angle $\boldsymbol{\psi}$, yaw angle $\boldsymbol{\varphi}$, drift angle $\boldsymbol{\beta}$, heading angle $\boldsymbol{\gamma}$, translational $\vec{V}^T = \begin{pmatrix} V_x & V_y & V_z \end{pmatrix}$ and angular $\vec{\omega} = \begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix}$ velocities of the hovercraft movement, longitudinal $\boldsymbol{a}_x$, lateral $\boldsymbol{a}_y$ and vertical $\boldsymbol{a}_z$ accelerations of the hovercraft:

$$\boldsymbol{\theta} = \boldsymbol{f}(\boldsymbol{\psi}, \boldsymbol{\varphi}, \boldsymbol{\beta}, \boldsymbol{\gamma}, \vec{\mathbf{V}}, \vec{\boldsymbol{\omega}}, \vec{\mathbf{a}}).$$

Geometric relationships for the BFS:

(14) $S \cos(\alpha_1 - \delta - \beta) - A_1 \sin(\varphi_1 - \alpha_1 + \delta) + A_2 \cos(\varphi_2 + \alpha_1 - \delta - \beta - \gamma) = D;$

(15) $A_1 \cos(\varphi_1 - \alpha_1 + \delta) - S \sin(\alpha_1 - \delta - \beta) - A_2 \sin(\varphi_2 + \alpha_1 - \delta - \beta - \gamma) = 0;$

(16) $L = L_1 + L_2 + S;$

(17) $L_1 = 2R_1\varphi_1;$

(18) $L_2 = 2R_2\varphi_2$;
(19) $A_1 = 2R_1 \sin\varphi_1$;
(20) $A_2 = 2R_2 \sin\varphi_2$;
(21) $L_1/L_2 = c$,

where
α_1 - the angle between the horizontal *ND* and the direction of the radius $O_1 K_2$ of the inner section of the flexible receiver DK_2;
A_1 - chord length of the inner section of the receiver section DK_2, *m;*
A_2 - the length of the diaphragm of the outer section of the receiver section AK_1, *m*;
φ_1 - half of the central angle of the arc of the cross-section of the internal section of the receiver DK_2;
φ_2 - half of the central angle of the cross-sectional arc of the outer section of the receiver AK_1.
In the system of equations (1) - (21), the given values are: D, z_{IP}, L_{IP}, B_{IP}, θ, L, L_2, S, c, $h'_{C.Э}$, δ'', δ', δ, p_P, p_{IP}, $C_z(\alpha, h_{3AT})$, ρ_B, v, α, and the unknowns are 20 values: L_1, L_2 A_1, A_2 R_1, R_2, T_1, T_2, T_3, Q_1, Q_2, Q_3, $h_{зam.z}$, Q_{3AT}, A_{XAP}, α_1, β, γ, φ_1, φ_2.
Coordinates of the point K_2 of attachment of the inner line of removable elements to the inner section DK_2 of the flexible receiver in the *ZNY* coordinate system (see Fig. 1.):

(22) $$Z_{K_2} = b - A_1 \cos\left(\frac{\pi}{2} - \alpha_1 + \varphi_1\right); \quad Y_{K_2} = -A_1 \sin\left(\frac{\pi}{2} - \alpha_1 + \varphi_1\right),$$

where
b - horizontal projection of the distance between the mounting points of the receiver $b = ND = D\cos\delta$, *m*.
Coordinates of the point K_1 of attachment of the outer line of removable elements to the outer section AK_1 of the flexible receiver in the *ZNY* coordinate system (see Fig. 1.):

(23) $$Z_{K_1} = Z_{K_2} - S\cos(\alpha_1 - \beta); \qquad Y_{K_1} = Y_{K_2} + S\sin(\alpha_1 - \beta).$$

Coordinates of the lower point K_3 of removable elements in the *ZNY* coordinate system (see Fig. 1.):

(24) $$Z_{K_3} = Z_{K_1} + h'_{C.Э}\cos(\delta'' + \alpha_1 - \beta); \qquad Y_{K_3} = Y_{K_1} - h'_{C.Э}\sin(\delta'' + \alpha_1 - \beta).$$

Coordinates of the center of curvature O_1 of the inner section of the flexible receiver in the *ZNY* coordinate system (see Fig. 1.):

(25) $$Z_{O_1} = b - R_1\cos(\alpha_1 - 2\varphi_1); \qquad Y_{O_1} = R_1\sin(\alpha_1 - 2\varphi_1)..$$

Coordinates of the center of curvature O_2 of the outer section of the flexible receiver BFS in the *ZNY* coordinate system (see Fig. 1.):

(26) $$Z_{O_2} = X_{K_1} + R_2\cos\left(\frac{\pi}{2} - \alpha_1 + \beta + \gamma\right); \qquad Y_{O_2} = Y_{K_1} + R_2\sin\left(\frac{\pi}{2} - \alpha_1 + \beta + \gamma\right).$$

CONCLUSIONS

The described mathematical model makes it possible to determine the shape and stress-strain state of the BFS when the vessel is moving sideways, which in turn makes it possible to determine the danger of the phenomenon of tightening the flexible skirt under the hovercraft hull.

The use of the described mathematical model in the design of hovercraft will make it possible to create more reliable ships of this type.

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CFD ANALYSIS OF THE AIR FLOW INSIDE THE LANDSCAPE WIND TUNNEL UNDER CONSTRUCTION AT BSHC

Daniel FELLOWS*, Nikita DOBIN, Grigor NIKOLOV** and Rumen KISHEV****

Abstract. *A new, large-scale wind tunnel is to be built at BSHC in order to expand the aerodynamics department so that it can serve more industries and applications. To ensure that the wind tunnel design is adequate for such intended uses, there is a need for an analysis of how it behaves; this will be calculated using CFD methods in ANSYS FLUENT.*

The wind tunnel is equipped with six separate turbines to produce an inlet velocity of air, the test section will be open, and the air will be recirculated through the tunnel back to the fans. For the focus of this study, there is only a concern for monitoring the turbulence the fans produce and the level of turbulence in the test area, therefore there will not be a complete enclosed geometry used.

The results will be illustrated and graphically displayed to show a clear picture of the turbulent flow throughout the geometry.

Key words: *CFD analysis, wind tunnel.*

1. INTRODUCTION

1. 1. Overview

The need of establishing an aerodynamic laboratory in Bulgaria emerged in the 80s of the last century, with intention to serve a number of public entities and especially shipbuilding, Ministry of Defense, Bulgarian Airlines, Ministry of Mechanical Engineering, etc. Yet at the time of erecting of Bulgarian Ship Hydrodynamics Centre (BSHC), many leading Bulgarian and foreign experts have pointed out that, to complete the capacity for model research, an aerodynamic laboratory is absolutely necessary.

Nowadays, all technical industries are developing very fast and, as a consequence, the need for wind tunnel experiments is seriously increasing. The need for research in shipbuilding is unconditionally high, but there are many other industries that also need model tests in a wind tunnel, including:

- renewable energy conversion;
- environmental protection;
- road structures and civil engineering;
- shipbuilding and shipping;
- ground transport vehicles and equipment;
- airborne vehicles and equipment;
- sports;
- defense industry.

Currently, following the constant rice in the power computer technology and the development of mod-ern software technologies, more and more mathematical and numerical modelling methods (CFD) are used to calculate the characteristics of air flows. CFD is a reliable tool for theoretical calculation and creation of a visual physical picture of the flow.

On the other hand, the complexity, and in many cases the uniqueness of the studied processes leads to the need for model or field experiments to validate the obtained numerical results.

Currently BSHC has been granted large investment project for expansion of the research infrastructure in marine sciences and technology, within the frame of which erection of a large landscape wind tunnel is envisaged. In the process of design, two variants have been considered - a closed loop wind tunnel as well as an

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open test section loop wind tunnel. The second version is considered in this report, using experimental data from tests with 1:5 scale model of similar wind tunnel in operation at BSHC for validation of CFD assessment.

The work done consists of highlighting the boundary conditions for the setup of the simulation and the mesh quality to verify the accuracy of the simulation. The results and discussion follow along graphic displays of the results to give a full representation of the wind tunnel.

1. 2. Previous studies

A study close to this one, including a subsonic closed loop wind tunnel, has previously been carried out by John Kaiser Calautit and Ben Richard Hughes. In the study they used CFD methods in or-der to accurately calculate the flow of fluid around the model. To do so they used the numerical model, three- dimensional Reynolds-averaged Navier-Stokes (RANS) equations and the continuity equation. As well as Semi-Implicit Method for Pressure-Linked Equations (SIMPLEC) velocity-pressure coupling algorithm with the second order upwind discretization. Standard k-epsilon turbulence model (Calautit & Hughes, 2016). The experimental features of this previous study will be the base that this simulation will be built upon.

2. GEOMETRY AND MESH

2. 1. Setup

The geometry and scale used for calculations correspond to those of the open type tunnel with elliptic section, a scaled model of which is under operation at BSHC. In Figure 1, the entire sketch of the wind tunnel is shown. For the purpose of this simulation, the focus of the study was to measure the level of turbulence created in open working area. Due to this and the size of the model it was appropriate to only include the most necessary parts of the geometry as shown in Figure 2. As the model is a closed circuit, the pressure outlet was adjusted accordingly to replicate a closed cycle.

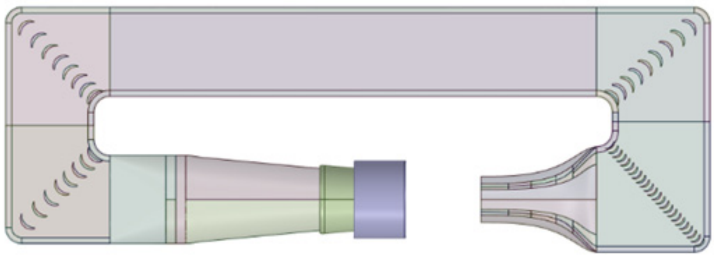

Fig. 1. Geometry of wind tunnel

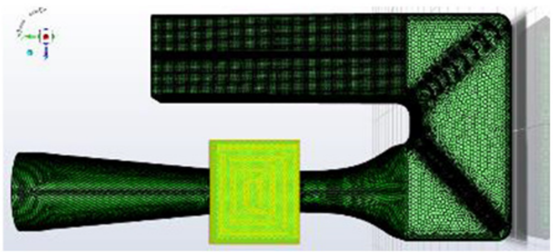

Fig. 2. Geometry used for calculations

2. 2. Turbines configuration

After all conditions where simulated with a velocity inlet and mass flow outlet conditions, six individual turbines where put into position and the boundary conditions where changed to pressure inlet and outlet. The turbines are shown in Figure 3. The turbines are located in the top section of the wind tunnel, facing the right corner to create a clockwise flow of air. In order to make the turbines rotate, mesh motion is selected with the center of each selected as the axis of rotation, here the direction vector and the speed can be selected.

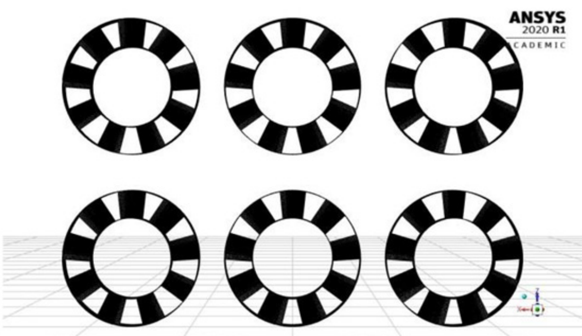

Fig. 3. Turbine configuration

Once the geometry was created, the mesh was generated by using fluent meshing techniques to create a high quality volume mesh, to achieve a skewness of below 0.98% and the interfaces line up with one another accurately. To setup the model and to check if it correctly worked a course mesh is used as shown in Table 1. To experiment with configurations the fine mesh is used as there was an increase of turbine speed.

3. BOUNDARY CONDIDTIONS

3. 1. FLUENT options

As this is a 3D CFD model and it is assumed that it is a highly curved mixing layer environment, conclusions drawn from the research paper called "The turbulence structure of a highly curved mixing layer" (Castro and Bradshaw, 1975) are taken into an account throughout the research of the wind tunnel. When setting up the simulation, calculation options and boundary conditions are selected which are presented in Table 2 and 3. Due to the environment in which the turbulence is being calculated in, the turbulence model, detached eddy (DES) is used. This is so that the computer can transfer between RANS areas and LES in detached areas efficiently, cutting down computation time. K-ω, SST was used as the turbulence model as the K-ε model has shortcomings with overestimating the shear stress, therefore delays separation (Argyropoulos & Markatos, 2014). The Boundary conditions provide a template to follow when carrying out a simulation so that it is an accurate representation as well as providing consistently when influencing factors are changed. Table 3 includes all the geometry parts and what type they are classed as within FLUENT.

Mesh statistics

Table 1

Mesh type	Mesh size (m)
Course	0.12
Medium	N\A
Fine	0.014

Calculation options

Table 2

Fluent calculation options	Option selected
Solver	Pressure based, transient time, gravity = 0
Viscous	DES, K-omega
Materials	Air, aluminum
Cell zones	Domain, Turbines, open test section
Solution method	SIMPLE, Second order Implicit
Solution controls	Default

Boundary conditions

Table 3

Sections	Type
Inlet	Pressure inlet
Outlet	Pressure outlet
Walls	Wall
Turbines	Wall
Flow directors	Wall
Interior domain	Interior
Interior turbines	Interior
Open working section	Symmetry / Pressure outlet

4. RESULTS AND DISCUSSION

4. 1. Velocity profiles

To display the levels of turbulence within the test section of the wind tunnel accurately, a velocity pro-file is taken from the middle of it. As turbulent flows are slower in a single vector direction, the higher the velocity in one show that, it is a laminar flow in that region. Therefore, the higher velocity region is the region with the least turbulence and should be taken as the maximum area for testing. Any area outside of the laminar flow region we have an inaccurate result due to the interference of turbulent flow generated by the wind tunnel. The Figures 4 and 5 bellow show the velocity profiles taken from inside the test section at 8 and 12 seconds.

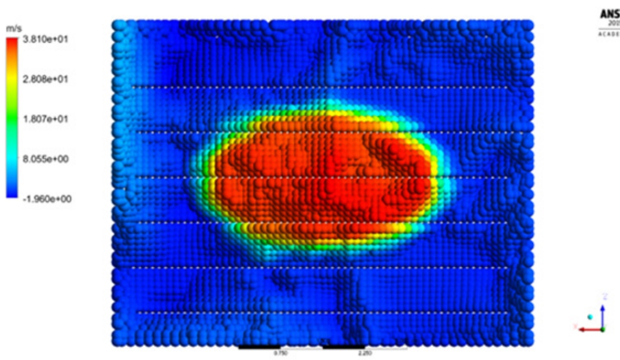

Fig. 4. Velocity profile at 8 seconds

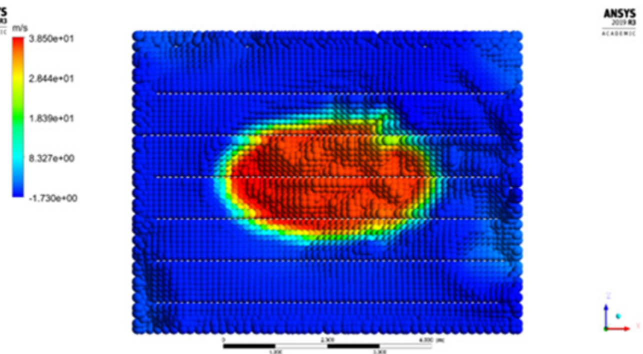

Fig. 5. Velocity profile at 12 seconds

As the results show, the highest velocities are converged in an oval shape, highlighting the area of laminar flow which averages 4m length and 2.5m height. Figure 6 shows the formation of the flow, the sharp and long peak indicates that the flow is laminar as there are a lot more higher velocities, if the peak was a round done this would indicate that the average velocity is low, therefore there is a turbulent flow.

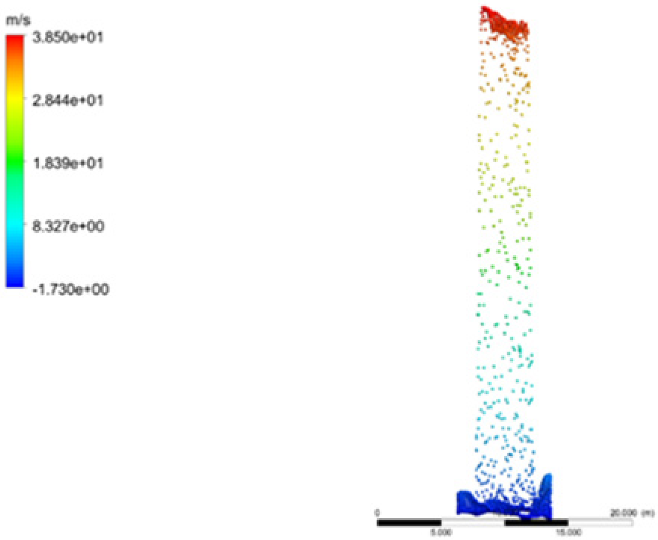

Fig. 6. Formation of flow through test section

5. CONCLUSIONS

5. 1. Discussion

As the results indicate, the shape of the laminar flow is directly in relation to the compressors outlet as this is an open test section. Due to the cross sectional area of the laminar flow in comparison to the cross sectional area of the compressors outlet, it can be assumed that the laminar flow would continue this trend within a closed test section environment although further calculations would be needed to conform this. The consistency between the data points displayed in Figures 4 and 5 show that the flow directors preform optimally but the deformation in Figure 5, highlights that there is a slight change in the level of turbulence over a duration. This could be eliminated by a further addition of a filter or more diffusors to control the velocity of flow within the geometry.

6. ACKNOWLEDGEMENTS

This research was partially supported by:

• Erasmus+ EC Project;

• MASRI - Infrastructure for Sustainable Development of Marine Research including the Participation of Bulgaria in the European Infrastructure Euro-Argo, an object of the National Roadmap for Scientific Infrastructure (2017-2023) of Re-public of Bulgaria;

• Bulgarian Ministry of Education and Science under the National Research Program "Young Scientists and Postdoctoral Students" approved by DCM # 577 / 17.08.2018.

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PRACTICAL ASSESSMENT OF STERN BOAT RECOVERY OPERATION

Silvia KIRILOVA*, Rumen KISHEV* and Doron MARCUS**

Abstract. *Workboats are often used for performing various operations at sea, such as search and rescue, transportation ship to ship or to/from shore, wreck assessment, etc. Several deployment techniques are in use, but recently the stern ramp is considered as more convenient and universal.*
At BSHC, some preliminary investigation was carried out on the stern boat recovery in waves, mostly to assess stern ramp influence on ship motions and time gap available for recovery. Numerical results backed experiments and traced the way for further detailed research.

Key words: *boat deployment, boat recovery modeling, relative motions in waves, stern boat ramp.*

INTRODUCTION

Principally, the problem of assessing boat deployment operation concerns interaction of two floating bodies advancing at low speed in adverse seas and shortening the distance between them. While the distance is large (in the beginning of recovery operation) the two bodies move independently to each other, the only parameters coordinated are the speed and the direction of heading. This make possible to consider motions of both vessels independently. Because of big difference in masses, motion characteristics differ as well. At the moment the boat approaches the mother ship, relative motions of ship stern and boat become of importance for the success of operation. Thus, relative motions were the main concern of that research.

A generic couple of mother ship and boat was subjected to seakeeping tests and calculations to assess motions of the vessel and relative motions at stern ramp location. It is assumed, that the stern ramp is closed en-route and opened only at boat-involved operations. The influence of submerged part of the ramp when opened is of prime interest as well, but the available software was not able to ac-count for this, so all estimations of ramp opening influence on relative motion at stern have been done experimentally.

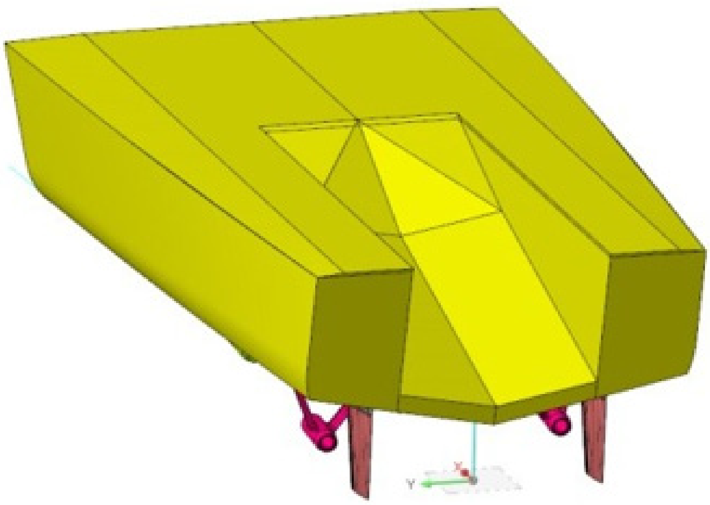

Fig. 1. Sketch of the generic stern boat ramp

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1. CALCULATIONS

As basic tool for analysis, the in-house program package SEA-6 [4] has been used. The program calculates wave loads and response amplitude operators of 6 DoF motions at the center of gravity, as well as relative vertical motions at selected locations along the hull.

The program is based on the modified linear STF strip theory and utilizes Kochin-Frank close-fit method [1] for calculation of pressures along the submerged part of the hull. The method had proved its accuracy for conventional ship-like forms, but cannot deal with U-shaped (double bounded) cross section contours. Because of this, calculations were carried out for closed transom only, and motions at open ramp condition were estimated experimentally.

2. MODEL EXPERIMENTS

Tests have been run in head seas at relatively low speed of advance, in order to match expected operation conditions at boat recovery.

Three series of seakeeping tests have been carried out, namely:

A. Ship model with transom stern (ramp apparel installed). Motions and relative motion at stern have been measured. Results have been backed by calculations.

B. Ship model with stern ramp opened. Motions and relative motion at stern have been measured.

C. Ship model with stern ramp opened and boat following. Video visualization of boat recovery by two cameras situated at stern and on-shore tank. Ship and boat models were controlled simultaneously.

Model motions have been measured by an optical tracking system and relative motions - by an resistance wire probe located in DP at a horizontal distance of 2 cm from the transom plane.

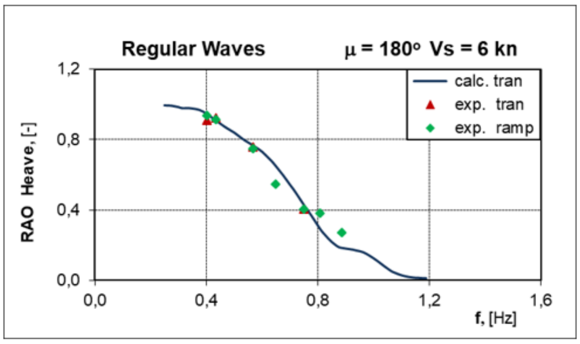


Fig. 2. Heave motion RAO

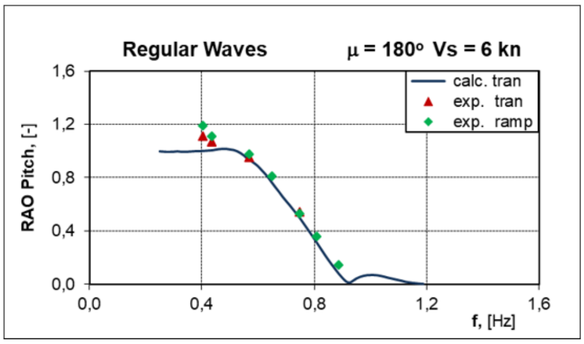


Fig. 3. Pitch motion RAO

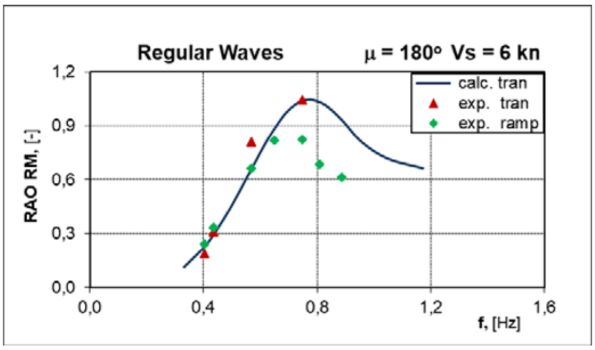


Fig. 4. RAO relative motions at stern

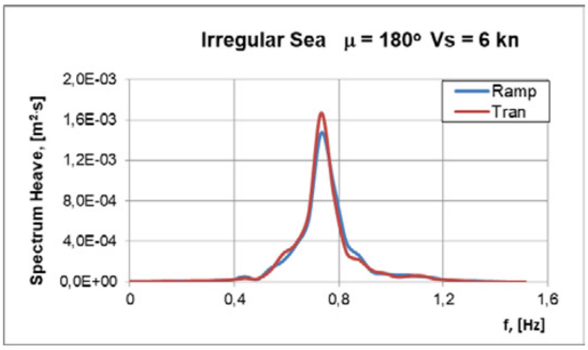
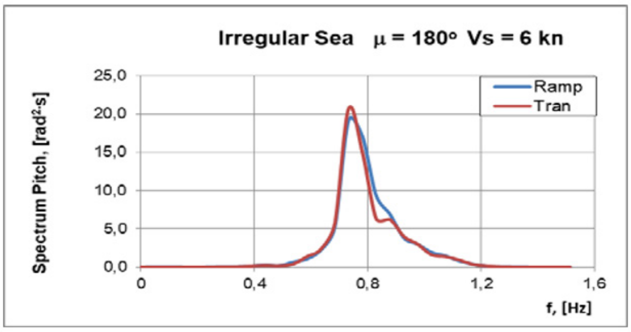


Fig. 5. Heave motion energy spectrum



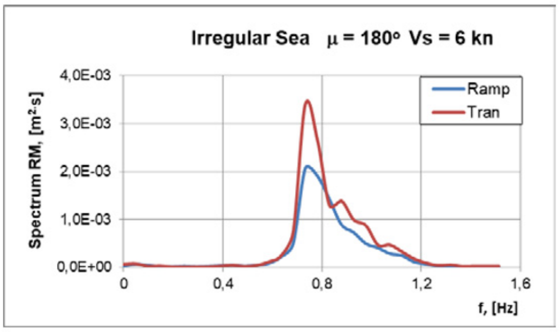


Fig. 6. Pitch motion energy spectrum Fig. 7. Energy spectrum of relative motion at stern

As can be seen, ramp condition does not influence significantly the vessel's motions at CG, but does visibly affect the relative motions at the ramp threshold.

4. COMMENTS

The results and observations of boat recovery procedure match the conclusions of other authors, i.e. [3], [5], [6].

It can be seen, that opening of ramp recess does not influence significantly the integral motions, heave and pitch being very similar, especially at this lower speed of advance. However, the effect on the relative motions at stern is significant - the appearing of the ramp change the stern flow and leads to significant reduction in relative motions at the entrance of the ramp, which enables boat recovery a lot, because lower relative motions increase time gaps between ramp edge emergences, within which the recovery conditions are acceptable.

For the test series C, a generic boat was scaled to fit the stern ramp, but boat engine power does not necessarily correspond to the real one. In this particular case, the engine was powerful enough to per-form the last stage of recovery procedure quite fast (matching the available time gap), which makes the operation success dependent on coxswain skill mostly. During the tests, 11 out of 12 approaches happened to be successful, after intensified training of the boat control operator.

Fig. 8. Boat approach toward the stern ramp

It must be noted, that the boat recovery operation is subjected to strict recommended procedures. In [7], a set of criteria for safe deployment operation have been formulated, concerning simultaneous satisfaction of motion limits:

- RMS roll < 8°;
- RMS pitch < 2,5°;
- RMS heave < 1,5 m;
- RMS sway < 1,5 m;
- Accelerations at stern ramp VA / LA < 0,2 g.

In [4], ramp availability period is suggested to be about 20 sec, while [5] and [6] suggested the average time period between two successive ramp emergences to be 10-15 sec.

While motion related criteria are comparatively easy to meet, the time gap of ramp availability still needs further elaboration, due to human factor interference.

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PERFORMANCE COMPARISON OF PARALLEL CFD SIMULATION OF SHIP MOTION AT ADVERSE SEA CONDITIONS

Vyara KOLEVA-EFREMOVA, Todor GUROV*, Grigor NIKOLOV, Dobrin EFREMOV**

Abstract. *With the implementation of the Computational Fluid Dynamics (CFD) into the industry and science, it becomes possible to solve complex tasks such as hydrodynamics analysis, weather forecast, biological engineering and etc. Both, licensed and open source CFD products are available at the market but the most important question stays: "How to parallel the task to achieve better performance in a short time?“. By increasing the complexity of the task, to respond to this question becomes more and more difficult.*

In this article we investigate a CFD simulation of a ship motion at waves using the OpenFoam software, the preparation of the fluid domain, boundary conditions and ship hull is done by specialists of BSHC. Such a complicate task requires a lot of computational resources. For this experiment the Avitohol HPC platform is used to achieve the performance ratio of different cases. The MPI interface is used for paralleling the CFD model between the cluster's nodes. The results are compared with the CFD simulation performance of the ship motion at calm water and are made conclusions about the behaviour and efficient of Avitohol's resources. Also is made plans and schedule for the future project of BSHC for CFD computational cluster.

Key words: *CFD, MPI, OpenFoam, Parallel simulations, Ship.*

INTRODUCTION

A simulation of multiphase flow requires great computational resources. This is mostly the main limitation when we speak about CFD simulations. The Computational Fluid Dynamics (CFD) is used to solve complex problems that involve fluid flows based on numerical analysis and data structures [1, 12]. The precision of these numerical methods depends on the mesh refinement. In fact more elements/cells mean higher accuracy, but lead to higher memory consumption and core hours for number processing. One solution is to use some HPC cluster to run such complex simulations which are not suitable for a desktop, or we can reduce the costs associated with computational resources by using suitable cloud-based solutions like SimScale [2]. Such kind of research could lead to optimization of the assembling of “supercomputers”, for example about the future project of BSHC for CFD computational cluster.

For this experiment, the Avitohol supercomputer system is used [3]. It consists of 150 computational servers HP SL250s Gen8, equipped with two Intel Xeon E5-2650v2 CPUs and two Intel Xeon Phi 7120P co-processors, 64GB RAM, two 500GB hard drives, interconnected with non- blocking FDR InfiniBand running at 56Gbp/s line speed. The total number of cores is 20700 and the total RAM is 9600 GB, respectively.

The CFD test cases consider the ship motion at calm water and waves respectively. Till now the first one is often described, while the second is not still widely studied due to insufficient computer and software capacity.

As a CFD solver it is selected OpenFOAM v5.0. Compared to the others CFD solvers, available on the marked like ANSYS Fluent for example, OpenFOAM has significant advantages - it is free, open source solution with high reliability and accuracy. It is easy scriptable and allows effective optimisation by rapidly changing the setted up geometry. One of the experts in the CFD industry - TotalSIM chooses OpenFOAM for their solutions [4]. Version 5.0 is backward compatibility but includes also new functionalities compared to version 4.0, like waves modelling, which is needed for the intent of our study [5]. To run our job on parallel the Message Passing

Interface (MPI) will be used between the cluster's SMP nodes. The Avitohol has available Intel MPI library version 2.2.

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The aim of this experiment is to find dependencies between the parallel efficiency achieved in case of a ship at calm water and this one achieved in case of the same ship in multiphase flow. With this we can made conclusions about the Avitohol's potential.

PRE-PROCESSING

Mathematical approach

Computational Hydrodynamics is an analysis using different mathematics methods to solve some differential equations such as the Navier-Stokes unit. Because their analytical solution is possible (for now), only in some particular cases, it is necessary to use numerical approaches to solve it. The method used to solve the mentioned equations, implemented in the academic software applications, is the finite volume method. In this case, the computational domain defined by the set boundary conditions of the partial differential equations is divided into a finite number of elements called a mesh. The number of cells in typical computing mesh can reach tens of millions, and even then the mesh resolution may not be sufficient to accurately estimate the magnitudes of studied fluid flow. The artificially use of a large number of network cells, results in an indefinite increasing of the work time required for numerical simulations. To overcome this disadvantage, one way is to apply parallel data processing.

Let spatial and temporal domains are defined by $\Theta_t \supset K^n$ and $(0, t)$ respectively, where K^n introduce the number of space dimension, with Ω_t we denote the boundary of Θ_t, x and t represent spatial and temporal co-ordinates. The Navier-Stokes equations for incompressible fluid flow are [13]:

(1) $$\rho\left(\frac{\partial u}{\partial t} + u.\nabla u - f\right) - \nabla.\sigma = 0 \quad \text{for } (0, t)$$

(2) $$\nabla.u = 0 \quad \text{for } (0, t)$$

where

ρ, u, f and σ are density, velocity, body force and the stress tensor respectively.

The Dirichlet and Neumann-type boundary conditions are taken into account and are represented as follows:

(3) $$u = g \text{ on } (\Omega_t)_g \; n.\,\sigma = h \text{ on } (\Omega_t)_h$$

where

$(\Omega_t)_g$ and $(\Omega_t)_h$ are subsets of the boundary Ω_t and n is normal vector. The initial condition of the velocity is defined on Θ_t at $t = 0$:

(4) $$u\,(x, 0) = u_0 \qquad \text{on} \qquad \Theta_0$$

GEOMETRY AND TEST CONDITIONS

The selected geometry for this study is standard ship model KCS (KRISO Container Ship). The ship model geometry is consist by 116062 numbers of cells and converted to STL file format, which describes only the surface geometry of the three-dimensional object without any representation of colour, texture or other common CAD model attributes [6]. On figure 1 is shown the 3D model of the ship hull.

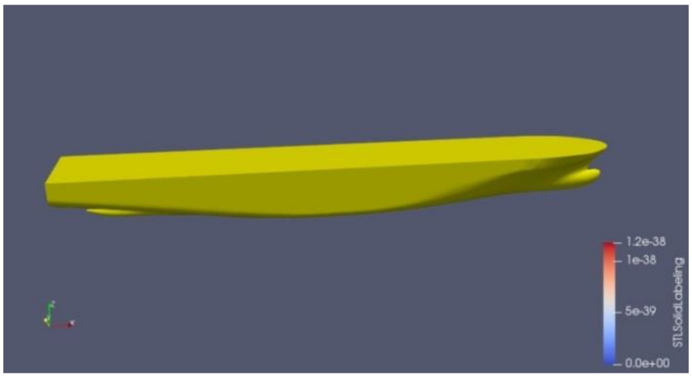

Fig. 1. 3D ship model

For the purpose of this study, the domain is divided to two fluid subsections - water and air [12]. The mesh is generated via Cervical Vertebral Maturation (CVM) method (fig.2),[7]. The total number of cells of the mesh is 1 154 737. One of the sides of the domain box is configured to be movable to generate the Boundary Conditions of the wave's pattern. OpenFOAM v5.0 includes libwaves.so library, which is required for the wave generation and will be loaded at run time.

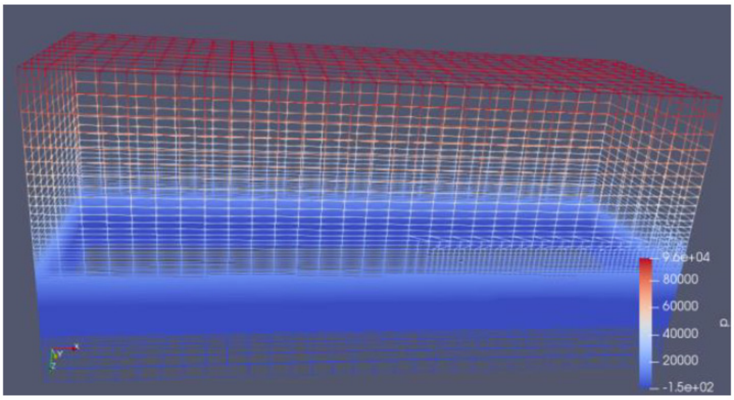

Fig. 2. Mesh generation

In CFD, the strategy for increasing efficiency in the simulation process is to divide the main task into several sub-tasks [14]. In defining the acceleration coefficient of the computational process, the interaction between the times required to solve the problem of using a single computational point and the time to applying parallel processing:

(5) $$L = T_S/T_p$$

where

T_S is the time for sequential processing and T_p is the time for parallel processing of the task.

The computational efficiency of the system is determined by the value of divided by the number of computer cores, ideally. One of the reasons for poor performance is a poorly balanced cluster. In order to predict the expected theoretical acceleration in parallel processing, the most popular approach is the Amdal model (L_A), which shows the maximum theoretical acceleration of the simulation:

(6) $$L_A = NP + (1 - P)$$

where

N represents the computational physical nuclei P the number of parallel processes.

In a nutshell, Amdal's law shows that the effectiveness of parallel simulation depends on the algorithm of the task and is bounded by each task. Increasing concurrent processes is not effective for all tasks, even more if you take into account the data transmission time between the nodes, expression (6) has its maximum. This implies a limitation in the scalability of the computational scheme, which means that from a certain point the addition of more computational cores will increase the time required for the numerical simulation.

As a pre-processing, the mesh is decomposed, meaning the domain is grouped into pieces based on the used number of logical cores. For this action is used the scotch algorithm which requires no geometric input from the user and attempts to minimise the number of processor boundaries [8]. Other important controls are configured such as time control, time precision, data writing etc. Total time of the simulation is set to 10s, time step is 0.001, write interval - 1, write precision - 6 (default value).

OpenFOAM has several solvers applicable for different tasks. For this study, icoFoam solver is selected since it is used for incompressible, laminar flow of Newtonian fluids. The solver uses PISO algorithm to solve the continuity equation and moment equation. It is an efficient method to solve the Navier-Stokes equations in unsteady problems [9][10].

RESULTS

CFD results

At figure 3 it's shown the KCS ship into calm water (without waves). While at figures 4 and 5 we can see the wave pattern and how the waves interact with the ship's body. The CFD results are represented via ParaView visualization application - this is the post-processing tool provided by OpenFOAM. ParaView operates a tree-based structure in which data can be filtered from the top-level case module to create sets of sub-modules [11].

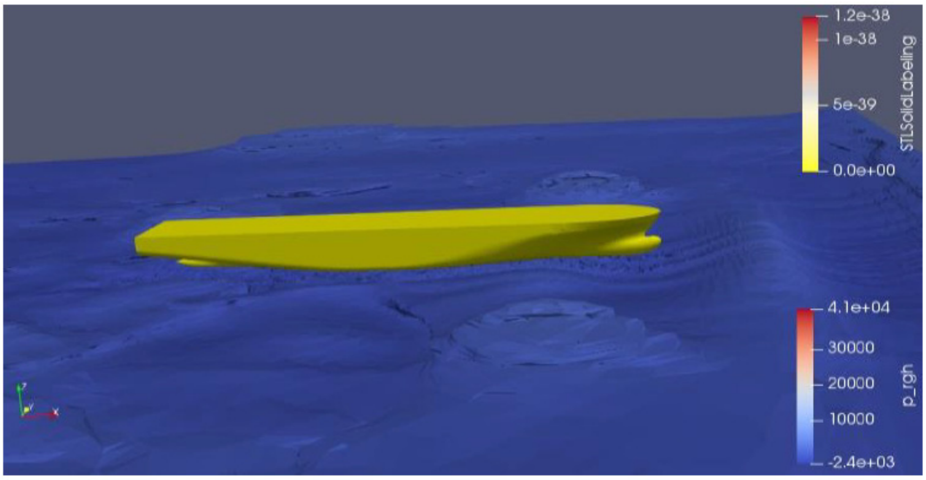

Fig. 3. CFD simulation of the wave pattern of a ship on calm water

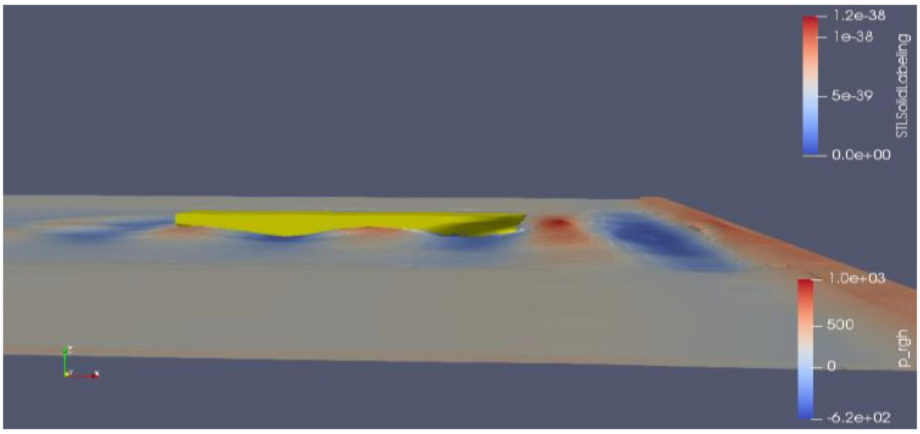

Fig. 4. CFD simulation of the wave pattern of a ship on multiphase flow (1/2)

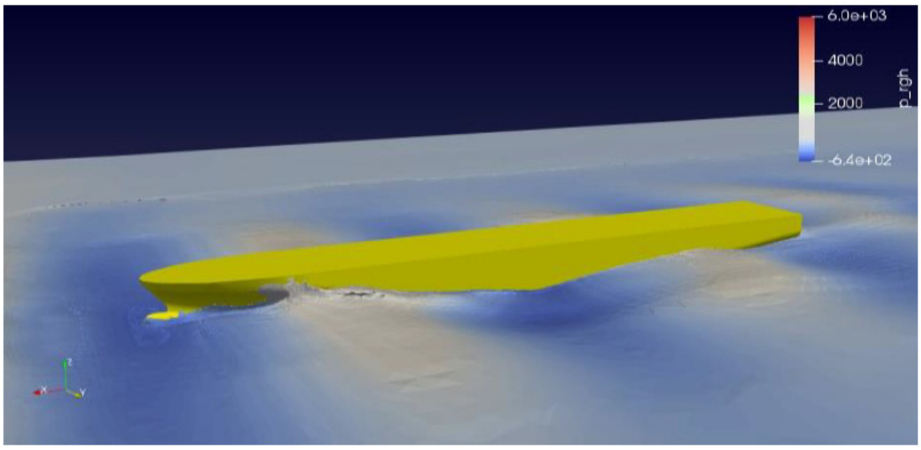

Fig. 5. CFD simulation of the wave pattern of a ship on multiphase flow (2/2)

OpenFOAM scaled results

In tables 1 and 2 are shown the scaled results by the simulations at calm water and at waves. In the pre-processing stage, the task was decomposed several times based on the number of used CPU cores. Since this decomposition is executed by the host machine (it is not run in parallel) the total time for the decomposition is not included to the final average time of the simulation because it is not take effect on it. As we already mentioned, the Avitohol system consist of 150 servers (nodes), integrated into 8 racks. Each node is equipped with two Intel Xeon E5-2650v2 CPUs with 16 CPU cores. Each rack has 20 nodes, so with decomposing the task from 16 to 1024 pieces we can test: the parallel efficiency between the nodes in one node, between the nodes and between the racks of Avitohol, and to make conclusions about the performance capabilities of the system.

The "Average time" column in the two tables is calculated based on the elapsed time of the simulation for 10 iterations. It is taken the clock time from the log of the simulation, since this is the "real" time required to complete the simulation.

Open Foam scaled results for the MPI parallel tests (CFD of a ship at calm water)

Table 1

Nodes	CPU Cores	Average Time(s) per 1000 steps	Speedup performance	Speedup, doubled number of nodes
1	16	2090	-	-
2	32	1392	1.50	0.00
4	64	1087	1.28	0.85
8	128	1213	0.90	0.70
16	256	2037	0.60	0.66
32	512	4543	0.45	0.75
64	1024	7123	0.64	1.42

Open Foam scaling results for the MPI parallel tests (CFD of a ship at waves)

Table 2

Nodes	Logical Cores	Average Time(s) per 175 steps	Speedup performance	Speedup, doubled number of nodes
1	16	3989	-	-
2	32	2541	1.57	0.00
4	64	2316	1.10	0.70
8	128	1570	1.48	1.34
16	256	4665	0.34	0.23
32	512	8310	0.56	1.67
64	1024	31370	0.26	0.47

CONCLUSIONS

At figures 6, 7 and 8 we can see the speedup and the parallel efficiency, achieved as a result from the Avitohol calculations. It is important to mark that the speedup depends from many components and it's different for both CFD cases (calm water and waves). Till the speedup decreases, the task permits to be decomposed to more and more pieces. From certain point (128 cores for calm water and 256 cores for multiphase flow), additional decomposition is unwanted, since this slows the calculations. We can conclude that the total number of used cores must be increased/doubled whit the complexity of the task. When doubling the used number of cores, the aim is to achieve execution time decreased by the factor of 1. 5. For both cases we can say, that the total parallel efficiency is close to the using of 256 cores of Avitohol system.

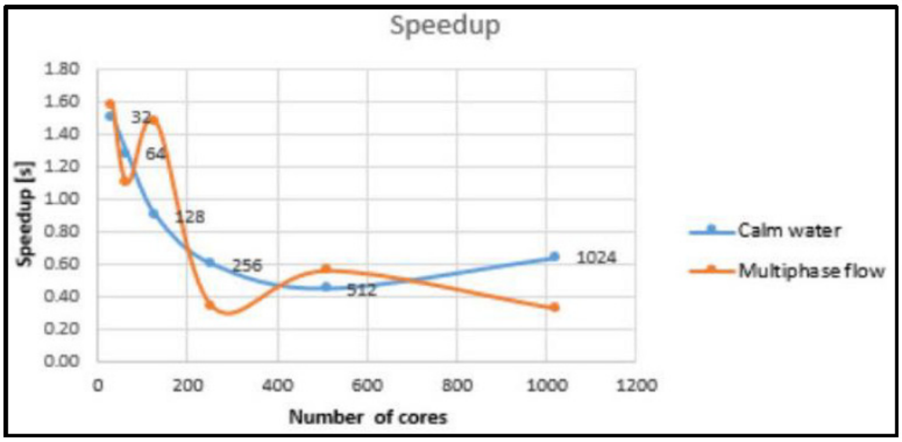

Fig. 6. Speedup

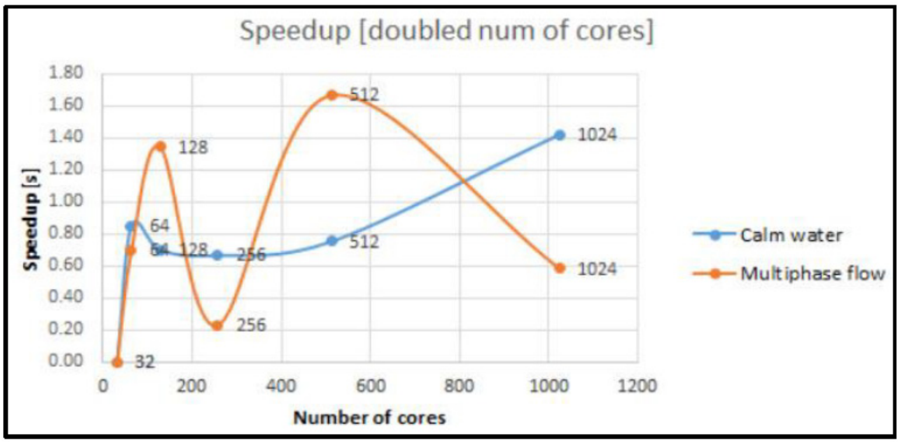

Fig. 7. Speedup (doubled number of cores)

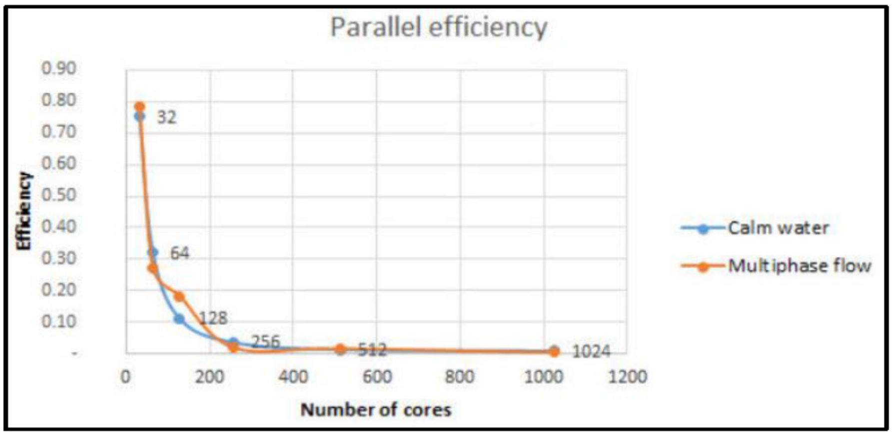

Fig. 8. Parallel efficiency

In this work we presented parallel CFD simulations of a ship in different environment via OpenFoam CFD toolbox. The results from scalability of using MPI parallel model at calm water and adverse sea conditions like waves were studied based on the introduced scalability. The "Pre- processing" section describes the used mathematical approach and the configurations made via the OpenFOAM CFD tool. The "Results" section represents the CFD results of both test cases and the numerical results of the parallel jobs. The achieved performance results are visualised and analysed in section "Conclusions". As a future work, we plan to test the simulation models using Intel Xeon Phi coprocessors which are available in the Avitohol supercomputer system and by this investigation is made plans and schedule for the future project of BSHC for CFD computational cluster.

ACKNOWLEDGEMENTS

I would like to thank to Bulgarian Ship Hydrodynamic Center - Varna (BSHC), for their support, as well as Dr. Grigor Nikolov for his valuable advices and guidance. This work was supported by the Bulgarian Ministry of Education and Science under the National Research Program "Young scientists and postdoctoral students" approved by DCM # 577 / 17.08.2018.

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Black Sea 2020

MARITIME TRANSPORTATION AND PORT OPERATIONS

PROSPECTS FOR SEA TRANSPORT OF INTERMODAL CONTAINERS IN THE BLACK SEA

Lichko NAYDENOV*, Petar GEORGIEV*

Abstract. *The recent development of the Short Sea Shipping in the Black Sea region has shown that intermodal transportation will play an important role in the future. At the same time, the coaster fleet of the Black Sea and the East Mediterranean region is of considerable age, and the increased freight rates enforce new orders of ships. The present study analyses the prospects for sea transport of intermodal containers in the Black Sea. These include statistics for world container transport, and in the Black Sea Region, actual situation of East-West transport corridors, with focus on those crossing the Black Sea. The paper presents statistics for the main dimensions of containerships that visited the main Black Sea Ports during one month. Based on the results from the study, a proposal for project assignment of new ships for intermodal transportation in the Black Sea is defined.*
Key words: *containership, intermodal transport, Short Sea Shipping, ship design.*

INTRODUCTION

In recent years, environmental concerns have attracted the attention of the International Maritime Organization (IMO) and we can register a significant increase in the number of regulatory environments. In this direction are the recently introduced requirements and numerous studies related to Energy Efficiency Design Index (EEDI), Ship Energy Efficiency Management Plan (SEEMP), Energy Efficiency Operational Indicator (EEOI) and Energy Efficiency Existing Ship Index (EEXI) [1]. The energy efficiency requirements of the different types of ships, which have entered into force in the last 7 years, require the introduction of additional criteria in the design of the ship, taking into account the impact on the environment.

At the same time, considerable attention is being paid in Europe to the wider promotion of Short Sea Shipping. For these ships, the new environmental requirements also prove to be a serious obstacle, as the areas in which they operate have been declared emission control areas and must be passed through with the use of low-sulphur fuel, which is more expensive. On the other hand, both the development of the Asia-Europe international transport corridors and various China's initiatives, call for the Black Sea and the transport of goods across it to be a part of these corridors.

The aim of the presented study is to collect and analyse as much information as possible related to the prospects for the construction of energy efficient ships for intermodal transport in the Black Sea. Several tasks have been solved and the results are presented in separate chapters. The first subchapter examines the state of container transport in general and in the Black Sea in particular. The next part presents the existing transport corridors and how Bulgaria fits within them and the port infrastructure. A separate chapter is devoted to the analysis of the main dimensions and main characteristics of ships operated in the Black Sea and visited seven of the main ports in the basin. Ship dimensions are compared with regression relations derived from a large number of existing container ships. Finally, the elements of a design assignment for an energy efficient container ship for intermodal transport in the Black Sea are defined.

STATUS OF THE CONTAINER TRANSPORT

World container transport

Container ships are the fastest growing type of ships, and over 60 years, the container capacity has increased more than 25 times [2]. The development of containerships is influenced by the development of world trade and maritime transport (Figure 1). The capacity of the container fleet increased in 2018 by 6%, compared to

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4% in 2017. This capacity exceeds the demand in global maritime trade in containers, which increased by 2.6% as of January 1, 2019, reaching a total volume of 152 million TEU [3]. Overall, in the period 2011-2016, the demand for container shipments was lower than the available capacity of the vessels.

In terms of the cost of transporting a single FEU, the commonly accepted measure is the World Container Index (WCI) set by Drewry (https://www.drewry.co.uk/). This index is composed of freight tariffs on eight main routes to/from the USA, Europe and Asia. The change of WCI for the last 2 years is presented in (Figure 2). The index is updated every week and since May 2020, it has been constantly growing (with small exceptions). For the last week of August 2020, it increased by 3.4% compared to the previous week to $2251/FEU.

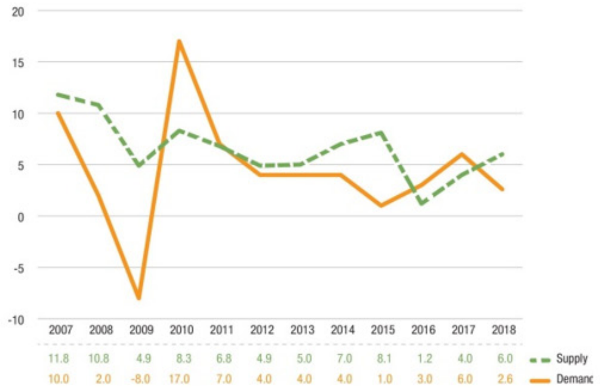

Fig. 1. Demand and supply of container transport for the period 2007-2018 in %

Fig. 2. WCI amendment for the last two years (https://www.drewry.co.uk/)

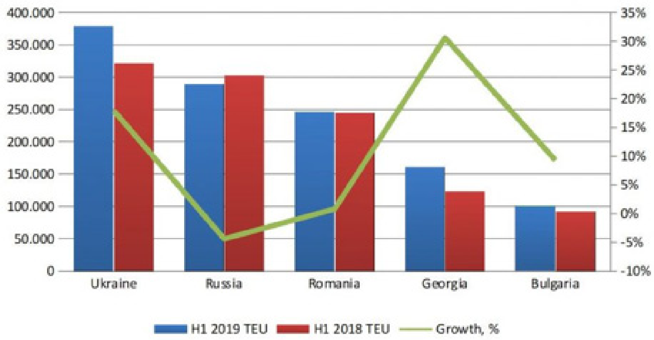

Fig. 3. Development of container transport for the first half of 2019 in the Black Sea [4]

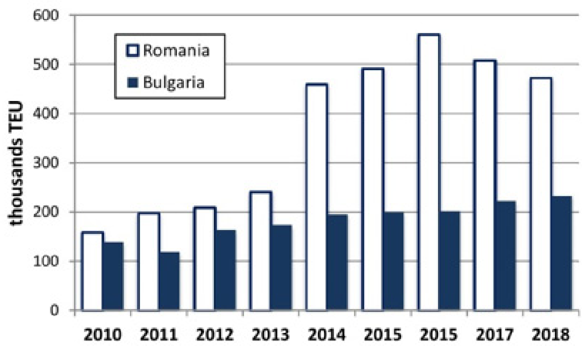

Fig. 4. Development of container transport for both EU countries in the Black Sea [5]

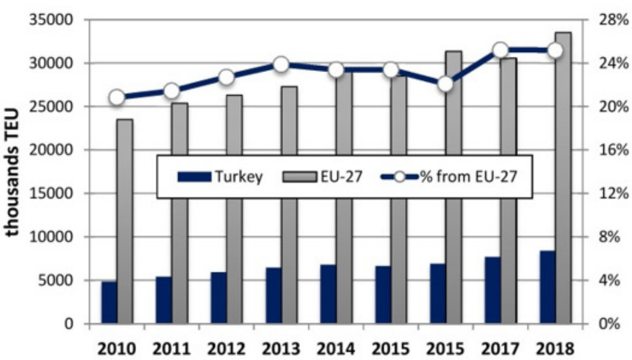

Fig. 5. Comparison of the transported containers of Turkey and EU-27 [4]

Fig. 6. European network of Short Sea Shipping [6]

Container transport in the Black Sea

In the first half of 2019, the Black Sea container terminals of Bulgaria, Georgia, Romania, Russia and Ukraine handled 1,582,932 TEU containers, including empty containers. This number does not include transhipped containers [4]. The number of full containers was 1,176,621 TEU (74.33% from total). The total growth achieved from these five countries in the first half of 2019 was 8.52% compared to the same period from the previous year/2018. There is increase in turnover in all countries except Russia. In the first half of 2019, the highest growth was achieved by Georgia and Ukraine: 30.62% and 17.89%, respectively (Figure 3). During this period, 57.54% of the processed full containers were imported and 42.46% were exported.

Thus, the percentage of containers with cargo handled by each country in the first half of 2019 is distributed as follows: Ukraine - 32.21%, Russia (Black Sea) - 24.58%, Romania - 20.95 %, Georgia - 13.68% and Bulgaria - 8.58%.

In terms of the leading carriers in the Black Sea, for the first time in recent years, ZIM entered the TOP-5 carriers, which are as follows: MAERSK, MSC, COSCO Shipping, ARKAS and ZIM. In total, these carriers controlled 71.40% of the market.

Eurostat statistics provide the development of container transport by country and for the E-27 as a whole. Figure 4 presents comparison between the volumes of container traffic for two EU member states in the Black Sea region. For Bulgaria, there has been a continuous growth since 2011, while for Romania since 2015 there has been a decline in volumes. Turkey is included in Eurostat's container transport statistics from 2010. Figure 5 compares the volumes of containers transported in Turkey and EU-27 countries. The percentage of Turkey container transport has been in the range of 20%-24% for the last eight years.

In Georgia, there are two container terminals in the ports of Poti and Batumi. These ports serve a market of 18 million people from the Caucasus region (Georgia, Azerbaijan, and Armenia) and another 145 million from landlocked countries in Central Asia (Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan and Tajikistan). The growth of transported containers was 13% in the first quarter of 2018 compared to 2017 [7].

TRANSPORT CORRIDORS AND PORT INFRASTRUCTURE

Transport corridors in Black Sea

Despite the developed network of short sea shipping (SSS) (Figure 6) the European Commission is taking action to strengthen the further development of short sea shipping in three directions: Administrative simplification; Supporting industry in choosing new technologies to comply with new and stricter environmental legislation; Integration of short sea shipping in complete logistics chains. Along with the construction of the important for the EU network of SSS, of particular importance for Bulgaria is the use of the geographical location in terms of cargo flows - east - west following the "Silk Road".

Transport Corridor Europe-Caucasus-Asia (TRACECA) is an internationally recognized program aimed at strengthening economic relations, trade and transport communication in the Black Sea region, the South Caucasus and Central Asia, established in September 1998 (http://www.traceca-org.org/en/countries/). The route includes the transport system of the 13 Member States: Azerbaijan, Armenia, Bulgaria, Georgia, Iran, Kazakhstan, Kyrgyzstan, Moldova, Romania, Tajikistan, Turkey, Ukraine and Uzbekistan.

A better alternative to the TRACECA corridor is The Trans-Caspian International Transport Route (TITR - Figure 7). Transportation of goods along this corridor began in 2013 by the port administrations of Azerbaijan, Kazakhstan and Georgia. Proof of the vitality of this corridor is the announcement from "Transport and Logstics.bg"[1] about train composition, which has travelled the distance from Khorgos (on the border between China and Kazakhstan), to Izmit (Turkey) in 12 days. The transport is organized by the TITR consisted of 43 FEUs carrying various goods. The block-train entered Kazakhstan via Altinkol railway station and travelled to the port of Aktau (Caspian Sea). From there, the containers were transported to the port of Baku in Azerbaijan by feeder ship (Figure 8). After crossing the Caspian Sea, the train got back on track and through Akhalkalaki, Georgia, reached the Turkish city of Izmit on the Baku-Tbilisi-Kars railway.

In 2003 the Executive Secretaries of the United Nations Economic Commission for Europe (UNECE) and the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) lay the foundations for the construction of the Euro-Asian Transport Links (EATL) [8].

[1] https://www.logistika.bg/bg/menu/null/post/26319/12-dena-s-blok-vlak-ot-Kitaj-do-Turciq (in Bulgarian)

Due to its favorable crossroads location, Bulgaria is one of the countries through which half of the European corridors pass - these are corridors IV, VII, VIII, IX and X with a total length of roads of over two thousand kilometres, and corridor VII entirely follows the Bulgarian section of the Danube (Figure 9). Seaports are part of the rail and road routes and ensure the intermodality of transport in the main corridors between Asia and Europe. In view of future studies, the location of the Bulgarian ports of Varna and Burgas and the opposing ports of Poti and Batumi (Georgia) are considered as part of the rail and road routes of EATL (Table 1)

Main ports in Black Sea

When analysing the possibilities for intermodal transport across the Black Sea, the information about the main ports is important.

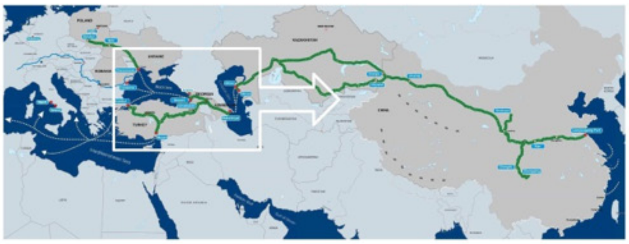

Fig. 7. The Trans-Caspian International Transport Route (TITR) (left) and the end part with Caspian Sea and Black Sea (right) (https://middlecorridor.com/en)

Fig. 8. Feeder ship „Beket Ata“ (https://photos.marinetraffic.com/

Fig. 9. EATL corridors trough Bulgaria (adapted from https://europost.eu/)

Bulgarian Black Sea ports and their connection with EATL routes [8]

Table 1

Port	EATL ROUTES (CORRIDORS)
	RAIL ROUTES
Varna	**3h**: Border with North Macedonia - Sofia - Pleven - Varna (Port) - Poti/Batumi (Port); **3i**: Curtici - Arad - Timisoara - Craiova - Bucharest - Giurgiu - Russe - Kaspichan - Varna (Port) - Poti/Batumi (Port) **8d**: Varna (Port) - Novorossiysk (Port) - Poti/Batumi (Port)
Burgas	**3j**: Dragoman - Sofia - Gorna - Burgas (Port- Poti/Batumi (Port)
	ROAD ROUTES
Varna	**4d**: Sofia - Pleven - Ruse - Varna (Port) - Poti/Batumi (Port)
Burgas	**3e**: Rostov-na-Donu-Krasnodar-Novorossiysk (Port)-Kavkaz(Port)- Samsun (Port)/ Poti/ Batumi (Port) / Burgas (Port)

Characteristics of main Black Sea ports.

Table 2

Port	Quay, m	Depth, m	Handled TEU	Source
Varna (BG)	461	11.0	94,20(Mid 2017)	https://port-varna.bg/en/TERMINALS/Varna-Zapad
Constanta (RO)	1045	14.5	666,036 (2019)	https://www.portofconstantza.com/pn/en/home
Odessa (UA)	960	12.5/14.20	850,000 per year	http://cto.od.ua/en/wa.html
Novorossiysk (RU)	875	15.0 pier №38*	700,000	http://www.nutep.ru/en/about/review.php
Poti (GE)	700*	14.5 m*	over 1 million	https://www.apmterminals.com/en/poti
Anaklia (GE)	n.a.	16.0*	600,000*	https://www5.jetro.go.jp/newsletter/toi/2019/6%20Anaklia%20Port%20and%20Special%20Economic%20Zone%20-%20November%202019.pdf
Ambarli (TR):			2,7 million (2011)	(http://www.worldportsource.com/ports/ commerce/TUR_Port_of_Ambarli_2079.php)
Marport	800	14.5		
Mardas	910	13.0-15.0		
Kumport	2080	13.5-15.5		

* In the process of construction

In this study, information was collected on main ports from the bordering countries (Table 2.). The best five container terminals in the region in the first half of 2019, although with changes in the positions regarding the volume of processed cargo, remain: DPW ("Dubai Ports World", Constanta, Romania); APM ("APM Terminals", Poti, Georgia); NUTEP[2] (Novorossiysk, Russia); CTO (Container Terminal Odessa, Ukraine) and BKP ("Brooklyn-Kiev Port" Odessa, Ukraine). The analysis of the characteristics shows that most of the terminals are managed by foreign operators, as well as the large-scale plans for investments (ports in Georgia) and for granting a concession for management and maintenance.

Intermodal containers

Freight transport in Europe continues to grow and in particular road transport is expected to increase by around 40% by 2030 and by just over 80% by 2050[3]. EU transport policy therefore aims to reduce road transport to less polluting and energy efficient modes of transport. The Council Directive 92/106/EEC (known as the Combined Transport Directive)[4] introduces several support measures. One of the "regulatory" support measures is the use of 45 foot containers.

The advantage of a 45ft high cube pallet wide container is the larger volume (89 m^3 vs 76.4 m^3 for FEU). It is slightly wider and much longer than a standard 40ft high cube container. Therefore, two euro pallets can be loaded side by side, providing more loading space than a container with regular width (Figure 10). The 45 ft containers are stowed on top of the FEU (Figure 11) and cell guides are designed taking into account the bigger length. For mixed stowage, a 5‘adapter for 40‘containers in 45‘cell guides could be used [9].

CONTAINER SHIPS OPERATING IN THE BLACK SEA

SSS in the Black Sea

The transport of goods in the Black Sea is considered as part of the corridors between Asia and Europe and an element of the short sea shipping system [10]. The main traffic and the density can be judged from the respective map (Figure 14). The colour scale shows the number of crossings on an area of 5 km^2 per year. More than 50% of SSS transported goods in the Black Sea are liquid cargoes (https://ec.europa.eu/eurostat/). This may explain the busy traffic from the port of Odessa to the Bosphorus. Table 3 shows the first 10 carriers in the Black Sea and Figure 12 and Figure 13 present some of the services.

[2] Новороссийское узловое транспортно-экспедиторское предприятие (in Russian)
[3] https://ec.europa.eu/transport/themes/logistics-and-multimodal-transport/multimodal-and-combined-transport_en
[4] https://ec.europa.eu/transparency/regdoc/rep/10102/2017/EN/SWD-2017-362-F1-EN-MAIN-PART-1.PDF

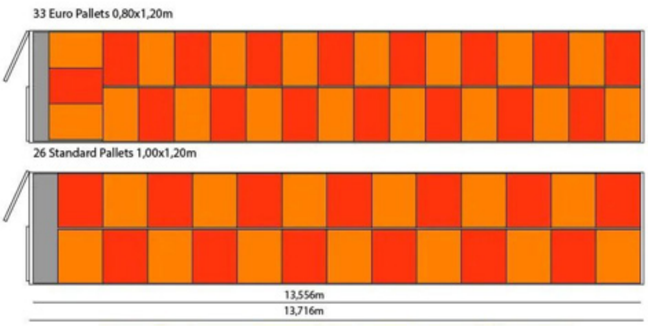

Fig. 10. Stowage of pallets in 45 ft pallet wide container (https://www.onze.lt/konteineriu-talpa/)

Fig. 11. Wrong and correct stowage of 45ft containers (https://www.container-logic.com/ single-post/ 2016/02/17/ Container-Types-Part-2)

Fig. 12. East Black Sea Service(EBS) EVERGREEN -LINE[5]

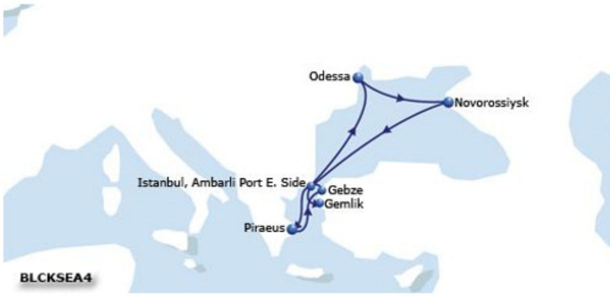

Fig. 13. 3PF Black Sea Service 4 of CMA CGM[6]

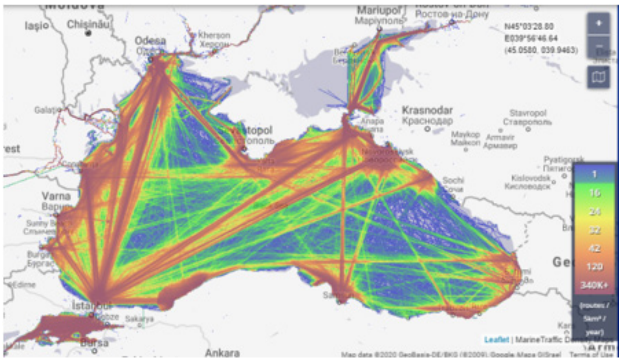

Fig. 14. Density of ship routes in the Black Sea at the end of 2017 (https://www.marinetraffic.com/)

Top 10 operators in the Black Sea[7]

Table 3

Carrier/Feeder Operator	No of services	No of ships	Average TEU capacity	Annual trade capacity
MSC	79	131	2,000	6,420,000
Maersk Line	82	171	2,100	5,796,000
X-Pre. Feeders	54	72	1,500	2,804,000
Evergreen	42	67	1,900	2,528,000
CMA CGM	51	89	1,400	2,328,000
Unifeeder	32	42	1,100	1,286,000
Arkas Line	23	38	1,900	1,268,000
PIL	27	40	1,300	1,250,000
Hapag-lloyd	16	24	2,200	1,152,000
Cosco Shipping Line	26	30	1,400	1,087,000
Total top 10 operators	569	841	1,800	25,918,000
Share top 10	*64%*	*66%*		*60%*

[5] https://www.evergreen-line.com/static/jsp/service.jsp
[6] http://www.cma-cgm.com/products-services/line-services
[7] https://container-xchange.com/blog/feeder-vessels/

Statistical data for container ships

In order to analyse the characteristics of the ships used for transporting containers in the Black Sea, data were collected for all ships that visited the ports of Varna, Burgas, Constanta, Odessa, Novorossiysk, Poti and Ambarli in the period between July 18 and August 18, 2020. The names of the ships are extracted from the website https://www.myshiptracking.com/ports, for each of the ports. The rest of the information is obtained from the Equasis website (https://www.equasis.org/). The site provides a link to the Classification Society database.

Information was collected on 139 ships of various types (Figure 15) with percentage distribution presented in Figure 16. It is noteworthy that the analysed Black Sea ports are visited by all possible container vessels. Just over 50% of these ships are "Small feeder" and "Feeder". Most of the ships (40.3%) are under DNV-GL class followed by ABS with 22.3%. and BV, LR, RINA and NK.

Type	No TEU
Small feeder	Up to 1000
Feeder	1001 - 2000
Feeder max	2001-3000
Panamax	3001-5000
Post-Panamax	5001 – 8000
New Panamax	8001 – 1000
Ultra-large	above 10000

Fig. 15. Container ship types

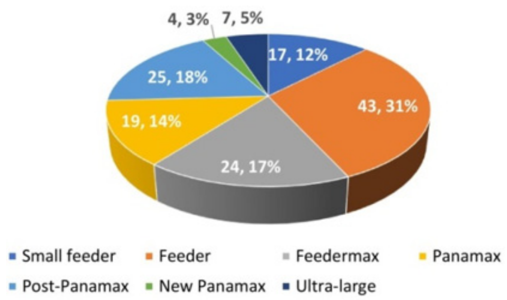

Fig. 16. Distribution of container ships by type

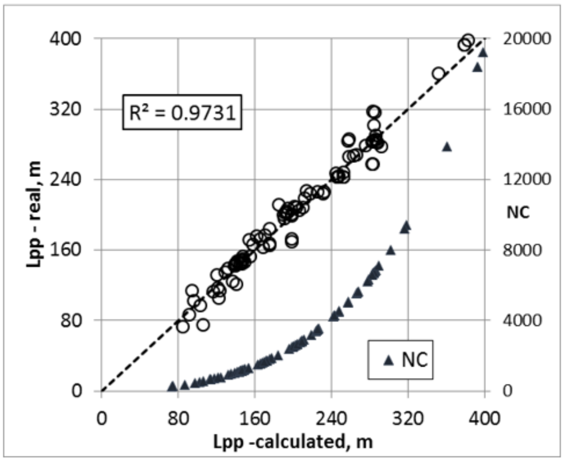

Fig. 17. Calculated vs real data for Lpp, m

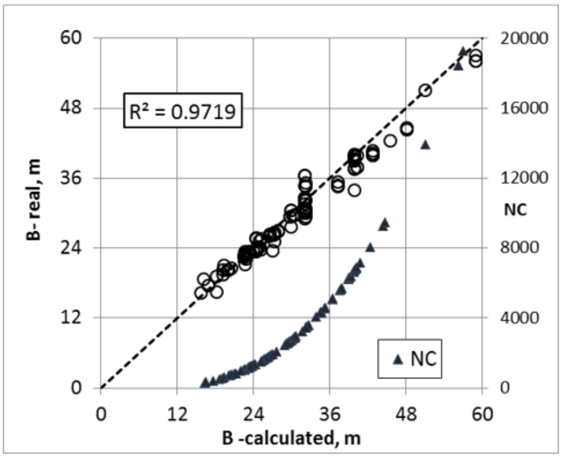

Fig. 18. Calculated vs real data for B, m

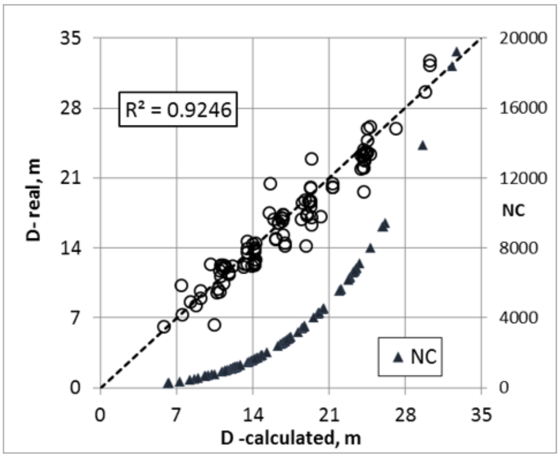

Fig. 19. Calculated vs real data for D, m

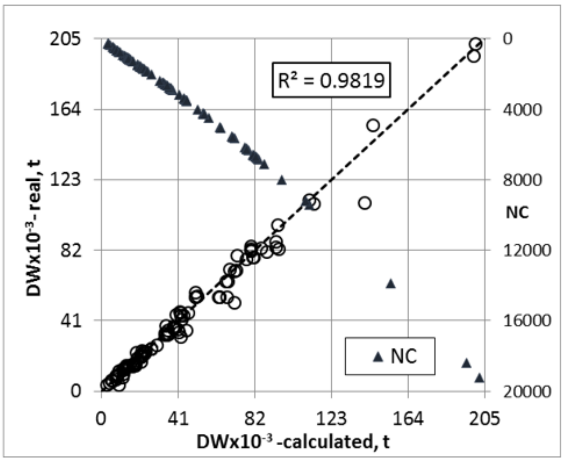

Fig. 20. Calculated vs real data for DW, t

Relational or empirical method of ship design according to Papanikolaou [11] is based on comparative data from a similarly built ship. A variation of this method is the use of empirical design formulas deduced through regression fitting of relevant statistical data. For successful application of these regression relations, it is assumed that the relationships are sufficient and reliable for the type and size of the ship under investigation.

In this study, some characteristics of the ships which visited the Black Sea ports are compared with derived regression relationships for larger number of ships presented in [12]. The following relationships were analysed:

$$Lpp = 1.5022 + 0.413355\ Ln(TEU)^3 \qquad B = 7.425 + 0.96\ (TEU)^{0.4} \qquad D = -\ 7.766 + 3.442\ (TEU)^{0.25}$$

$$DW = 1317.745 + 2.24\times10^{-3}\ Ln(TEU)^8$$

Figure 17 - Figure 20 present a very good match between the real and calculated values for the main dimensions and deadweight of the studied ships. On the graphs, the number of containers (NC) is shown as well. The presented formulas can be used for preliminary estimation of the main dimensions in the conceptual design of a container ship for operation in the Black Sea.

DESIGN REQUIREMENTS FOR FUTURE CONTAINER SHIP

Based on the presented data, the following findings could be summarized concerning the intermodal transport across the Black Sea.

- In all countries of the Black Sea region, there is an increase in transported volumes of containers;
- Trade between Asia and Europe along the transport corridors continues to develop, although affected by the epidemic crisis in 2020 caused by COVID-19;
- Successful transportation of goods from China to Turkey with reduced deadlines;
- The Trans-Caspian International Transport Corridor is also actively developing, where both ferry ships and feeder dry cargo ships are used to cross the Caspian Sea;
- There is a solid network of short sea shipping routes in the Black Sea, with a developed logistics infrastructure;
- The modern development of intermodal transport includes wider use of 45-foot containers, due to their larger volume and optimal placement of up to 14% more standard and Euro pallets;
- The developing road infrastructure of the trans-European corridors in Bulgaria contributes to the construction of real intermodal transport through the territory of Republic of Bulgaria;
- The development of a strategy for the development of the Black Sea is underway and the construction of maritime transport from ships with high energy efficiency is an area in which research should be directed.

Taking into account the above findings, we define the following assignment for new container ships for intermodal transportation in the Black Sea:

- Container capacity up to 2000 TEU (Feeder type);
- The main dimensions and the general arrangement to allow the transportation of 45-foot containers with two options: only on the deck; on the deck and in the holds;
- The ship to serve the line Poti-Varna-Poti or alternatively Anaklia-Varna-Anaklia;
- The economic indicators and the number of ships to be estimated for the annual volume of transport of 250 000 TEU;
- The ship shall meet the imposed requirements for project energy efficiency index (EEDI);
- The speed of the ship, to be determined after analysis of the minimum required power for navigation in bad weather in the conditions of the Black Sea on the marked route.

A container ship for 1700 TEU developed by Damen can be used as a prototype for conceptual design (Figure 21)

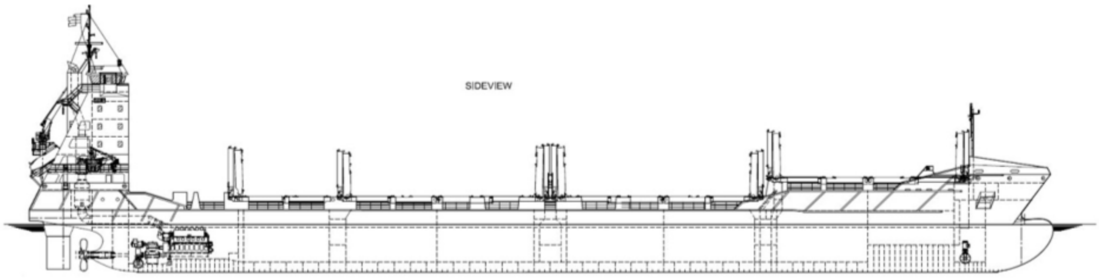

Fig. 21. Side view of container ship for 1700 TEU [13]

CONCLUSIONS

The presented study shows that the positive prospects for the sea transport of intermodal containers in the Black Sea can be based on several factors:

- The favourable condition of container transport worldwide and the increased volumes specifically in the Black Sea;
- Developing Asia-Europe transport links and China's new initiatives in this direction;
- The EU's vision for the development of short sea shipping and efforts to support combined transport by easing the conditions for transporting 45-foot intermodal containers;
- The existing environmental requirements require the search for compromise and innovative solutions regarding the choice of main dimensions and features of the ship's shape. The current views are that the parameters of the ship should be optimized to take into account the real operating conditions for the given route;
- The latter will define an approach for building a ship with high energy efficiency, taking into account the specific features of the Black Sea, and thus contribute to the ecological balance in the basin.

Future research should analyse the capacity of Black Sea ports and whether it will be a factor that will determine the speed of container ships.

ACKNOWLEDGMENTS

The presented results were obtained from studies carried out within the project NP8/2020 from the scientific program of TU - Varna, funded by the state budget.

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STATE-OF-THE-ART OF CONCEPTS FOR LIVING AT SEA

Radoslav MOMCHILOV*, Olena VIDENOVA, Rumen KISHEV****

Abstract. *In the paper, an overview of the resent status of the complex of problems related to the future human life at sea is presented, including climate changes, increasing world population and related food and energy consumption, resources and free territory in the World Ocean, technology development, VLFS solution, as well as problems for future investigation.*
Key words: *climate changes, blue economy, life at sea, floating cities.*

INTRODUCTION

The forthcoming climate changes, expressed in an increase in average temperatures, an increase in the intensity of atmospheric phenomena, melting of the polar ice and the related expected rise in sea level, is considered by the European Commission and the world scientific community as a very likely scenario which will eventually cause a global change in the way of life of mankind and especially in the industrialization and urbanization of maritime spaces. The need to transfer the human daily life and related production activities to marine conditions will increase. In this regard, it is necessary to study or create new technologies in order to minimize the risk to human life and health in the new habitat.

1. PREREQUISITES

1. 1. Climatic problems - rising temperatures, drought and rising water levels from melting polar ice

Increased economic activity worldwide is accompanied by intense release of green gases into the atmosphere, which leads to a greenhouse effect and, consequently, to a slow but steady rise in average temperature, as documented by NASA's Goddard Institute for Space Studies. The research summarized in the works of International Symposiums on Coastal Ocean Space Utilization [1], [2], show that the trend will remain unchanged in case of "business as usual" scenario, see i.e. Fig. 1.

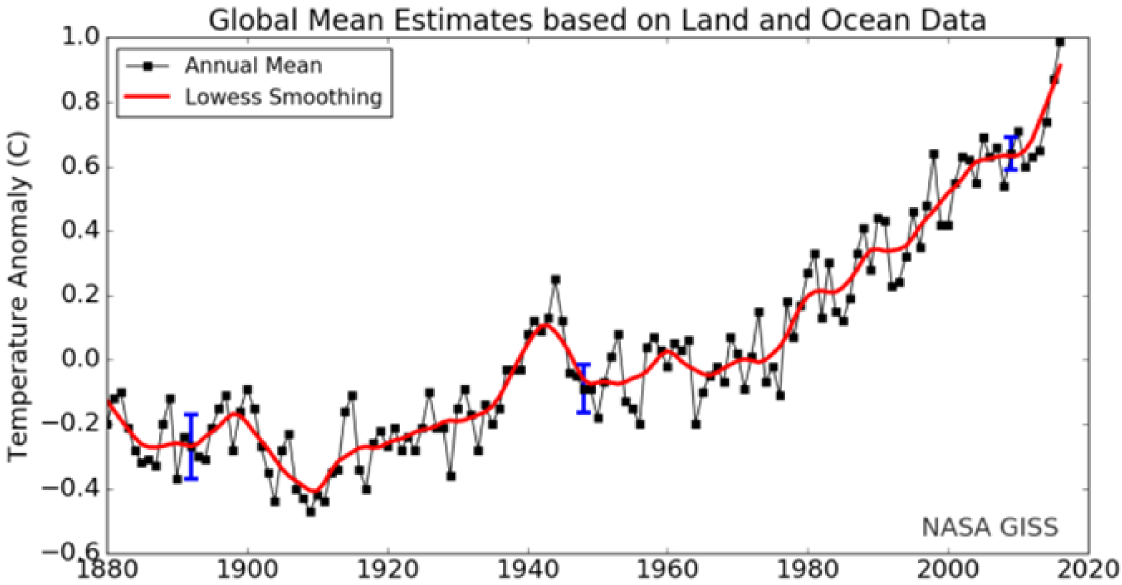

Fig. 1. Global mean temperature estimates

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** Bulgarian Ship Hydrodynamics Centre, Varna, Bulgaria

As a consequence, higher temperatures are expected to raise sea level by:
• expanding ocean water,
• melting mountain glaciers and small ice caps,
• causing portions of the coastal section of the Greenland and Antarctic ice sheets to melt or slide into the ocean.

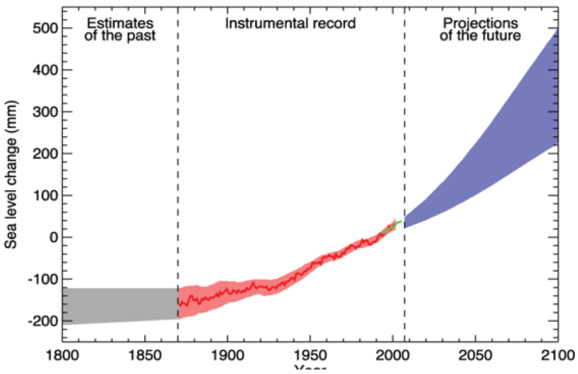


Fig. 2. Sea level change statistics (IPCC 2007)

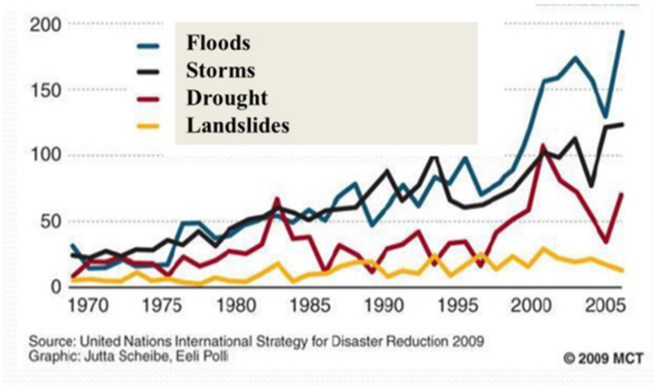


Fig. 3. Atmospheric disaster occurrence prediction

In Fig. 2, the estimates are shown of past sea level (from 1800 to about 1870), measured changes in sea level (from about 1870 to 2006), and projections of future sea level rise to the year 2100. Considering these tendencies, the Intergovernmental Panel on Climate Change (IPCC) estimates that the global average sea level will raise by 0.2 - 0.6 m until 2100, plus the unknown contribution from increased discharge of ice into the oceans from Greenland and Antarctica.

The above effects are expected to sharpen intensity and strength of atmospheric phenomena to disastrous levels, as predicted by UN [1], [2], [7], see Fig. 3..

Something more, if the sea level upraise follows the worst scenarios, large portion of coastal line and river estuaries will be constantly flooded, and large urban infrastructures in those areas will be irrevocably damaged and lost. The humanity must be prepared for this scenario and the expansion toward open ocean areas is challenging, but seemingly outright.

1. 2. Increasing world population and food and energy consumption

Environmental change and climate change pose a serious challenge to global peace. If urgent action is not taken, water and food shortages will worsen significantly over the next 30 years, leading to social protests, riots and armed conflict. This is stated in a series of reports prepared by two independent Inter-national Research Centers - Institute for Economics and Peace (IEP) and the Institute for Climate and Peace (ICP), cited in [1], [2], [7], [10].

Environmental threats will be particularly strong in countries with high fertility rates, mostly in Africa, but also Asia. They are already suffering from a lack of resources and growing poverty. The reports are based on reliable statistics from the Center for Migration Monitoring, including those caused by environmental and political factors.

According to the reports, the world's population by 2050 will grow by 3.5 billion people, while global food demand will increase by 50%. Water supply problems are already emerging, affecting even a number of European countries. As a result of the environmental crisis, the number of "climate" refugees in the world could reach 1.2 billion by the middle of the century. The struggle for natural resources, energy sources, lack of water and food will inevitably create an explosive social situation in some countries in Asia, Africa and the Middle East. It is in these countries that changes in the environment and natural disasters are likely to lead to mass displacement, which will threaten regional and global stability. Migrant flows will flow mainly to Europe and North America, where the environmental situation will be much better. The waves of new migration will inevitably exacerbate the political and social situation in developed countries.

Life at sea, in large floating cities and islands is a possible solution to this problem.

1. 3. The world's oceans - resources and free space

The world's oceans occupy more than two-thirds of the earth's surface, support more than 70% of planetary photosynthesis and provide more than 90% of the space inhabited by living organisms. This is a huge resource source and a vast sphere for the expansion of human activity. However, the difficult, sometimes aggressive and uninhabitable environmental conditions have historically limited the development of this area, especially to the development of fishing, maritime transport and limited use of coastal areas. The modern active industrialization of marine areas dates back to about 50 years ago and many associate it mainly with the extraction of oil and gas, but in fact a significant share have the extraction of mineral resources and chemical raw materials, fish, mussels and other aquaculture, use of water for deployment of large industrial, coastal protection and transport facilities, such as floating airports, floating factories, floating port facilities, quays, etc. The newest and most promising direction is the absorption of renewable energy by sea waves, currents and wind. Expected human expansion toward sea areas can be substantially assisted by this concentration of goods.

2. DEVELOPMENT OF TECHNOLOGIES

2. 1. Assessment of technologies

The technologies for utilization of waste sea space started with reclaiming land from shallow coastal areas and swamps, then erecting of concrete or stone embankments, fixed structures, and variety of floating units.

In [5], weighted matrix comparison was used to score some common platform types against critical design aspects. The scoring uses a 1-10 scale with10 as the best score. Cost, design life, stability, sea-keeping and survivability were determined to be the most important aspects. The result is shown in the table below, demonstrating the overall advances of mega-floats (VLFS).

Assessment of technologies [5]

Table 1

Criteria	Weight (1-10)	Fixed		Floating		
		Reclaimed Earth	Fixed Structure	Submersible	Semi-sub	Mega-float
Construction cost (volumes / simplicity)	10	4	5	7	7	10
Maintenance cost	10	8	5	5	5	6
Design life	10	10	7	7	7	7
Stability	10	10	10	9	7	8
Seakeeping	10	10	10	9	8	8
Survivability	10	8	5	5	8	8
Ease of transportation of structure	8	5	5	9	9	7
Ease of transportation of inhabitants	8	10	10	9	5	6
Modularity / flexibility	8	0	3	6	10	10
Wave induced loading	8	8	5	5	6	3
Tones per inch / Moment to change trim	8	10	10	9	4	8
Applicability to water depth	5	3	5	2	5	8
Freeboard (low assumed good)	3	8	8	8	9	9
Waterline changes with tide (assumed bad)	3	0	0	0	10	10
Totals		**819**	**749**	**774**	**772**	**857**

When designing artificial floating islands and cities, it seems rational to use a modular approach, which assumes that the entire mega-structure consists of separate individual smaller modules. The basis of each module is a floating hull that can be borrowed, for example, from well-operated (and proven over time) semi-submersible platforms. Each module will be connected to the adjacent elements. The mooring of the entire system and the individual elements has to be elaborated, accounting for mutual interaction of modules. Due to little experience in this field and many unresolved issues, the topic became interesting and relevant in terms of development, design and re-search (both computer and model) of individual elements of construction and the entire mega-complex. It is necessary to study their behavior in different sea conditions - with different intensity of waves, wind and sea currents.

The advantages of the modular approach are:

• Possibility for reconstruction (fast transformation from one type of object to another, using the main structure);

• Reconfiguration (LEGO-type structure)

Although the modular approach implies the above-mentioned challenges, this concept represents an opportunity for cost savings due to the scalability of production in perspective in the transition from a pilot demonstration model to a full-scale application.

The main elements of the future floating mega-structures are the following:

1. Floating base - a structure on which residential buildings and other necessary elements of urban planning are erected;
2. Station keeping devices - mooring systems of passive or active type.
3. Elements connecting separate modules of mega-structure with each other (assemblies)
4. Protective elements protecting the structure from the wave impact, such as floating breakwaters or other type of hydro-technical facility.

Components that can be used to complete full-fledged floating cities, providing the necessary living conditions, have already been built or planned, i.e. power plants (nuclear, solar, OTEC, current turbines, etc.), protective structures, desalination plants, floating airports, floating living quarters, gardens and entertainment areas, etc.

Due to the innovativeness of mega-structures of this type, a complex study of both individual modules and elements of the system and the mega-structure as a whole is needed.

2. 2. Application of VLFS

Application of Very Large Floating Structures (VLFS) is a comparatively new technology introduced in Japan about 50 years ago. Even if only partially realized so far, it offers many advantages over conventional methods of exploring new territories.

First of all, VLFS applications are diverse, with both specific and complex functions. VLFS can be used to export industrial plants to sea areas. Another practical application is construction of power plants operating with renewable energy sources. There are projects and practical implementations of facilities for desalination and purification of sea water, for nurture of fish and aquacultures, extraction, storage and processing of raw materials, oil and gas, port and bridge facilities, airports, emergency centers, etc. Combining these capabilities, VLFS can be used as a basis for an artificial island (floating city) that is suitable for human life and is completely autonomous and independent. There are a number of such projects, the construction of which is a matter of time and a suitable economic situation.

VLFS advantages:

• Floating structure can be mobile and does not have to be built on site, but thanks to its mobility can be moved to places where the structure is needed;

• Floating structures do not endanger the environment because they are not built directly on the seabed and do not disturb marine ecosystems;

• Structures can be deployed over a large area;

• They have relatively lower cost than alternative stone embankments or fixed at the bottom facilities, when the water depth begins to increase above 30-50 m;

• Floating mega-structures are not threatened by natural disasters such as earthquakes and tsunamis, which affect many countries located in coastal areas;

• They are autonomous and self-sufficient, which is achieved through the use of renewable energy and as a consequence - independence from the electricity grid;

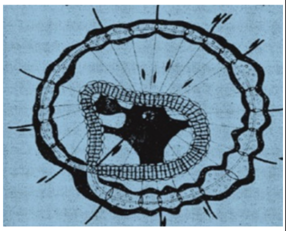
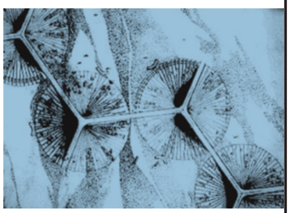
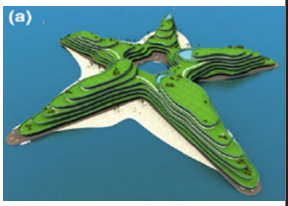
• When using a modular approach for construction, a possibility exists of replacing entire elements that make up the mega-structure.

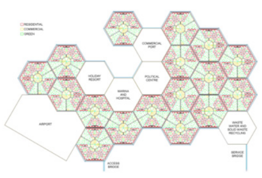
The disadvantages of VLFS are the same as with any other type of artificial structures operated in the sea - the possibility of accidents in which the ecology of the area may be endangered. In this regard, the safety requirements are of high importance yet in the design phase of such facilities in order to minimize the risk of man or elements inflicted disasters. In addition, the floating structures are permanently subjected to environment, and probability of occurrence of high storms and even abnormal (killer) waves - must be taken into account.

It is necessary to note the complexity in predicting the behavior of complex assembled configurations, considering both their individual modules interconnected in large-scale structures and the structure as a whole. This is due more to the complexity than a disadvantage, as well as to a lack of experience in operating such large-scale structures (such as floating artificial islands and cities) in open sea conditions.

The other disadvantage is the high cost of all phases of the implementation of a project of such scale: both in the design, construction and operation and maintenance of the floating structure.

2. 3. Summary table of prototypes [3], [4],[6], [8], [11], [12, [13], [14], [15]

No.	*Name*	*View*	*Country*	*Type*	*Status*
1	Unabara Sea City		Japan	Floating City	Project, 1960
2	Kasumigaura		Japan	Floating City	Project, 1961
3	Floating Islands on Han River		South Korea	Touristic and Conference Centre	Built and operating
4	Greenstar		Maldives	Hotel and Conference Centre	Project
5	Lilipads		Dubai	Floating City	Project

6	Floating Cities in Osaka Bay		Japan	Floating City	Project
7	The Citadel		Westland, Netherlands	Floating Apartment Complex	Project Waterstudio
8	Megacity		Canada	Floating City	Artistic design 2016
9	Kon-tiki		Ukraine	Floating Island Resort	Artistic design 2019
10	Artisanopolis		USA, French Polynesia	Modular floating city	Artistic design 2015
11	Seasteading		USA	Modular floating city	Artistic design 2015
12	The World		Dubai	Modular floating city	Artistic design 2011
13	Floatec		Netherlands	System of floating houses	Project
14	Kiribati		Kiribati	Floating city based on hexagon modules	Project 2015

3. TASKS FOR FUTURE RESEARCH

Now the ideas of life at sea, for large floating cities and islands still seem futuristic, but with the growing environmental and social problems worldwide, solutions for the sustainable reclamation of the world's oceans may become inevitable. For the practical realization of this endeavor it is necessary to solve a number of complex tasks of technological, social and organizational nature, among which:

- Advance solutions for composite modules, inter-action, couplings, positioning, corrosion and protection
- Capacity of very large engineering structures to withstand harsh environment - abnormal waves, drift forces, currents and winds
- Utilization of new advanced materials, like composites, metal foams, etc.
- Dealing with ecology problems, like waste and air/water pollution, influencing the marine life
- Energy supply, most logically from local renewable sources
- Water supply for industrial and household needs
- Communications and maintenance
- National and regional planning
- Architecture and urban planning
- Administration, legal and regulatory framework

Obviously, it is matter of international interest and must be tackled internationally, under "blue growth" programs and prospective worldwide.

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Black Sea 2020

SHIPBUILDING AND SHIP REPAIR

PAST, PRESENCE AND FUTURE OF RIVER AND RIVER-SEA CRUISE PASSENGER SHIPS IN UKRAINE AND RUSSIA: DESIGN AND OPERATIONAL EXPERIENCE POINTS OF VIEW

Alexander EGOROV

Abstract. *Research of operational experience, including risk analysis and reliability of Ukrainian and Russian river and river-sea cruise passenger ships is carried out. The analysis of failures with PS hulls occurred since 1983 is executed. Technical recommendations from the position of navigation and ecological safety for design of PS are given.*

New PS are necessary for the following reasons: limited possibilities of modernisation of available ships because of outdated design; unsatisfactory indicators of comfort of passenger cabins and public spaces on ship; impossibility of river-sea cruises. The forthcoming write-off of PS fleet will cause essential damage to internal river passenger traffic; conception of river cruise can disappear.

For avoiding of such scenario it is recommended on medium-term perspective to build new fleet: PS projects of "Dnipro / Volga-Don max" class of PV300, PV300VD, "Volga-Balt max" class of PV500VB, "BBK max" class of PV09, PV11 as the most fully corresponding to market tendencies.

Key words: *concepts, cruise market, passenger ships, prognosis, river and river-sea cruises.*

INTRODUCTION

Today river and river-sea cruise passenger ships (PS) transport about 350-400 thousand tourists on Russian and Ukrainian rivers, which includes 150 thousand foreigners. Realities of domestic tourism are that to favourite river cruises of foreign tourists from the USA, Germany, Australia and China on route Moscow – St. Petersburg, partly sea lines Moscow - Sochi, Kiev - Constanta, "circular" cruise on Caspian Sea, east Russian river lines were added.

At this moment in Russia, Ukraine and generally in world practice of PS operation there is practically no fleet of river-sea cruise ships.

By expert estimates in Russia and Ukraine the market size can make 600-750 thousand tourists by 2030 [1].

The market assessment allows to draw conclusion that, with taking into account the predicted reduction of ships of old series and operational experience of existing PS, not less than eight new cruise ships will be required by 2025.

Thus, problem of creation of safe river and river-sea cruise ships became actual and important for domestic water transport and tourist industries.

AIM OF THE PAPER

Research of operational experience, including reliability and failures analysis of PS hulls for the period since 1983; justification of modern and safe river and river-sea ships' concepts which are of interest for domestic cruise companies: PV500VB, PV300, PV300VD, PV09 projects. These ships will be operated on classical river lines, and also make episodic cruises in coastal zones in accordance with assigned class.

MAIN TEXT

In the process of research of operational experience of PS authors made following conclusions about PS reliability:

- operational conditions for PS are more quite than for cargo vessels;

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- as a rule, PS have constant and more experienced crew and staff;
- PS have smaller draughts and rarely get aground;
- change of PS loading conditions is insignificant;
- PS start navigation later and finish it earlier than cargo vessels; that practically excludes ice damages' risk;
- PS sides are protected by crinolines, so level of side construction damage is lower than for cargo vessels, despite on often moorings and lockings during navigation;
- PS have no aggressive cargoes and grab cargo handling operations.

Corrosive wear for PS is in 2-4 times lower than for cargo vessels. Research has shown that, for example, 30-years corrosive wear for classic PS was, as follows: 2.4% for bottom shell, 2.1% for side shell, 6.3% for main deck shell, 2.1% for tank top shell, 2.8% for transverse bulk-heads plating, 2.1% for bottom members, 2.4% for side members, 2.3% for deck members. Increase of corrosive wear is detected at deck construction in the area of living compartments (places of bilge waters) and at the sewage tanks.

During the research totally information about 213 accidents with PS was collected since 1983 [2, 3].

All accidents (213 ones) were analysed on the basis of data that was accessible to the authors, also with the help of mathematical modelling of different events' scenarios by events trees and fault trees construction. Authors' conclusions sometime don't coincide with official ones and are of research nature only.

Generalized risk level for PS was defined for each danger type by IMO-based methodology [4] with accounting of 3-point scale type relative responsibility factor (weightiness).

Risk level   is a product of danger appearance probability   and consequences level of the same danger . Conditional probability   was determined due to 5-point scale ("1" - appearance frequency at 0-20% of casualties, "2" - 21-40%, "3" - 41-60%, "4" - 61-80%, "5" - 81-100%).

Risk matrixes for PS were made for two variants: first one is for all investigated casualties (see Figure 1) and second one is for disasters only (see Figure 2).

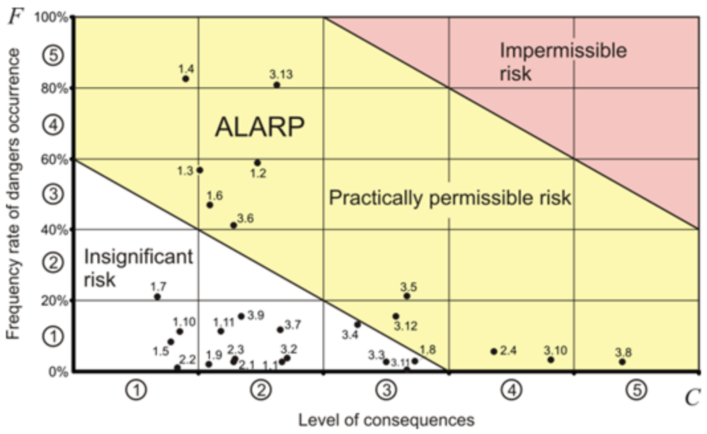


Fig. 1. Risk matrix for PS - all investigated casualties

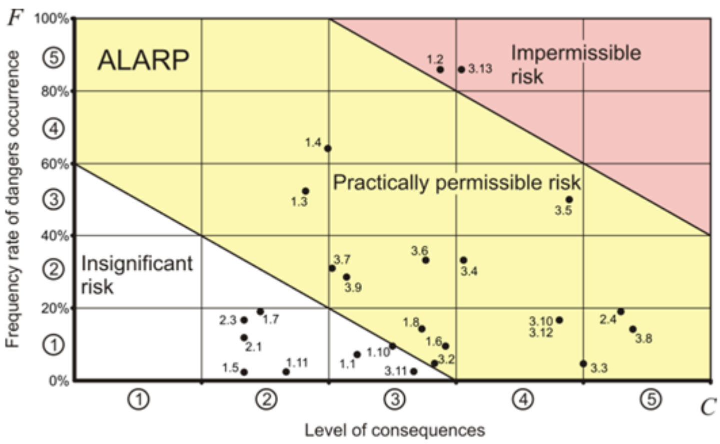


Fig. 2. Risk matrix for PS - disasters

Analysis of Figures 1 and 2 allows to conclude about dangers ranking:

- danger 1.2 (actual providing of hull constructions water-tightness) and 3.13 (careless of crew, non-fulfilment of technical operation rules requirements) have the maximal range for PS; risk level for this dangers lays in the ALARP zone so it is of minimal practically permissible level type;

- danger 3.4 (navigation mistakes), 3.5 (touching ice, harbour walls or lock walls), 3.6 (careless of terminal services) have a rather high formal level risk either due to frequency or due to consequences. These dangers lay also in ALARP zone (minimal permissible risk level).

- danger 2.4 (breaches of Stability and Damage Stability Booklet restrictions) 3.3 (grounding) and 3.8 (vessel overload) belong to ALARP zone due to consequences severity; it may be noted that overload of passenger ship is the most serious problem for small ships, this danger consequences hardness is the biggest.

- danger 1.3 (breach of technology), 1.4 (defects' missing during survey) belong to ALARP zone due to high frequency of occurrence.

Due to approaches adopted in the Formal Safety Assessment methodology [5] dangers that belong to "impermissible risk" zone should to be subjected to risk control procedure (decreasing frequency and/or consequences severity) at any required expenditure capacity. Dangers that belong to ALARP zone require technical-economic analysis that has to define cost optimal measures for risk level decreasing.

Practical variants of risk control include organization measures (during operation) and measures during design.

Solving the problem of PS risk control for dangers 1.2 lies in the sphere of organizational-technical measures at the stage of hull actual conditions survey during ships operation. Other dangers are of human factor effects and require corresponding control measures, e.g. implementation of Safety Management System for river ships; it's inadmissible when non-professionals operate passenger ships.

Number of accidents and disasters to ships age chart (see Figure 3) was made on the base of statistical data.

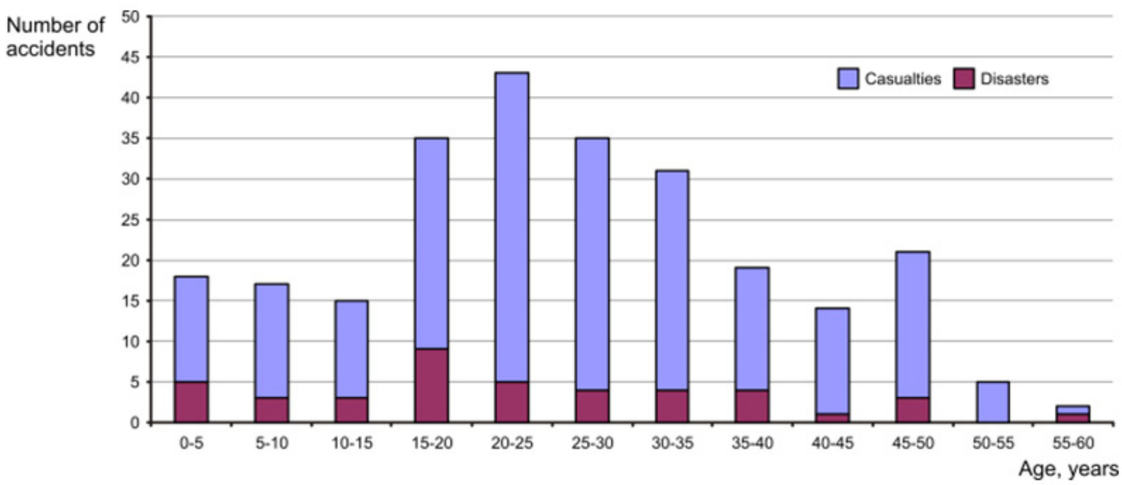


Fig. 3. Number of accidents and disasters to PS age chart

For all consequences levels the role of machines failures is practically a bit bigger than quarter; fires and explosions, hull damages and flooding occupies about 20.7% each; equipment failure occupies 10%. Relative danger of accident class looks enough interesting. Two accidents from three ones connected with flooding and stability failure are followed with PS wreck. Every fourth ship with hull accident gets lost.

Authors also made research of age structure of PS fleet.

From 254 river cruise passenger ships built in Soviet period 98 (38.6%) have been written off (6.7% - 17 ships were lost in accidents, 31.9% - 81 ships were utilized). There were 32 ships out of operation (12.6%) with middle age of 57.7 years. In operation - formally 124 ships (48.8%) with middle age of 45.2 years. Mean age of utilization - 47.1 year. In the next decade this fleet most likely will be decommissioned and we will have only about 50 ships [1] (without ships which can be built during these years but which are not ordered yet, see Table 1).

Prognosis of written-off of PS on 2019

Table 1

Project	Year of written-off	Remaining life time, years	Number of active vessels on 2019	Prognosis of vessels on 2025	Prognosis of vessels on 2030
26-37	2029	10	11	6	1
92-016	2033	14	7	5	2
301	2035	16	20	16	10
302	2040	21	24	22	18
305	2028	9	13	2	0
588	2031	12	24	12	3
646	2025	6	5	2	0
785	2019	0	0	0	0
860	2019	0	0	0	0
Q-040	2031	12	4	2	1
Q-056	2032	13	2	2	2
Q-065	2032	13	3	3	3
PKS-40	2040	21	3	3	3
463	2023	4	1	0	0
R-18A	2030	11	2	2	1
RT-258	2025	6	1	1	0
588 / REGK.002	2037	18	1	1	1
1168	2036	17	1	1	1
PV08	2042	23	1	1	1
PV09	-	-	1	1	1
PV300	-	-		2	2
PV300VD	-	-		1	1
PKS-180	-	-		2	2
Total			**124**	**87**	**53**

New PS are necessary for the following reasons: limited possibilities of modernisation of available ships because of outdated design; unsatisfactory indicators of comfort of passenger cabins and public spaces on the ship; impossibility of river-sea cruises; increased risk of failures due to ships' age.

The forthcoming write-off of PS fleet will cause essential damage to internal river passenger traffic; conception "river domestic cruise" can disappear.

For avoiding of such scenario it is recommended on medium-term perspective to build new fleet: PS projects of "Dnipro / Volga-Don max" class of PV300, PV300VD, "Volga-Balt max" class of PV500VB, "BBK max" class of PV09, PV11 as the most fully corresponding to market tendencies. Already realized in 2017 PV09 river-sea cruise passenger ship (see Figure 4) became the first newly built in "line-up" of new generation cruise ships (see Table 2).

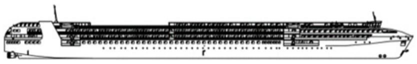
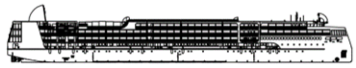
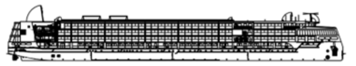
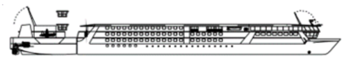
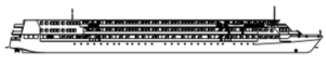
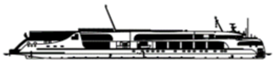
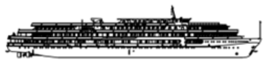
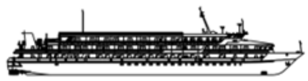
Fig. 4. General view of PV09 river-sea cruise ship
Author photo: Pavel Pheklistov

Choice of classification society class of perspective cruise passenger ship assumed following: assignment of class based on sailing areas in accordance with planned directions of transportations; definition of ice class in accordance with saved-up experience and tendencies to extension of the navigation period including winter operation; assignment of economically reasonable life-time cycle of the ship.

Crew has to be formed with taking into account ship power plant automation, automation of deck works (automatic anchor mooring winches), automation of process of loading of supplies and mechanization of process of cleaning of decks (washing machines, etc.) and with taking into account usage of specialties combination.

Side views of parametric "line-up" of new generation PS

Table 2

No	Project, maximal passenger capacity	Side view
"Volga-Balt Max" class		
1	PV500VB, 518 pax	
"Volga-Don / Dnipro Max" class		
2	PV300VD, 310 pax	
3	PV300, 329 pax	
4	PV250, 250 pax	
"Danube Max" class		
5	PV200D, 200 pax	
"BBK Max" class		
6	PV200BB, 200 pax	
7	PV09, 36 pax	
100-150 pax		
8	PV150, 150 pax	
9	PV06, 120 pax	
10	PV08, 112 pax	
Single day cruises		
11	PV01, 250 pax	

PV500VB concept architectural-structural type is as follows: steel, triple-screw motor ship (with full-turn rudder propeller at CL), with slopping stem and transom stern, with excess freeboard, with forecastle, with four-tiers living superstructures through the whole ship's length, with wheelhouse located fore and engine-room located aft. Main particulars are as follows: Russian River Register (RRR) class notation is M-PR 2.5 (Ice 30) A; length overall is of 179.86 m; length between perpendiculars is of 176.00 m; breadth overall is about 17.00 m; breadth is of 16.80 m; depth is of 5.50 m; maximal draught is of 3.20 m; height overall from BL is of 16.40 m; crew and service staff is of 117 persons; autonomy by fuel is of 15 days, by other store types is of 10 days.

PV300VD concept architectural-structural type is as follows: steel, triple-screw motor ship, with slopping stem and transom stern, with excess freeboard, with extended forecastle, with four-tiers living superstructures through the whole ship's length located amidship, with wheelhouse located fore and engine-room located aft (see Figure 5). Comfort level on PV300VD ship will correspond 4-5* hotel standard.

PV300VD "Volga-Don / Dnipro Max" class ship will work on lines Moscow - St. Petersburg and also will make voyages Moscow - Sochi, Astrakhan - Caspian ports.

The ship's class will allow also to visit ports at Black and Mediterranean seas.

General arrangement of PV300VD ship is presented on Figure 6. Ship's main particulars are as follows: length overall 141 m; length between perpendiculars 135.56 m; breadth overall 16.82 m; breadth 16.60 m; depth 5.50 m; draught maximal 3.20 m; air draught from BL 16.25 m; crew and service staff 90 people; autonomy by fuel 15 days; autonomy by other stores 10 days.

PV300 "Volga-Don Max" class ship will work on lines Moscow - St. Petersburg, and also will make voyages in coastal zones in accordance with assigned RRR class M-PR 3,0.

PV300 concept architectural-structural type is as follows: steel, self-propelled river-sea motor ship with two full-rotated rudder propellers, with plumb stem and transom stern, with excess freeboard, with extended forecastle, with four-tiers living super-structures through the whole ship's length, with wheelhouse located fore and engine-room located aft (see Figure 7). Comfort level on PV300 ship will correspond 4-5* hotel standard.

General arrangement of PV300 ship is presented on Figure 8. Ship's main particulars are as follows: length overall 141 m; length between perpendiculars 135.36 m; breadth overall 16.80 m; breadth 16.60 m; depth 5.00 m; draught maximal 3.00 m; air draught from BL 16.25 m; crew and service staff 144 people; autonomy by fuel 15 days; autonomy by other stores 5 days.

Fig. 5. General view of PV300VD river-sea cruise ship

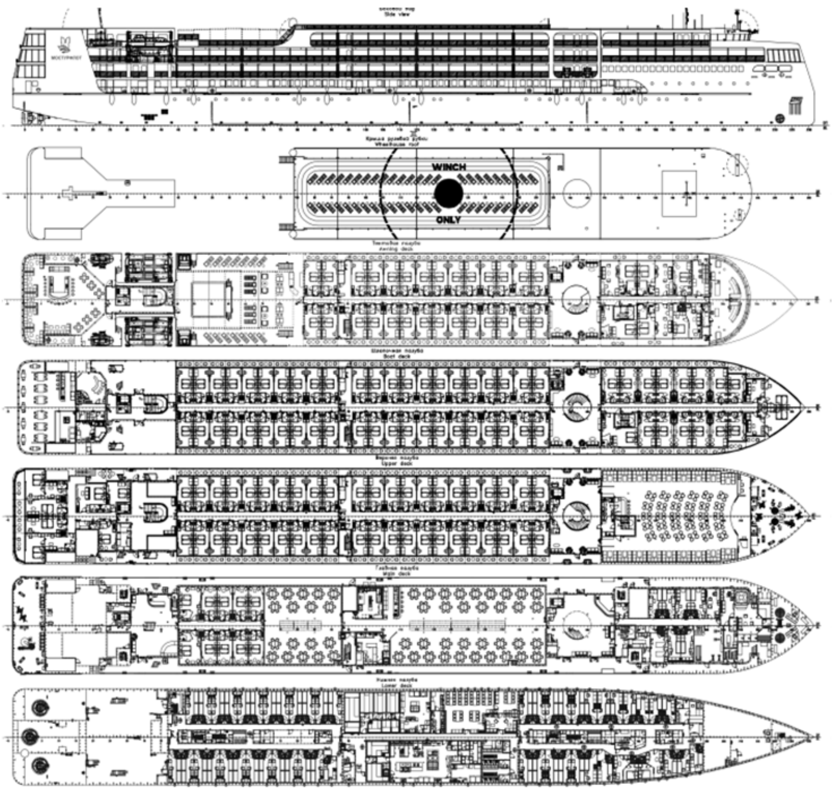


Fig. 6. General arrangement of PV300VD river-sea new generation cruise ship

Fig. 7. General view of PV300 river-sea cruise ship

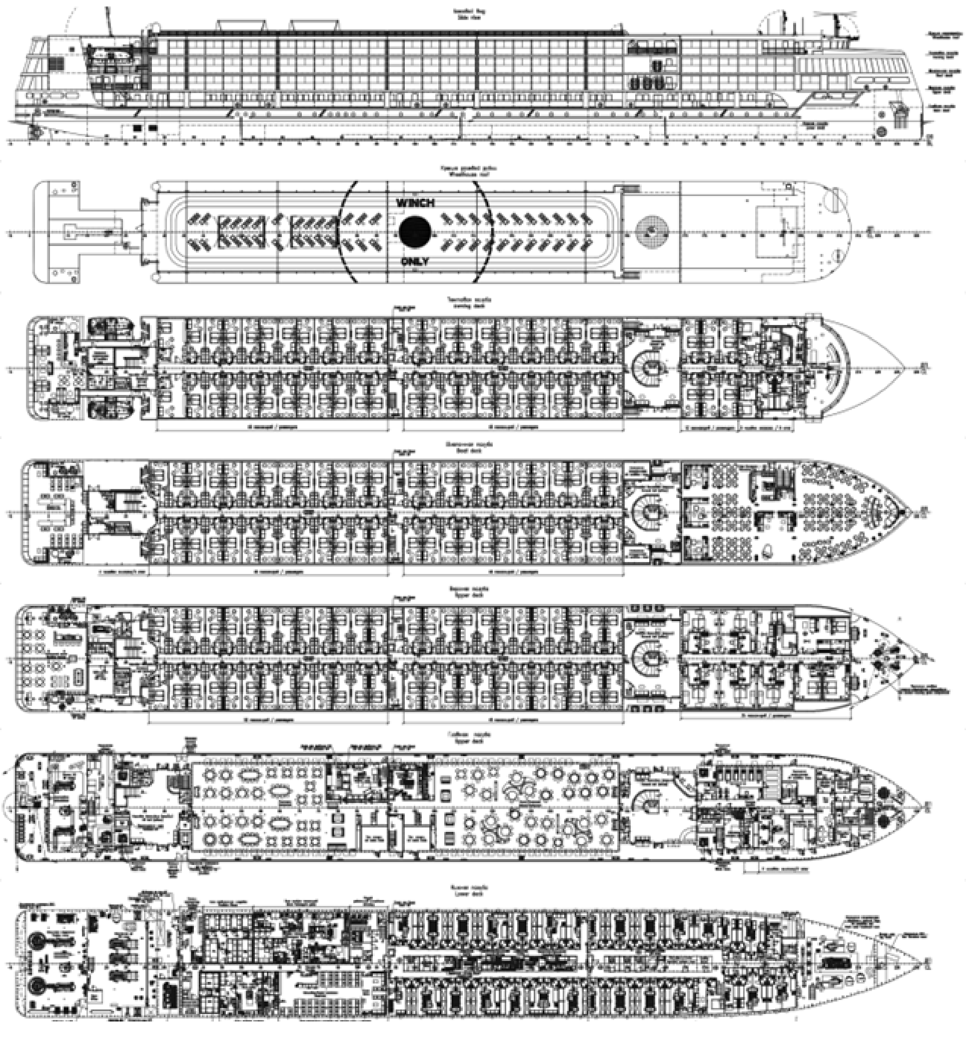


Fig. 8. General arrangement of PV300 river-sea new generation cruise ship

CONCLUSIONS

The most serious restraining factor of growth of domestic cruise tourism industry is lack of modern safe river and river-sea cruise ships. In the next decade this fleet most likely will be written off and we will have only about 50 ships. For the solution of problem of updating it is offered to connect river and some coastal sea routes on the basis of modern cruise ships of PV500VB, PV300, PV300VD, PV09, PV11 projects. These ships fit to all standards of modern cruise and hotel industries. There are all types of necessary rest (restaurants, Spa centres, fitness, bars, etc.). All leading domestic cruise operators took part in development of ships therefore concepts completely meet their requirements. Ships are not only up-to-date high comfortable and handy ships but also safe, ecology “clear” passenger carriers that fully meet requirements of all International (PV300VD ship) and Russian requirements (PV09, PV300, PV300VD, PV500VB, PV11 ships).

PV09 river-sea cruise ship “Shtandart” was laid down in 2014 and put into operation in 2017. The ship is intended for cruise voyages through European inland waterways of Russia, including Volga-Balt, Volga-Don, Belomor-Baltiysk Canal, Volga river, Moscow River; also on lines between Moscow port, St.-Petersburg port and Belomorsk port through Belomor-Baltiysk Canal; with sailing to White Sea and to the region of Solovetsky Islands, Gulf of Finland; Caspian, Azov and Black Seas. PV300 river-sea cruise ship “Mustay Karim” was laid down in 2017, launched in September 2019. The ship is put into operation in August 2020. She will be operated on long cruise lines Moscow - St. Petersburg, Moscow - Astrakhan, Moscow - Rostov-on-Don, Rostov-on-Don - Novorossiysk with replacing classical cruise ships of 301 and 302 projects and representing new river-sea routes. PV300VD river-sea cruise ship “Petr Velikiy” is intended for work on lines Moscow - St. Petersburg, Moscow - Rostov-on-Don - Sochi, Astrakhan - the ports of the Caspian Sea, and in Black and Mediterranean Seas. The ship was laid down in 2016, launched in May 2019 and is planned to be built in 2021.

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ABOUT DESIGN OF 22MW ICEBREAKER OF IBSV01 PROJECT

Gennadiy EGOROV*, Nickolay AVTUTOV**

Abstract. *In paper necessity of building of multifunctional icebreaking supply vessels for all-year work in Gulf of Ob area is shown. Main design and building stages of one of the most powerful 22 MW diesel-electric icebreakers of IBSV01 project put in operation with high arctic class Icebreaker8 are grounded. The special attention is paid to hull form and propulsive com-plex. Trial results which fully meet Customer requirements both on running and functional qual-ities have shown high maneuver-ability and icebreaking capability.*

Key words: *design, hull form, icebreaker, Northern Sea Route, supply vessel.*

INTRODUCTION

In 2018 the Vyborg Shipyard put into operation two of the world's most powerful (among new built ones) diesel-electric icebreakers with capacity of 22 MW, which can operate in continuous 2 m ice with 30 cm snow cover.

Keel of the IBSV01 head vessel of the series "Alexander Sannikov" (see Figure 1) was laid down in November 2015; she was completed in June, 2018. Second vessel "Andrey Vilkitskiy" was completed in December, 2018.

The vessel's concept design Aker ARC 130A was worked out by Aker Arctic Technology; the technical design IBSV01 was worked out by Marine Engineering Bureau.

Fig. 1. IBSV01 vessel "Alexander Sannikov". Author of photo is Ivan Borodulin

It is planned to produce up to 8.5 million tons per year of low-sulfur Novy Port crude oil at the Novo-port oil and gas condensate field; this crude oil exceeds in purity Urals and Brent ones [1]. Transportation of this crude oil is foreseen by marine way from the Arctic terminal "Gates of Arctic", located in the Gulf of Ob in the area of the Kamenniy Cape on the Yamal Peninsula. Cargo vessels are running from the ice edge in the Barents or Kara Seas to the entrance of the Gulf of Ob under icebreaker support of nuclear-powered linear icebreakers. Then towards the port of Sabetta icebreaker support is provided by small-draught nuclear-powered icebreakers of "Taimyr" type that also renews channels through heavy ice in the water area of ports [2].

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At the next stage of the cargo vessels movement, special small-draught diesel icebreakers / support vessels are required to ensure the all-year round safe approach of "Shturman Albanov" type tankers to the Arctic terminal, mooring and towing operations and protection of the "Gates of Arctic" from the ice impact.

AIM OF THE PAPER

Substantiation of the technical solutions adopted during the design and construction of one of the world's most powerful diesel-electric IBSV01 icebreakers that ensure tankers operation at the terminal in the Gulf of Ob.

MAIN TEXT

Perspective concept of IBSV01 icebreaker / support vessel has to solve the following main problems:

- 42K Arctic Shuttle tankers' icebreaker support between the port of Sabetta and the area of the Ka-menniy Cape in the Gulf of Ob at ice conditions;
- 42K Arctic Shuttle tankers' icebreaker support towards cargo region of Arctic terminal at ice condi-tions;
- security support during mooring and loading of these tankers.

As it's noted in [3], projects of special-purpose vessels, offshore vessels and icebreakers indicate a ten-dency in world shipbuilding to equipped such objects by additional functions to the maximum extent. In addi-tion, the most perspective direction in the development of hull shapes for ice navigation vessels is the further improvement of traditional ice contours. They allow to ensure a harmonious combination of good ice qualities of the vessel during operation both in continuous and natural broken ice. Correct determination of the main and auxiliary missions of a multipurpose vessel, the selection of appropriate prototypes, usage of reliable statistical data and approximate dependencies allow to determine the combination of the optimal characteristics of the hull shape and main dimensions at the initial stages of design.

The characteristics determined in this way provide high ice-passing ability, good running ability in still water and satisfactory seaworthiness; all this predetermines the success of a multifunctional ice navigation ves-sel.

This concept is intended for all-year operation in the area of the Kamenny Cape in the Gulf of Ob. Accordingly, the choice of a diesel-electric power plant is carried out on the basis of sufficient propulsive power for independent passage through ice in ice conditions prevailing in the area of operation. The concept has to operate in continuous 2 m ice with 30 cm snow cover at a speed of 2 kn, running ahead both bow or stern.

As a supply vessel that would work with enough large tankers in a rather narrow channel, the IBSV01 concept has to be able to maneuver well when working in icy slush and continuous ice, so the special arrange-ment of full-turn rudder propellers (RP) was chosen, namely two ones aft and single one fore.

In general the vessel should reach speed of about 16 kn in the deep water at 85% ME loading while wind and waves are of Beaufort force 3.

Bollard pull should reach about 200 t at 100% ME loading.

IBSV01 hull contours that meet the above requirements, was created on the basis of model tests carried out in towing tanks (deep-water and ice ones) by Aker Arctic Technology and at the Krylov State Scientific Cen-ter (KSSC).

The general view of hull model is given in the Figures 2 and 3.

Fig. 2. IBSV01 hull model developed in the Aker Arctic ice tank

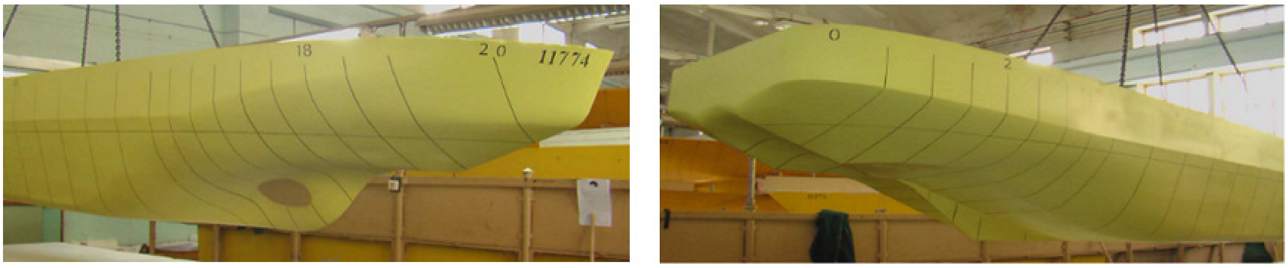

Fig. 3. IBSV01 hull model developed in the KSSC

According to the test results it was noted that ice-passing ability for deep water is better for stern ahead running and vice versa for shallow water. Test for running through 7.0 m icy slush was carried out for shallow water only; concept vessel reached speed of 1.7 kn at bow ahead and of 4.0 kn at stern ahead. Number of ma-noeuvres was checked, namely: passage through the ridges of hummocks, exit from the ice channel by bow ahead and stern ahead, turns when moving ahead and astern; turn in ice channel by "star" pattern running. Manoeuvring properties were provided due to the presence and appropriate arrangement of three RP, while the model manoeuvred stern ahead better than the bow ahead. When passing a ridge of hummocks the model behaved differently when moving bow or stern ahead. When moving bow ahead, after vessel's stop it was necessary to overcome the hummocks by jerks. When moving stern ahead, on the contrary, jerks were not required; hummocks were successfully overcome due to ice progradation by the propellers of RP.

Propulsion capacity of 21.5 MW was defined due to tests results. Two RP aft and single RP fore togeth-er with bow thruster of "propeller in the tube" type also provide meeting of RS requirements concerning DYNPOS-2 class for dynamic positioning (DP) system. The DP system provided compensation for shifting from given course or from given positioning point under the following weather conditions: in winter while ice cohesion less than up to 50%; in summer while wind speed is less than 25 m/s, current speed is less than 1.2 m/s and wave height less than 3 m. which allows to ensure the vessel's position keeping at the point during diving opera-tions, as well as when working near drilling platforms. Two aft 7500 kW and single fore 6500 kW Azipod full-turn rudder propellers were accepted as main running and manoeuvring gears for IBSV01 concept.

Each rudder propeller is equipped by single 4-blade fixed pitch propeller with removable blades (bolt clams). Diameter of the aft propellers is 4200 mm, 4000 mm for the fore one. Propellers are made of stainless steel.

Vessel is equipped by 1800 kW bow thruster of "propeller in the tube" type; fixed pitch propeller's di-ameter is of 2700 mm. Bow thruster is equipped by frequency-controlled drive unit that provides continues DP work in the ice conditions.

As a supply vessel, the IBSV01 concept has got general arrangement with open aft deck (area 500 m^2 and permissible load of 5 t/m^2) that ensure stowage of deck cargo and towing operations. Towing winch is locat-ed at the fore part of the cargo deck under a canopy.

Living compartments, bridge and main diesel-generators rooms are located in the middle part of the vessel.

Fore part of the vessel provides running in all ice conditions according accepted limits and vessel's ice strengthening.

Aft part of the vessel provides wide spectrum of ice and escort operations at the accepted operational region and for design ice conditions.

IBSV01 general arrangement scheme is given in the Figure 4.

As a results, for IBSV01 concept the following class notation of Russian Maritime Register of Shipping was set: KM ★ Icebreaker 8 1 AUT1-ICS FF1WS DYNPOS-2 EPP ANTI-ICE ECO SDS<12 Winterization (-50) Tug. This class notation fully reflects the multi-functionality of the vessel.

IBSV01 main particulars are given in the Table 1.

IBSV01 main particulars

Table 1

Parameter	Value
Length overall, m	121.7
Length overall, without towing notch, m	116.5
Length by DWL, m	107.90
Breadth by DWL at middle, m	25.0
Breadth by main deck, including fence constructions, m	26.0
Depth, m	11.5
Draught by DWL, m	8.0
Draught maximal, m	8.2
Displacement by DWL, t	13397
Displacement by maximal draught, t	12590
Deadweight by DWL, t	3774
Deadweight by maximal draught, t	4581

IBSV01 vessel is of unrestricted sailing type, including sailing though the Northern Sea Route; she is designed taking into account the principle of zero discharge or leakage of oil during operation. All solid and liquid wastes are stored onboard and disposed of onshore.

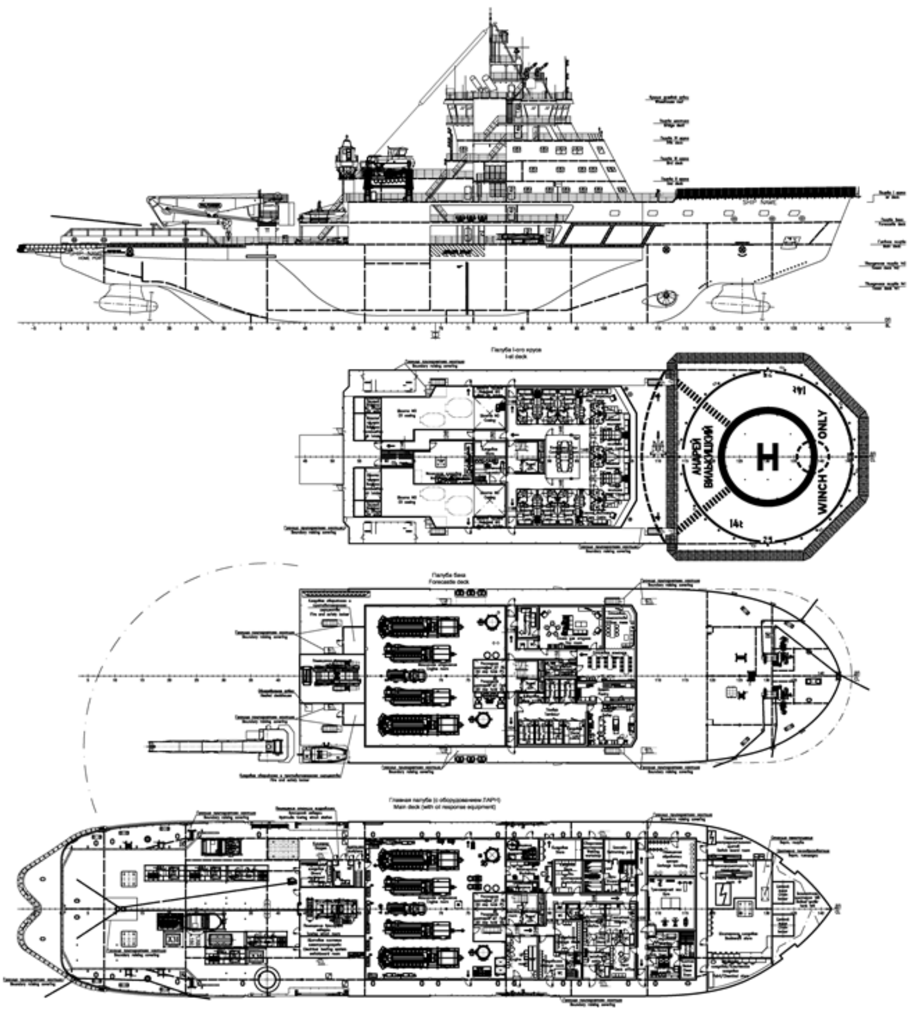

Fig. 4. General arrangement of the 22 MW IBSV01icebreaker

For these purposes, during the design and construction requirements of the “Polar Code” (“International Code for Ships Operating in Polar Waters”) and the “Requirements for the Design, Equipment and supply of ships following the Northern Sea Route” were fully taken into consideration in addition to the requirements of the RS Rules and International Conventions. For example, all tanks that contain liquid marine pollutant (fuel oil, lub. oil, etc) are arranged in the way that their content doesn’t contact with outer shell.

It is interesting to note that the mounting of the Azipod RP was carried out not on the slipway in tradi-tional way, but afloat in the shipyard’s water area by using a special technological pontoon of P05A prj., devel-oped by the Marine Engineering Bureau and specialists of the Technical Center for Production Preparation of Vyborg Shipyard. P05A pontoon is a steel П-shape one divided into 4 ballast tanks with slip deck and 2 sponsons. The Azipod RP afloat mounting let the shipyard to free the slip deck of semi-submersible barge “At-lant” for formation hull of the second IBSV01 vessel.

At the running trials, the second IBSV01 vessel “Andrey Vilkitskiy” has reached the maximal speed of 16.8 kn for bow ahead running and 15.0 kn for stern ahead running. The economic regime speed is of 12.0 kn. The actual bollard pull is of 210 t for bow ahead running.

The manoeuvring characteristics of IBSV01 vessels fully comply with IMO and RS requirements (reso-lution MSC. 137 (76), “Guidelines for determining the maneuvering characteristics of ships” RS, 2-030101-007).

The hull and rudder-propeller complex of IBSV01 vessel is designed for the Icebreaker 8 ice category, while the vessel can be operated at temperatures up to minus 50°C.

The vessel’s stability in all operational load cases meets the requirements of the “Rules” for vessels of an unrestricted navigation area.

Vessel’s trim at all typical loading cases is ensured by acceptable for practice values. Aft draught at all operational loading cases ensures full immersion of the propeller (minimum aft draught is 7.86 m). The fore draught at all typical loading cases provides moderate slamming (minimal fore draught is 7.48 m).

In general, the hull is made of high strength shipbuilding steel of 355 MPa yield strength. Steel of 500 MPa yield strength is used for outer shell in the ice belt region and for longitudinal bottom stiffening mem-bers. The vessel’s hull has 8 main watertight transverse bulkheads that divide the hull into 9 watertight com-partments. The requirements of the “Subdivision” chapter of the RS Rules concerning damage trim and stability of the emergency vessel are fulfilled for side and bottom breaches located anywhere along the vessel’s length between adjacent transverse bulkheads, as well as for ice damages.

Autonomy due to fuel oil and solid or liquid wastes is at least 30 days. Autonomy due to provision and fresh water stores is at least 40 days (taking into consideration the possibility of water replenishing using an evaporative-type water distiller).

The vessel is prepared for operation in winter conditions in order to provide the required working characteristics at low ambient temperatures in the port and adjacent areas of the Gulf of Ob and in accordance with the requirements of the RS ANTI-ICE and Winterization (-50°C) classes.

Vessel’s power plant consists of 4 main diesel-generators and single harbour generator. Additionally. single emergency diesel-generator is foreseen. Capacity of the main diesel-generators is 2 x 9900 kVA plus 2 x 4950 kVA.

Accommodation and service spaces are arranged in the superstructure above the main deck. The wheelhouse is made with all-round visibility. The vessel has cabins for a crew of 21, pilot cabin and the ship-owner’s representative cabin, as well as reserve cabins for 12 supernumerary staff, including terminal staff. All cabins are equipped with individual bathrooms. Accommodation of the rescued people is provided in the mess-room, rest lounge, crew dining room, as well as onto reserve berths in the cabins. There is also a hospital with two beds. The total number of places onboard is 35. Individual and collective life-saving appliances are foreseen.

To improve the habitability parameters on the vessel, a rolling damping system is provided. One U-shaped roll-off tank is places in the middle of the vessel. The steel structures inside the tank are designed to min-imize turbulence. The capacity of the water flow rate can be adjusted by changing the air flow rate between the parts of the tank.

For the prompt delivery of the emergency team to the ship in distress, an auxiliary boat with 6 people capacity is provided. The operation of the boat is possible till waves of force 6. The boat is equipped with a quick release hook for coupling with vessel’s crane. Boat’s lowering / lifting without people is carried out by 26 t deck crane. The auxiliary boat length is about 6.5 m, the carrying capacity is 1000 kg. The boat can be operated in the presence of small floating ice floes. The auxiliary boat can be used for booms deployment also.

Vessel is equipped by 2 enclosed tanker-type self-righting lifeboats of 35 people capacity. One lifeboat also meets the requirements for a rescue boat of 6 people capacity. Lifeboats are suitably prepared for winter use.

There are six 12-places life rafts onboard the vessel, 3 ones at each side. All rafts are equipped by rigid waterproof fiberglass corrugated containers. The rafts are mounted on steel racks. The rafts are equipped with a heating system for Arctic conditions. In addition to collective and individual life-saving appliances, the ship is equipped with special skid containers with sets of life-saving equipment and supplies for survival on ice.

The vessel is equipped with a landing helicopter platform for emergency evacuation of casualties, as well as for the delivery of additional personnel on board the ship (medical team, emergency team, etc.). This platform is located in front of the superstructure and is intended for MI-8 helicopter (maximum weight of 14 t and screw diameter of 25.35 m).

Loading of containers with equipment and supplies onto the ship and fulfilling of other cargo opera-tions is provided by one electro-hydraulic cargo jib crane of 26 t lifting capacity with 27 m outreach. Crane is installed at the centre part of the cargo deck StB. Possibility of lowering and lifting of oil grab skimmer or cargo grab by crane is provided. The cargo crane is capable to operate at full capacity in open sea conditions at wind force not more than 6 (wind speed 11 m/s, wind speed in gusts 25 m/s), at waves of force 5 (3% probability wave height of 3.5 m). At crane operations, the vessel's stability meets the requirements of the RS Rules for crane vessels.

The IBSV01 vessel is equipped by special firefighting systems, namely water system, foam system and powder system; they provide ability for fire extinguishing on emergency vessels and onshore facilities acces-sible for approach from the sea side in accordance with the FF1WS class.

Water is supplied to the emergency objects by 4 fire monitors with flow rate of 2500 m³/h and jet length of 150 m, installed on platform above the wheelhouse. At simultaneous working of all fire monitors at maximal flow rate in the direction corresponding to the minimal vessel's stability, makes thee resulting static list less than 1° (allowable value is 5°).

A separate foam fire extinguishing system is provided for the vessel's helipad. Two fire hydromonitors are placed at the helipad.

For providing special water fire extinguishing system by water, vessel is equipped by 4 pumps of 2900 m³/h capacity each, with drive from the main diesel generators. Water wall system is provided in order to protect the vessel from the thermal effects of a burning object.

Vessel's fire main system is served by two fire pumps of 80 m³/h and one emergency pump of 60 m³/h. Number and arrangement of fire valves and fire hoses are defined in accordance with Rules. Sufficient number of fire valves is arrange on the open deck in order to provide deck washing. Water fire extinguishing systems are served by heater, that ensure water heating up to 40°C for single hose for snow and ice removing from sensitive equipment. Local water fire extinguishing system is provided for main diesel-generators, harbour diesel-generator, fuel oil and lubricated oil separators, diesel oil boilers, incinerator, etc. A stationary high pressure car-bon dioxide fire extinguishing system with CO2 cylinders, valves and exhaust devices is provided for the engine room, emergency diesel-generator room, electrical equipment compartments and paint store. Additional porta-ble bilge water pump is provided on board in accordance with the class notation FF1WS to provide discharge of flooded compartments of emergency vessels.

Diving equipment for 12 m depth is provided for 2 divers. When ice is absent, descent of divers is car-ried out with help of diving ladder from the vessel's deck.

One of the main IBSV01 vessel's functions is the elimination of emergency oil spills. The vessel is sup-plied by oil spill recovery equipment for oil spill response operations. The vessel has ability to work with oil booms together with other vessels; also she is able to launch oil recovery crafts with help of cargo crane. In win-ter special grab oil skimmer may be installed onto cargo crane. Oil pill recovery equipment is stored in 4 TEU on the main deck. The recovered oil is pumped into special vessel's tanks through deck hatches; recovered oil is pumped out through the same hatches with the help of submersible pumps. There is foreseen possibility to load polluted ice floe into heated tanks for thawing. Oil recovery tanks are equipped by steam washing system. Oil recovery equipment also includes reels with hard oil booms of 200 m and 250 m.

A diesel-hydraulic unit is provided to drive the oil spill recovery equipment. One boom-laying boat is lo-cated on the deck of the vessel also. The vessel is equipped with equipment for spraying of dispersants on both vessel's sides.

As it is reported by the press-service of the "Gazpromneft-Yamal", 22 MW IBSV01 icebreakers of Ice-breaker 8 class "Andrey Vilkitskiy" and "Alexaander Sannikov" participated in the oil spill exercise for elimina-tion of simulated oil spill in the Gulf of Ob in July 2019.

According to the legend of the exercises, the vessels had to eliminate the consequences of a conditional emergency situation that occurred in the water area of the Gulf of Ob in the vicinity of the "Arctic Gate" oil terminal of the Novoport field after collision of a tanker with an unidentified object. The crews promptly deployed modern oil spill equipment and also deployed booms and skimmer with help of auxiliary crafts.

Each icebreaker has special oil recovery tanks of 1300 m³ total capacity, that allow storage of recov-ered oil for a long time. This is necessary for work in the Arctic region, where communication with the coast is not always regular during the off-season due to difficult ice conditions. During the trials the sea element also made adjustments to the service plans; so the wave height, wind speed and air temperature were monitored throughout the exercise.

Large-scale maritime exercises near the facilities of the Novopor oil field are held twice a year. The readiness of all services is checked in winter and summer, which makes it possible to work out the coordination of actions in different weather conditions. Summer 2019 is the first season of joint duty for icebreakers, there-fore, until September, a tight schedule of weekly trainings has been formed for the crews, that would allowed the vessels to better get used to the Arctic. Basing on the results of the exercises, "Gazpromneft-Shipping" got a permission to carry out oil spill operations, as well as SAR operations. The exercises were successful, the training goals were achieved, all the tasks were completed [4].

CONCLUSIONS

Running trials, field trials in ice and operation of IBSV01 vessels have shown that the vessels fully meet the Customer's requirements both in terms of navigation and functional qualities, show high manoeuvrability when operating in ice conditions.

As Alexey Ovechkin, General Director of "Gazpromneft-Yamal" noted, "icebreakers ... are fully pre-pared for the hard winters of the Far North, where every day they have to solve complex problems" [4].

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NEW 6300 DWT "NAVIS" TYPE RIVER-SEA DRY-CARGO VESSELS FOR OPERATION FROM AZOV PORTS OF RSD32M PROJECT

Gennadiy EGOROV*, Valery TONYUK**

Abstract. *Creation of concept of river-sea dry-cargo vessel of RSD32M project is described. The detailed analysis of main characteristics and its comparison with characteristics of vessels-analogues are executed. Coefficient of displacement utilization by deadweight is the best on all reviewed draughts. Relative coefficients of RSD32M project on other draughts are better than on other vessels of the same class. While operation in Caspian and Azov seas RSD32M project will have economic advantages in comparison with all other vessels.*

Key words: *design, efficiency, river-sea vessels, shipbuilding, water transport.*

INTRODUCTION

The classical ideas about the cargo parties for marine and river transportation with accounting real way conditions, in fact, fully determine the general particulars of river-sea vessels. RSD32M dry-cargo vessels are a striking example of such accounting of way conditions.

The customer supposed that the vessel should transport 5000 t of cargo, primarily grain, at marine draught of 4.20 m in Azov and Caspian Seas. Same time the vessel should have river loading capacity of 3000 t in order to be not worse than Omskiy type vessels, even at draughts less than 3.2 m.

Totally 8 vessels of these series (see Figure 1) were constructed by Oka Shipyard in 2019 for JSC "State Transport Leasing Company".

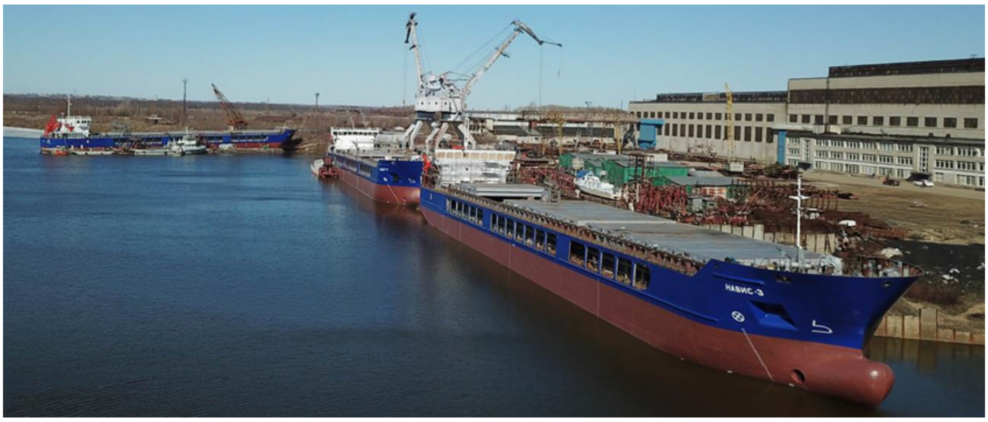

Fig. 1. Three RSD32M vessels during finishing construction works at Oka shipyard

AIM OF THE PAPER

Substantiation and description of the creation of a technologically easy and economically viable con-cept for cargo transportation at the Azov-Black Sea and Caspian regions.

MAIN TEXT

RSD32M vessels refer to the "Azov 5000" type due to MEB internal classification [1], in other words they belong to the Azov-Caspian "coaster" class, vessels of which have loading capacity about 5000 t for char-acter for Azov ports and Caspian ports (Astrakhan, Neka) draughts of 4.2-4.5 m.

RSD32M concept is the development of the RSD18 (UCF type) and RSD32 projects created by Marine

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Engineering Bureau in 2006-2016 and is “brother” of RSD17 (Mirzaga Khalilov type), “Valday” and “Rusich” types.

RSD32M concept is of “southern” type, so its class (R2) was accepted due to sailing region and ice class (Ice1); hatch covers were accepted of removable type equipped by frame crane; medium-speed diesels are used as main ones; classic for this type of vessels full-turn rudder propellers equipped fixed pitch propellers are used.

RSD32M vessels are intended for transportations of general, bulk, timber, grain, large-sized and heavy-lift cargoes, ISO containers, dangerous goods of 1 2, 3, 4, 5, 6.1, 8, 9 classes of IMDG Code and cargoes of category B of IMSBC Code (including coal).

Sailing regions include Azov, Caspian, Black, Mediterranean, Baltic, White and North Seas, including voyages around Europe in winter. Maximal vessels’ dimensions allow them to be operated at internal waterways Russian Federation through Volgo-Don and Volgo-Balt Canals.

The vessel can be operated at low draughts of 3.2-3.4 m in the river. For example, at fresh water draught 3.2 m deadweight is 3220 t and at draught 3.4 m deadweight is 3600 t; that allows insisting that this vessel in the river is some modern analogue of the dry-cargo vessels of “Omskiy” type (1743 and 1743.1 prjs.) and respectively fine change for numerous existing vessels of 1557, 614, 488A, 488AM2/3/4, 2-95, 2-95A/R, 92-13/040, 1743, 1743.1, 1743.3, 1743.7, 05074A and 791 prjs., that are so popular at private shipping com-panies.

The project is designed for a class notation KM ✪ Ice1 R2 AUT1-ICS CONT(deck, cargo holds Nos.1,2,3) DG(bulk, pack) of Russian Maritime Register of Shipping and meets all the requirements of interna-tional conventions acted at the moment of the vessel's keel laying.

Architectural-constructional type of the RSD32M vessels is as follows: steel single-deck motor vessel with 3 cargo holds, with 2 full-turned rudder propellers, with forecastle and poop, with living superstructure and ER located aft, with double bottom and double sides in cargo area, with bulbous fore end and transom aft end, with removable type hatch covers, with bow thruster (see Figure 2).

Forepeak, log and eco sounder trunk, boatswain room, paint room, general store room and 120 kW bow thruster of “propeller in nozzle” type are arranged fore.

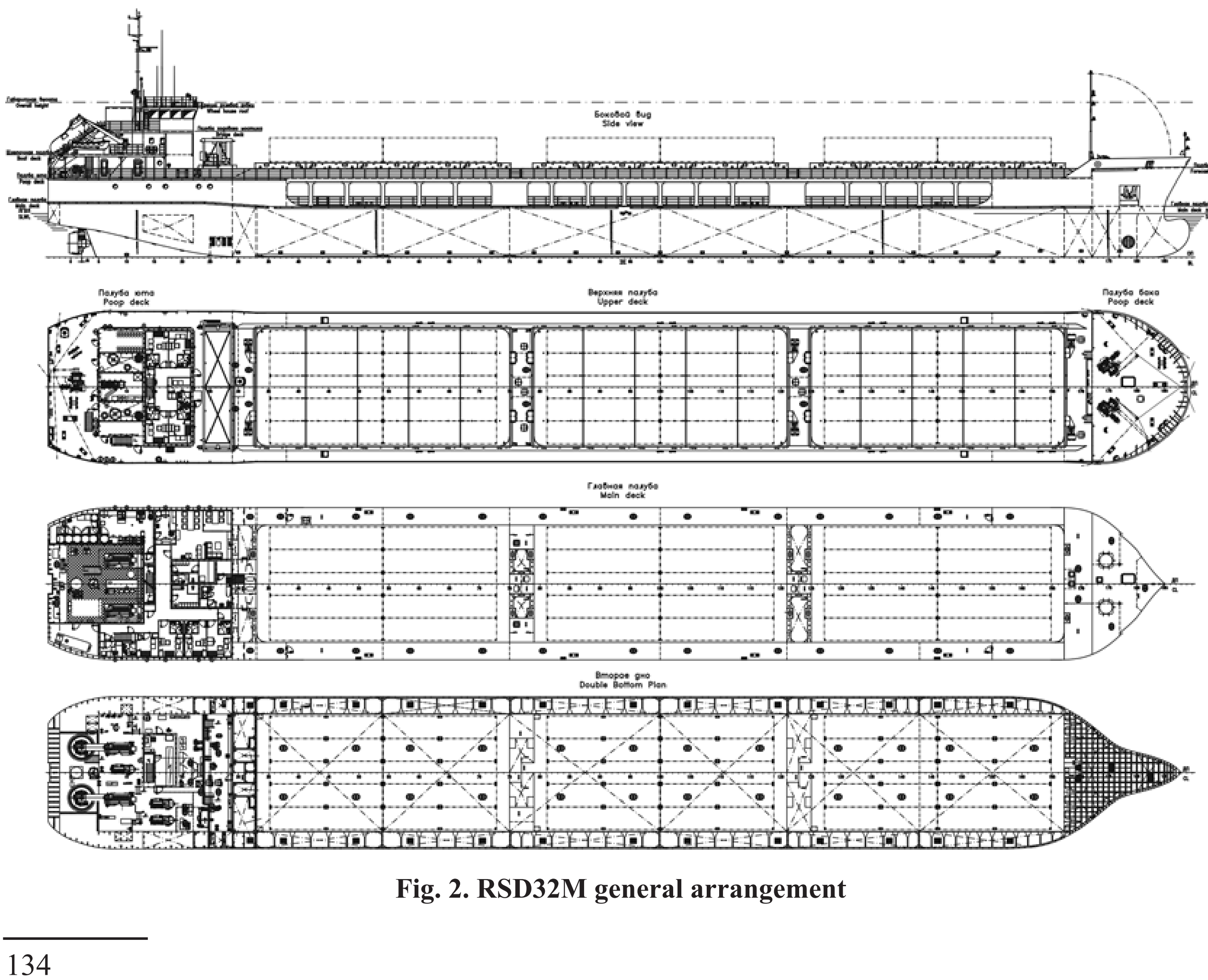

Fig. 2. RSD32M general arrangement

ER, poop and 3-tiers superstructure with working and living compartments for crew of 11 people (14 places) are located aft. Bridge is made with round view with minimal shading areas.

In accordance with recommendations [2] the following was used for hull construction: longitudinal framing system for deck, sides and bottom in the middle in conjunction with increasing of transverse framing and decreasing of longitudinal framing provide more fuller participation of hull plates in the overall bending, better response for local loadings during mooring operations and keeping of suitable external view.

Vessel's midship section is given in the Figure 3.

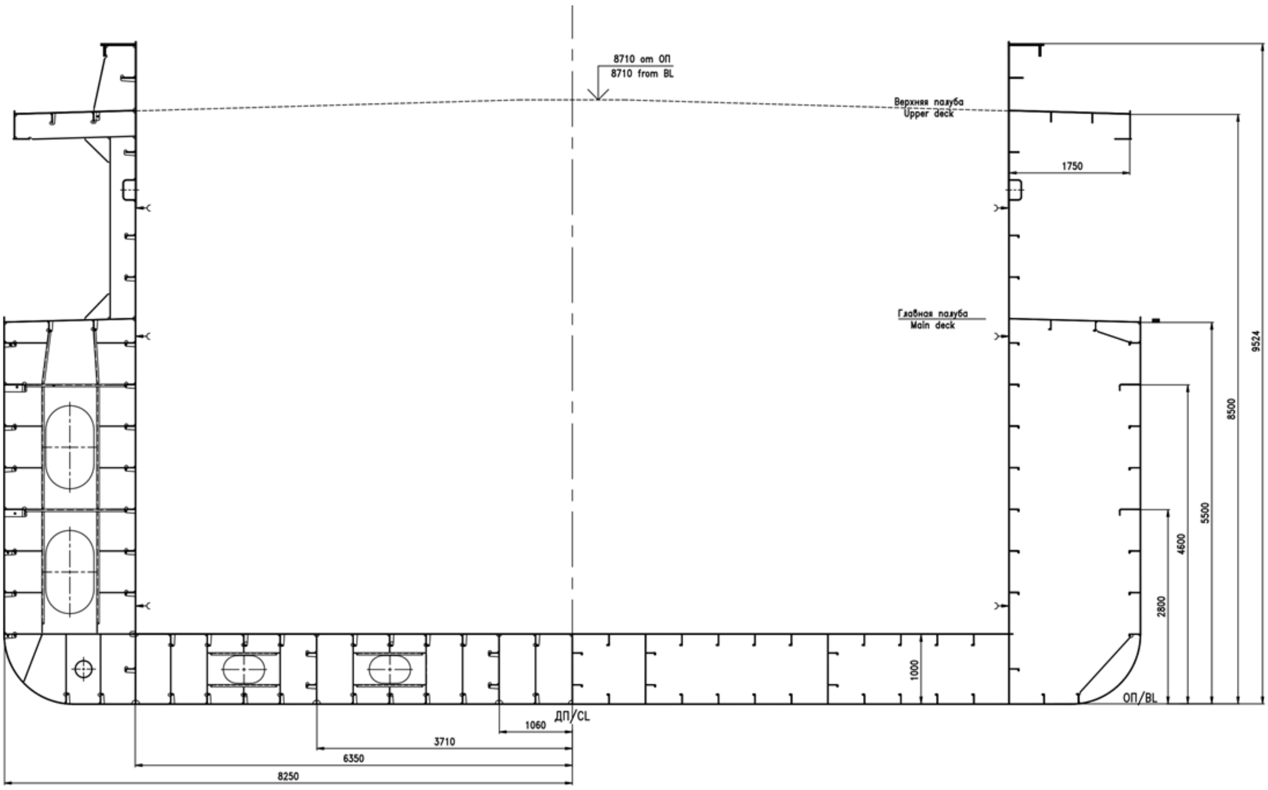

Fig. 3. RSD32M midship section

Cargo holds are box-shaped, smooth-walled, and convenient for cargo operations and placing the goods without stowage. Cargo holds have the equal dimension of 27.30 x 12.68 x 8.54 m. Hold's height ensures of arrangement of 3 tiers of ISO container of 8.5' height.

RSD32M vessel is equipped by removed hatch covers of "Lift away" type that was firstly used at do-mestic practice for 005RSD03 vessels of "Karelia" type and 003RSD04 "Caspian Express" type. Opening and closing of each section is operated with the help of a special frame crane, which is located in the area of the front bulkhead of the living superstructure. One of specifics of this hatch cover type is ability to open hold at any place by removing of corresponding hatch cover section.

Design load for hatch covers is of 3.5 t/m² for hold 1 and 2.6 t/m² for holds 2 and 3; this corresponds to Load Line Convention and allows to place onto them timber cargoes of 2.5 m height or 1 tier of containers of maximal weight.

Dangerous goods of classes 1, 2, 3, 4.1, 4.2, 5, 6.1, 8 and 9 (that can be extinguishing by water) can be transported on deck. Dangerous goods of classes 1.4S, 2.1, 2.2, 2.3 (non-flammable), 3, 4.1, 4.2, 4.3 (except FP < 23ºC), 5.1, 6.1, 8 и 9 can be loaded into holds.

Vessel's theoretical forms are created with help of modern CFD modelling methods on the basis of 3D parametric surface. Vessel's hull has cylinder part of 0.639 *L* length; block coefficient is 0.866 and waterplane coefficient is 0.943 for draught of 4.2 m, and 0.852 and 0.937 for draught of 3.6 m correspondingly.

Trials (in ballast condition) carried out by "Astra-NN" company [3] showed admirable manoeuvrability of the vessel with RP. Tactical diameter of the turning circle was of 1.5 *L* (norm is 5). At active stopping manoeuvre the vessel stopped from full ahead of 11.7 kn by 198 s at track reach 425 m (3.45 *L* while norm is 15).

Vessel's hull is strengthened for ice category Ice1. Ice1 category ensures regular year-round sailing in non-freeing seas, in rare ice brush of non-Arctic seas (episodic independent sailing in 40 cm rare ice brush at speed of 5 kn and sailing behind ice breaker in the canal through 35 cm cohesive plane ice at speed of 3 kn). This category also ensures operation during prolong navigation at rivers that correspond to Ice1 category while outside air temperature is not less that -23ºC. Design air temperature is 35ºC at humidity 65% in summer and -25ºC at humidity 85% in winter; water temperature is from 32ºC to 0ºC correspondingly.

Accepted ice category provides winter operation at Azov and Caspian Seas.

The ship steel of categories D36, A36, D32, D and A was accepted for basic hull constructions. Upper part of contiguous longitudinal hatch coamings and upper deck is made of D36 category steel with a yield limit of 355 MPa. Elements of forecastle and poop decks and living superstructure are made of A category steel.

Vessel's hull has double bottom and double sides, main and upper deck (with hatch opening of 0.77 *B*), contiguous longitudinal hatch coamings of 4 m height (from main deck). Double bottom height is 1.0 m, double sides width is 1.9 m.

Longitudinal hatch coamings are placed in the plane of longitudinal bulkheads of the cargo holds. Coamings have hard shelf (deck stringer of upper deck) at the height 3.0 m above main deck; this shelf transfers into forecastle deck fore and in the poop aft.

Due to usage of high contiguous longitudinal hatch coamings together equipped by hard shelf it be-came possible to provide increase of general strength together with increase marine cargo loading capacity and cargo volumetric capacity.

Transverse bulkheads are plane. Upper and main decks, bottom and tank top, sides and inner sides have longitudinal framing system; peaks and engine room has transverse framing system.

Transverse frame space is 650 mm through the whole vessel's length except 600 mm in the peaks (stern-fr. 29 and fr. 167-bow). Longitudinal frame space is 530, 600 and 650 mm. Transverse web frame space in the middle is 1950 mm.

The double bottom is designed for distributed load with intensity of 10 t/m², and also allows bucket grab usage.

Basing on the results of the calculated determination of the vessel's hull resistance, two 1200 kW medium-speed diesel engines (880 rpm) are include in the main power plant. Engines work to 2 full-turn rudder pro-pellers equipped by fixed pitch propellers in nozzles. Heavy fuel stores are placed in deep-tanks in area of the ER fore bulkhead. Sea sailing autonomy for fuel oil, fresh water and provision is 20 day; corresponding river autonomy is 15 days. Range of sailing is 4000 nm.

Auxiliary power plant includes three 160 kW diesel generators (DG) and single 90 kW emergency diesel generator (EDG). Diesels of these generators use MDO.

Vessel's machinery ensures compliance with all the requirements of the supervisory authorities for ves-sels of this type.

Lowering and rising of fore and aft anchors are provided by anchor-mooring winches. Vessel is supplied by 2 fore bower Hall anchors of 2500 kg each and single aft Hall anchor of 1750 kg. Anchors are placed in hawses with pocket and folding cover.

Life saving appliances include 14-places free falling salvage boat and two 16-places inflatable living rafts. Except free falling regime, the salvage boat can be also controllable lowered by gravitational unit equipped by boat winch. StB living raft on the boat deck is of controllable lowering type. More over, 6-places living raft is arranges in the region of the fore peak. There is 6-places rescue boat placed on the boat deck StB. Lowering and rising of the rescue boat and controllable lowering living raft is carried out by special crane.

The number of the communication equipment is provided in the scope of the requirements of the GMDSS for the marine areas A1 + A2 + A3. The complex of modern ship radio equipment provides disaster communications and navigation safety, as well as general operational communications.

Gyrocompass with repeaters, main magnetic compass, log, echo sounder, GPS receiver, two radar sta-tions, as well as AIS provide the navigator and consumer systems with navigation information.

There is ballast-discharge system served by 2 eclectic centrifugal pumps for ballast taking and discharg-ing. In accordance with international requirements, ballast system is equipped by ballast treatment unit.

In order to integrate the control and monitoring systems, an integrated automated control system (IASU) is provided, meeting the requirements of the RS AUT1-ICS class.

IASU is built on the basis of a computer network that unites the following subsystem elements into a single whole: monitor and control system of the propulsion complex; vessel's diesel engines automation system; power plant automation system; vessel's systems automation system; alarm system.

The structure of the IASU system is based on the principle of distributed configuration. The computer network of the system provides communication between operator stations and collection and control units lo-cated in close proximity to the control object. Redundancy of the network and system functions is provided with the help of a duplicated network and network equipment, which, in the event of failure of one communica-tion channel, ensures the forwarding of signals through the remaining channel.

In order to arrange crew (11 people) there are: 3 single block-cabins, 8 single cabins with toilet and shower and pilot cabin. Single reserve place is foreseen in 3 cabins. Total number of places onboard is 14 (in-cluding 3 reserve ones).

As it's known, special position among river-sea dry-cargo vessels is occupied by vessels of pro-jects 1557, 614, 488A, 488AM2/3/4, 2-95, 2-95A/R, 92-13/040, 1743 , 1743.1, 1743.3, 1743.7, 05074A and 791 with cargo loading capacity about 3000 t draughts 3.40-3.60 m in river. They make up about 60% of the total number of such purpose vessels and are the main transport unit for a significant part of Russian shipping companies.

Special role of these vessels is based on the fact that cargo loading capacity of 3000 t corresponds to historically usual consignment on the Russian market which equal weight of the cargo was transported by one train at 50-52 wagons. This circumstance allows to transport mass cargoes from river harbors of Russia to ports of Europe and Mediterranean Sea without intermediate storage in stores of a port and, accordingly, without additional flow rates on an overload and storage.

The principal specific of operation of such class vessels in today economic conditions is intensive oper-ation in the autumn-winter period from marine ports, where available draughts are bigger than in the river; this allows to increase marine cargo loading capacity to the level corresponding to the minimum freeboard according to the requirements of LLC.

The mean age of "Volgo-Balt" / "Sormovskiy" type vessels is now more than 30-35 years; that fully justifies the urgent need to replenish the fleet by new vessels of the same river cargo loading capacity, namely by RSD32M vessels.

At the same time, RSD32M vessels will replace the well-known series of the "Volgo-Don" / "Volzhskiy" type of about 5000 t cargo loading capacity at draught of about 4.2 m, (typical for Azov ports); age of these "old" vessels exceeds 30-35 years.

For such purpose Customer of the project intended to use RSD32M dry-cargo vessels.

However, in reality, today these vessels are used as Caspian ones with cargo loading capacity of 5000 t that is character for Caspian ports (Astrakhan, Olya, Makhachkala, Neka). This option also includes the possi-bility of transporting goods (with an incomplete cargo loading capacity) through the Volga-Don Shipping Canal.

Therefore, it is of interest to compare the technical and operational characteristics of the RSD32M ves-sel with the corresponding characteristics of the Caspian ones and the closest analogous vessels: "Kishine" type (prj. 1572), "Vasiliy Shukshin" type (prj. 1588), "Rusich" type (prj. 00101), as well as new vessels: "UCF" type (prj. RSD18) and "Mirzaga Khalilov" type (prj. RSD17).

According to the Table 1, the displacement-to-deadweight utilization coefficient for RSD32M vessel is the best for all the considered draughts (both for sea and river), except for the RSD17 vessel at Summer freeboard draught because RSD17 has such draught bigger. Same time, for Summer freeboard draught RSD32M vessel has the energy consumption per transport productivity at the level of other new designs of the Marine Engineering Bureau.

In general, the specific indicators for RSD32M vessel for other draughts are better than for other same class vessels, for example, for "UCF" ones (prj. RSD18) that also are used now as "Caspian" vessels.

Thus, when operating for the Caspian ports (Iranian and Turkmen ports has working draught of 4.5 m), the RSD32M vessels will have economic advantages over all other vessels.

When operating at sea with draught of 4.20 m and in river with draught of 4.00 m and less, the RSD32M vessels exceed in deadweight all vessels of the "Azov 5000" class, and at the same time RSD32M vessels have lighter hull weight and therefore are cheaper to build (in fact, that was set as design "super task").

Comparing of characteristics of RSD32M dry-cargo vessel and analogue ones

Table 1

Characteristic	prj. RSD18	prj. RSD17	prj. RSD32M	prj. 00101	prj. 1572	prj. 1588
Class notation	КМ ✪ Ice 1 R2 AUT3	КМ ✪ Ice2 R1 AUT1	КМ ✪ Ice1 R2 AUT1-ICS BWM(T) CONT(deck, cargo holds Nos.1,2,3) DG (bulk, pack)	КМ ✪ ЛУ2 [1] I A1	КМ ✪ Л3 [1] I	КМ ✪ Л1 [1] I A2
Length overall, m	123.18	121.70	123.17	128.20	123.50	124.40
Length between perpendiculars, m	118.63	116.94	116.73	122.80	117.00	116.80
Breadth overall, m	16.70	16.70	16.75	16.74	15.20	16.42
Breadth, m	16.50	16.50	16.50	16.50	15.00	16.12
Depth, m	5.50	6.20	5.50	6.10	6.50	7.50
Cubic number *LBH*, m³	11314	12601	11347	13091	12202	15320
Cargo holds capacity (up to lowest edge of hatch covers), m³	8595	9300	8804	8090	6070	6800
Number of cargo holds	3	3	3	3	4	4
Container capacity total / in holds, TEU	240 / 180	234 / 174	240 / 180	267 / 180	-	165 / 111
Number and output (kW) of main engines	2 x 956	1 x 2450	2 x 1100	2 x 1140	2 x 810	2 x 1103
Speed operational, kn	11.0	11.5	11.7	11.0	11.7	12.5
Rudder-propeller complex	2 propel-lers + 2 rudders	1 CPP + 1 rudder	2 rudder propellers	2 propel-lers + 2 rudders	2 propel-lers + 2 rudders	2 propel-lers + 2 rudders
Autonomy, days	20	20	20	20	20	30
Crew/places	12 / 14	12 / 14	11 / 14	10 / 12	27 / 31	25
Light ship weight, t	2351	2258	2266	2540	2050	2650
Summer freeboard draught, m	4.67	5.06	4.745	4.34	4.855	5.84
Deadweight, t	6125	6354	6328	5485	4723	6078
Specification SF of cargo, m³/t	1.48	1.59	1.77	1.54	1.37	1.20
Displacement-to-dead-weight utilization coeffi-cient (UC)	0.723	0.738	0.736	0.683	0.697	0.696
Energy consumption per transport productivity, kW/(t•kn)	0.0283	0.0335	0.0297	0.0378	0.0293	0.0290
Marine draught 4.50 m						
Deadweight, t	5753	5346	5849	5810	4145	3836
Specification SF of cargo, m³/t	1.59	1.92	1.59	1.45	1.58	1.98
UC	0.710	0.703	0.721	0.696	0.669	0.591

Table 1 (Continuation)

Marine draught 4.20 m						
Deadweight, t	5175	4813	5264	5190	3673	3353
Specification SF of cargo, m³/t	1.78	2.15	1.77	1.63	1.80	2.30
UC	0.688	0.681	0.699	0.671	0.642	0.559
Marine draught 4.00 m						
Deadweight, t	4619	4297	4700	4630	3237	2897
Specification SF of cargo, m³/t	2.01	2.44	1.94	1.84	2.06	2.72
UC	0.663	0.656	0.675	0.646	0.612	0.522
River draught 3.60 m						
Deadweight, t	3882	3612	3940	3880	2645	2285
Specification SF of cargo, m³/t	2.42	2.98	2.34	2.22	2.58	3.60
UC	0.623	0.615	0.635	0.604	0.563	0.463

CONCLUSIONS

There was created concept of dry-cargo vessel that transports 5000 t of cargo, primarily grain, with ma-rine draught of 4.20 m (for ports of the Azov and Caspian Seas). This concept has guaranteed cargo loading capacity of 3000 t in the river (as an analogue of the "Omskiy" type vessels, including draughts less than 3.20 m).

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DESIGN FEATURES OF THE MOST SUCCESSFUL RSD59 SERIES OF RIVER-SEA DRY-CARGO VESSELS IN XXI CENTURY

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Abstract. *Main characteristics of river-sea dry-cargo vessels of "Volga-Don max" class of RSD59 project are justified. It is shown that twenty seven such RSD59 "extra-full" multi-purpose vessels built in 2018-2020 have no analogues in the world and significantly in technical and economic parametres better than all available river-sea vessels on native market. Advantages of the RSD59 project in comparison with the best of previously constructed dry-cargo vessels of the "Volga-Don Max" class of the RSD49 project are as follows: deadweight at river 3.60 m draught is 5320 t (RSD49 vessel has 4507 t), increase is 813 t; deadweight at maximal sea 4.706 m draught is 8144 tons (RSD49 vessel has 7143 tons at draught 4.70 m), increase is 1000 t; existence of a long 77.35 m hold (RSD49 vessel has 52 m cargo hold), that allows transportation of oversized heavy-lift cargoes; this is relevant for the Caspian region market.*

Key words: *design, dry-cargo vessel, economy, main characteristics, river-sea market.*

INTRODUCTION

It is always interesting to compare the work of different vessel projects in the same conditions. This allows seeing their differences enough objectively. Two vessel types are operating in conditions of the same shipping line and the same way conditions with the same cargo, RSD49 dry-cargo vessel designed on the basis of the hull forms of the Bureau classic "Armada" tanker series and RSD59 "extra-full" dry-cargo vessel built on the basis of RST27 tanker's hull.

Furthermore, RSD59 prj. vessel greatly surpassed her predecessor in characteristics (especially in terms of carrying capacity and manoeuvrability).

Why do the "Volga-Don Max" class? 62% of the total number of new (built in the XXI century) self-propelled cargo vessels of river-sea and inland navigation ones, as well as restricted marine navigation areas ones are vessels of "Volga-Don Max" class. These vessels correspond to the dimensions of the Volga-Don shipping Canal (VDSC) and are intended to replace the well-known Soviet series of "Volgoneft" and "Volga-Don" vessels, i.e. they are universal in dimensions for operation on the European part of inland waterways of Russia.

At the conventional river draught 3.60 m they have the maximum possible carrying capacity of 4.700-5.500 tons, with the maximum carrying capacity of about 7.000-8.000 tons at the maximum draught. Corresponding to the VDSC dimensions makes it possible to use such vessels practically throughout the United deep-water system of inland waterways of the former USSR.

AIM OF THE PAPER

Justification of the parameters and features of the multi-purpose "Volga-Don Max" dry-cargo RSD59 vessel of the new series.

MAIN TEXT

Today, the most noticeable phenomenon in the water transport industry is the mass building of "extra-full" RST27 river-sea tankers and RST54, and also other created on this basis vessels, combined RST54 platform tankers and RST27M and RST12C oil/chemical tankers [1].

In 2010 it was theoretically proved that for the speed of 10 knots, which is typical for river-sea vessels, the influence of the block coefficient (BC) on towing resistance (for the range of 0.88 ... 0.93) is insignificant. The conclusion was fundamentally important and meant that it was possible to increase BC of river-sea vessels up

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to 0.932. This made it possible to "start" the RST27 project of "Volga-Don Max" class with "extra-full" hull forms, with parallel middle body, a bulbous bow and two fixed-pitch propellers in nozzles (full turned rudder propellers in the semi-tunnels) [2].

Preferred building of tankers was no a chance, as the economics of oil transportation by river-sea vessels was significantly better than by dry-cargo vessels approximately until 2016. Indirectly, this is confirmed by the fact that 161 new tankers of "Volgo-Don Max" class were built (by 2.8 times more than dry-cargo ones).

The RSD59 vessel "Pola Makaria" was the first dry-cargo vessel that has got "extra-full" hull forms (see Figure 1).

Fig. 1. "Extra-full" RSD59 vessel after launching

The known volatility of freight in the dry-cargo market prompted shipowners to use all possible ways to increase the profitability of the vessels. A special place is occupied by non-standard oversized cargoes. It can be said that operation of such "non-mass" cargoes, the appearance of which on the market takes place strictly by their own laws, significantly improve economic factors of modern dry-cargo vessels, such as, for example, 003RSD04 "Caspian Express" project with single 59 m hold and RSD49 "Neva-Leader" project with 52 m the second (out of three) hold.

The successor to the RSD49 project was the new dry-cargo RSD59 project, which was designed with "extra-full" hull forms and with two dry cargo holds, one of which has record for the "Volga-Don Max" vessels length of 77 m. (see Figure 2).

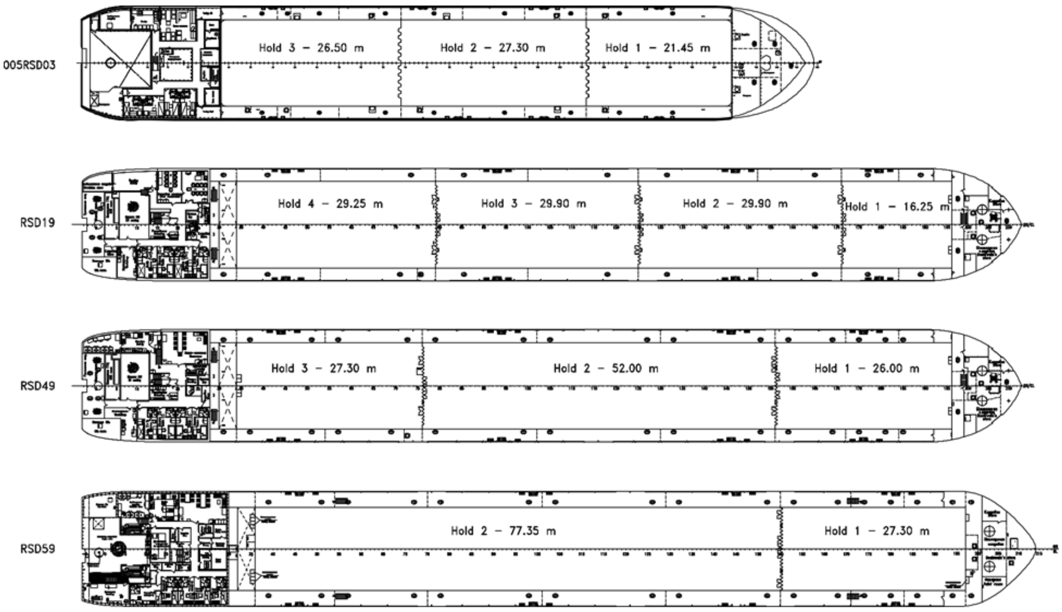

Fig. 2. Change of the holds' lengths at new vessels of "Marine Engineering Bureau" (from 27.3 m to 77.35 m)

A long hold allows transporting general cargoes with minimal area loss and, accordingly, using the holds' capacity better.

RSD59 vessels can be operated for transportation of general, bulk, timber, grain and oversized cargoes, dangerous goods of 1.4S, 2, 3, 4, 5, 6.1, 8, 9 classes of IMDG Code and cargoes of category B of IMSBC Code. Sailing regions are Mediterranean, Caspian, Black, Baltic, White, North Seas, including voyages around Europe and to Irish Sea in winter. The capacity of cargo holds is 11292 m³. Both cargo holds are box-shaped, smooth-walled, and convenient for cargo operations and placing cargoes without stowage. Their dimensions are: 77.35 x 12.24 x 9.0 m and 27.03 x 12.24 x 9.0 m.

Only single removable bulkhead is used for the transportation of dry cargoes, as grain, that has a hazard of dry shift (see Figure 3). The arrangement of this unit was defined by modeling of grain loads in order to minimize the number of bulkheads (as a rule, other vessels of this type require not one, but two removable bulkheads) and to decrease sagging while meeting the stability requirements for grain transportation.

The vessel's stability in all operational loading cases meets the requirements of Russian Maritime Register of Shipping (IACS member) for R2 restricted sailing region.

Sitting of the vessel in all typical loading conditions is ensured with trim acceptable for practical purposes. The draught aft in all service loading conditions ensures complete submergence of rudder propellers (the minimum value of draught aft makes 3.03 m). The draught forward in all typical loading with cargo conditions ensures moderate slamming (the minimum value of draught forward makes 2.94 m).

The new concept took into account the accumulated experience of applying of the other projects of Bureau, such as 005RSD03 vessels of the "Karelia" type and 007RSD07 vessels of "Meroving" type.

The hatch covers of a lift-away type were installed on the vessel. The opening and closing of each section is implemented with the aid of a special travelling gantry crane. The travelling gantry crane is mounted in the region of a fore bulkhead of a living superstructure.

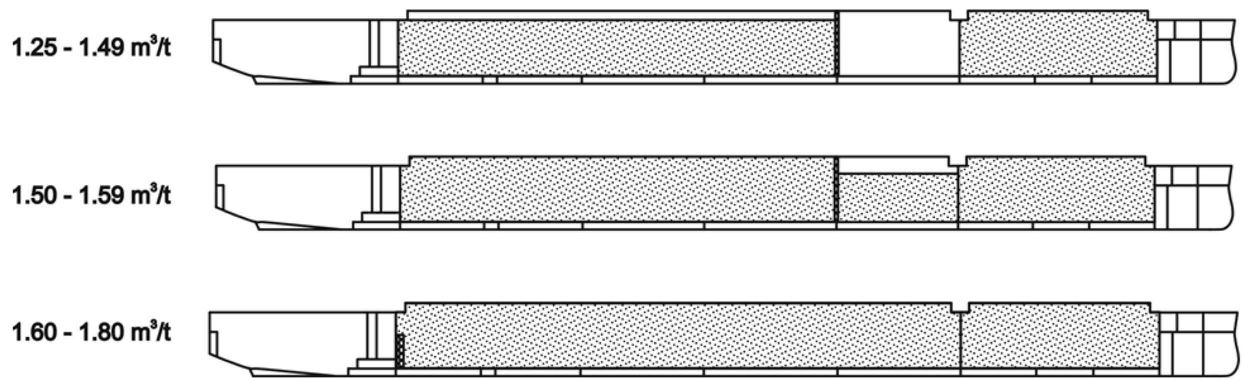

Fig. 3. Scheme of arrangement of non-cohesive cargo on the RSD59 vessel depending on the grain stowage factor (SF)

The usage of this type of hatch covers made it possible to reduce their weight and construction cost, simplify the application and technical operation.

As the operation's experience of new RSD59 vessels showed, such hatch covers allow opening of that part of the cargo space that is needed at the current moment (this is important during operation, for example, with grain, in conditions of variable weather).

In addition, removable hatch covers are quite efficient in the conditions of raid transshipment complexes, which was successfully demonstrated by the lead vessel. The strength of hatch covers is sufficient to accommodate timber cargo or one tier of the maximal weight containers.

Vessel's running and manoeuvrability is provided by two full turned rudder propellers, better manoeuvrability in narrow waters and in the difficult mooring conditions.

Architectural-structural type of RSD59 vessel is steel single-deck, motor ship, with two full turned rudder propellers, with two cargo holds, with forecastle and poop, with living deck-house and engine-room located aft, with parallel middle body, with bulbous bow and transom aft end with semi-tunnels and skeg, with lift-away type hatch covers, with bow thruster. (see Figure 4).

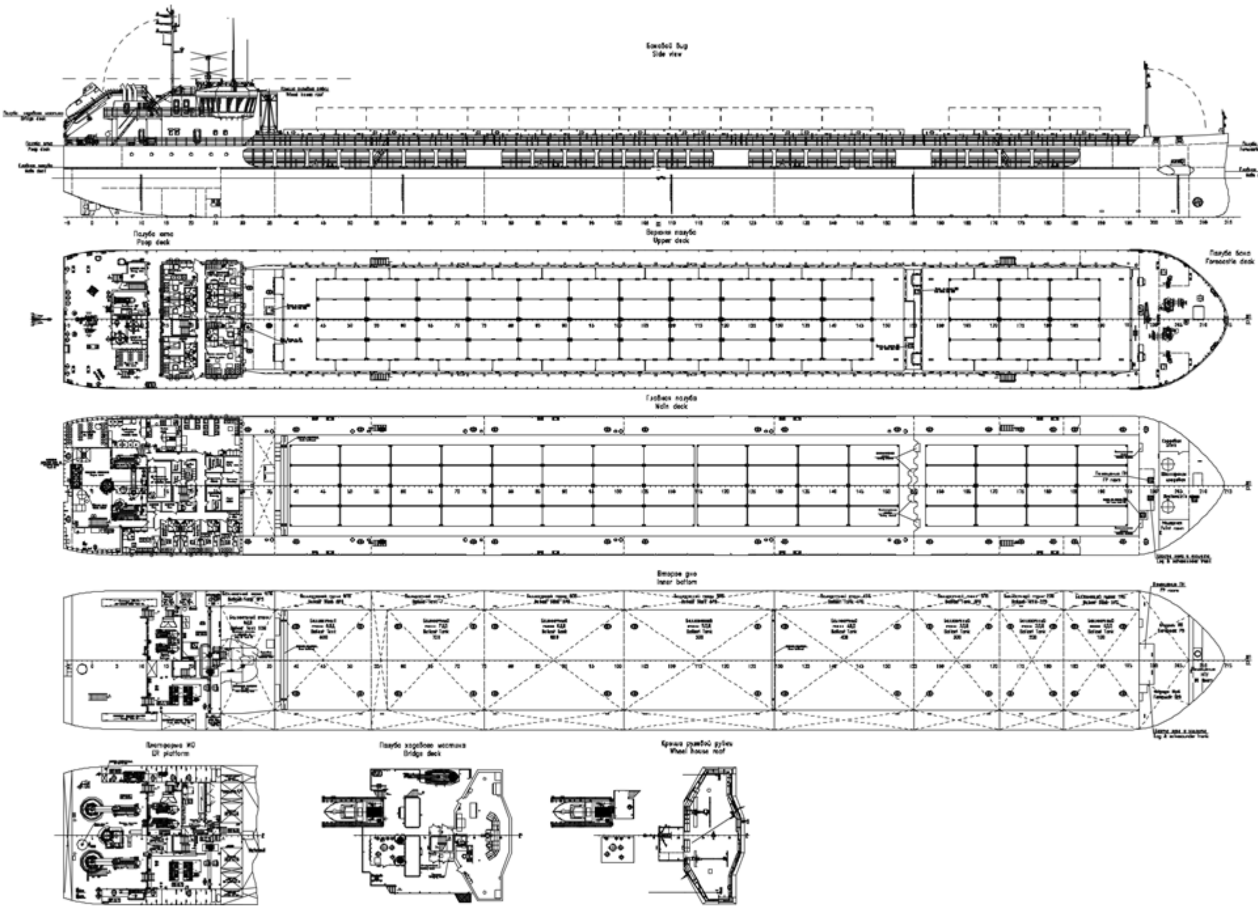

Fig. 4. The general arrangement of multi-purpose RSD59 dry-cargo vessel

The vessel's hull has a parallel middle part of 0.68 *L* length. A special form of the aft end is optimized for the arrangement of the rudder propellers. A set of compartments are arranged in the fore end with high and well-lengthened forecastle, as follows: forepeak, log and echo sounder trunk, skipper room, hydraulics station, paint room, deck store room and 230 kW bow thruster. ER and high and well-lengthened poop are located aft. Double-tier deck-house compromises living rooms for accommodation of crew of 11 (14 places + pilot); it was designed to ensure the restricted air draught of the vessel (13.8 m at 3.00 m draught).

The usage of a longitudinal framing system for decks, sides and bottom in the middle part, combined with an increase of transverse spacing and a simultaneous decrease of the longitudinal spacing, ensured more complete participation of the hull plates in the overall bending and better withstanding of local loads during mooring and keeping an acceptable overview of the construction. Designed vessel hull' life term is of 24 years. The ship steel of category D32 and A was accepted for basic hull constructions.

Vessel's hull was designed for Ice 2 class; it foresees regular round-the-year navigation in in the freezing non-Arctic seas (independent sailing in fine-broken rarefied ice of depth 0.55 m at speed 5 knots; sailing in a channel behind the icebreaker in solid ice of depth 0.50 m at speed 3 knots).

The hull has double bottom of 980 mm height, double sides of 2330 mm breadth, upper deck with opening of 0.724 *B*, continuous longitudinal coamings of cargo hatches of 3.93 m height with a strong horizontal stringer arranged at the height of 2.6 m above the main deck; this stringer passes into the forecastle deck fore and into the poop deck at the ER area. The transverse frame spacing is 650 mm in the middle part of the ship and 600 mm in the ends. The floors and web frames are installed on each third frame spacing in the cargo part of the hull. Longitudinal frame spacing is 510 mm in double bottom and is 625 mm in the double sides. The longitudinal coamings of the cargo hold are installed in the plane of the longitudinal bulkheads of the hold. Increase of the overall strength standard and of the carrying and cargo capacities have been provided due to the usage of high continuous coamings of the cargo hatches. Transverse bulkhead between holds is made corrugated. Main and upper decks, bottom, double bottom, sides and double sides have longitudinal frame system. The end and Engine Room have the transverse framing system.

The tank top is designed for distributed load of 12.0 t/m²; grab operations are foreseen also.

Two medium-speed 1200 kW diesel engines are used as main ones; they use heavy fuel oil up to 380 cSt. viscosity. Heavy fuel stores are placed in deep tanks in the region of the fore ER bulkhead; tanks are separated from the outside water by double bottoms and double sides. The marine autonomy is 20 days. The electric power plant consists of two 332 kW main diesel generators and one 90 kW emergency diesel generator.

Handling of the bow and stern anchors is carried out by anchor-mooring winches. Life- saving appliance consists of 16-people free-fall lifeboat, two 16-people life rafts and one 6-people life raft installed fore. The free-fall lifeboat may be controllably launched also by gravity-type unit with help of hydraulic winch.

The consistence of communications means is provided due to requirements of the Global Maritime Distress Signal System (GMDSS) for the marine areas A1+A2+A3. The complex of modern shipboard radio equipment provides communication during disaster and navigation safety, as well as general-purpose operational communications. Gyrocompass with repeaters, main magnetic compass, lag, echo sounder, GPS receiver, two radar stations and AIS station provide navigation information for the vessel. The ballast-bilge system is foreseen for ballast operations; it is served by two electrical self-priming centrifugal pumps and water-jet ejectors. The simultaneous operation of these pumps makes it possible to pump out all the ballast not longer than 8 hours. The vessel is equipped by a ballast water treatment unit (BWTU). Ballast tanks operations are carried out through the BWTU by two pumps simultaneously. Steering of the vessel, operation of the main propulsion plant, the rudder-propeller and the thruster, radio navigation equipment are carried out at the central integrated control panel in the wheelhouse. Automated system provides steering of the vessel from the wheelhouse without constant watchkeeping in the ER.

Comparison of the technical and operational characteristics of the RSD59 project with the corresponding characteristics of the “Volga-Don Max” class vessels is made in Table 1. The designed vessel is better than RSD49 and 006RSD05 projects made on the basis of the “Armada” type hull forms and much better than dry-cargo vessels of “Volga” and “Rusich” types for energy consumption per transport productivity unit. The advantage of the new RSD59 concept becomes overwhelming taking into consideration above mentioned, and also a significant increase of the absolute deadweight value (and the deadweight-displacement ratio), both for the full marine draught and, more significantly, for the full river draught (800 tons increase in comparison with the “Neva-Leader” type and 1495 tons increase in comparison with the “Volga” type) at approximately same lightweight and weight of equipment.

Main characteristics of river-sea dry-cargo vessels

Table 1

Characteristic	RSD49 “Neva-Leader”	RSD59 “Pola Fiva”	006RSD05 “Heidar Aliyev”	00101 “Rusich”	19610 “Volga”
Vessel’s class notation (Russian Maritime Register of Shipping)	KM ★ Ice2 R2 AUT1-C	KM ★ Ice2 R2 AUT1-ICS CONT (deck. cargo holds Nos.1.2) DG (bulk. pack)	KM ★ LU1 1 II A1	KM ★ LU2 1 I A1	KM ★ L3 1 I A2
Length overall, m	139.95	141.00	139.63	128.20	140.00
Breadth overall, m	16.70	16.98	16.70	16.74	16.56
Depth, m	6.00	6.00	6.00	6.10	6.70
Gross register tonnage, GT	5686	6143	5687	4960	4991
Net register tonnage, NT	3321	3317	3240	2140	1781
Holds capacity, m³	10921	11292	11408	8090	6864
Number of holds	3	2	4	3	4
Container capacity (hold / deck), TEU	289 / 219	248 / 192	274 / 204	267 / 180	144 / 92
ME power, kW	2 x 1200	2 x 1200	2x1120	2x1140	2x970
Speed at sea draught, kn	11.5	10.5	11.8 (85%)	11.0 (90%)	10.0 (100%)
Rudder and propeller complex	2 screws + 2 rudders	2 rudder propellers	2 rudder propellers	2 screws + 2 rudders	2 screws + 1 rudder
Endurance, days	20	20	15	20	20
Crew / number of places	10 / 12	11 / 15	12 / 14	10 / 12	18
Draught (in sea / in river), m	4.70 / 3.60	4.706 / 3.60	4.60 / 3.60	4.20 / 3.60	4.677 / 3.60
Specified SF of cargo, m³/t	1.64	1.40	1.71	1.63	1.18
Block coefficient	0.90	0.932	0.88	0.85	0.85
Deadweight-displacement ratio	0.721	0.753	0.727	0.687	0.696
Energy consumption per transport productivity unit, *Ne* / (DWT x *V*), kW / *t* x kn	0.0292	0.0280	0.0232	0.0359	0.0313
Deadweight at sea draught, t	7147	8144	6970	5190	6207
Deadweight at river draught, t	4507	5320	4580	3855	3825

The lead vessel of RSD59 series showed speed of 11.7 kn during trials at running line with main engines power of 2100 kW (87.5% of full output) and fore/aft draughts 3.2/3.3 m. In accordance with trials full loaded RSD59 vessel with 0.932 BC has towing power only on 4% bigger than RSD49 vessel with 0.90 BC.

Results of turning motion of RSD59 vessel with 2 rudder propellers in comparison with RSD49 vessel with 2 screws are shown in Figure 5. RSD59 (1) means 35° rotation of both rudder propellers; RSD59 (2) means 45° and 90° rotation of rudder propellers.

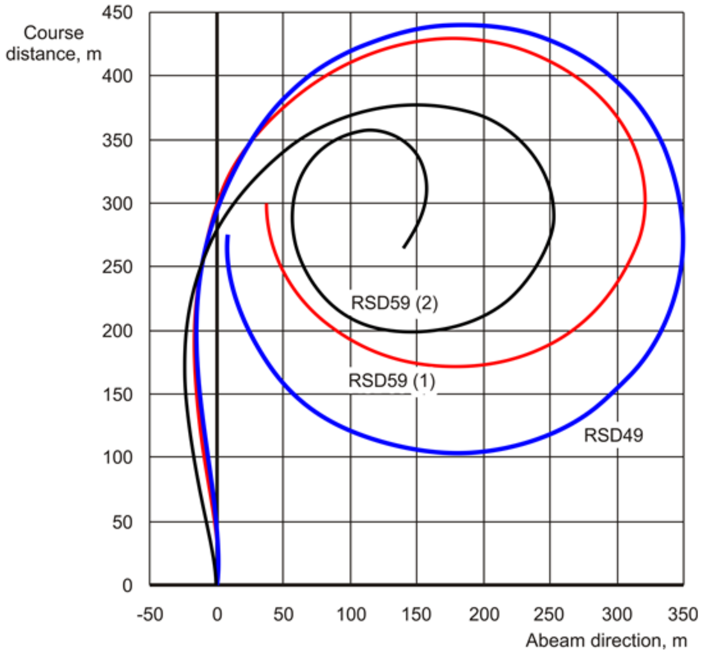

Fig. 5. Comparison of turning motions of river-sea vessels with different propulsion complexes

CONCLUSIONS

Twenty seven "extra-full" RSD59 multi-purpose "Volga-Don Max" class dry-cargo vessels built in 2018-2020 have no analogues in the world and are significantly better than all the vessels available on the domestic market for their technical and economic parameters.

Advantages of the RSD59 project in comparison with the best of previously constructed dry-cargo vessels of the "Volga-Don Max" class of the RSD49 project are as follows:

- deadweight at river 3.60 m draught is 5320 t (RSD49 vessel has 4507 t), increase is 813 t;
- deadweight at maximal marine 4.706 m draught is 8144 tons (RSD49 vessel has 7143 tons at draught 4.70 m), increased is 1000 t;
- the existence of a long 77.35 m hold (RSD49 vessel has 52 m cargo hold), that allows transportation of oversized heavy-lift cargoes; this is relevant for the Caspian region market;
- the hold's height is bigger for 600 mm (9000 mm) than for RSD49 vessel; that allows to transport 9'6'' containers ("high cube containers"), 3 ones in single stack;
- running and manoeuvrability of the vessel are provided by two rudder propellers (better manoeuvrability in the narrow waters, more cargo space due to the reduction of ER size).

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MODERN TECHNICAL CONDITION OF RIVER-SEA DRY-CARGO VESSELS FLEET

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Abstract. *Special studies were carried out with 1735 dry-cargo vessels built from 1956 to 2000. The analysis has shown, as of April 2020, from all vessels 831 units are operating with an average age of 39.8 years. 766 vessels (44%) were written off, of which 95 (12%) were lost in accidents with an average age of 31.2 years and 671 were scrapped with an average age of delivery on metal 36.5 years.*
Today, there are about 1052 dry-cargo vessels in operation, of which 79% are "old", remaining 21% were built in XXI century. Since 2000, 221 river, river-sea and restricted area dry-cargo vessels have been built (or bought on the market). It is shown that the main factor determining the parameters of cargo vessels in water transport is the cargo base.

Key words: *analysis, forecast, navigation area, river and river-sea dry-cargo vessel, technical condition.*

INTRODUCTION

Significant part of the world trading fleet consists of vessels with deadweight of less than 5000 tons. They usually carry out voyages between sea, estuary and river ports [1]. A significant part of them has restrictions on navigation areas, seasons, distances from the place of refuge, wave and wind conditions, i.e. refers to ships of a restricted navigation area. This fleet consists of two large groups: self-propelled river, river-sea and sea restricted cargo vessels of the most famous "Soviet" series, which have been built from 1956 to 2000, and new vessels of new projects, which were built in the XXI century.

AIM OF THE PAPER

To analyze the existing fleet of restricted sea navigation, river-sea going and inland navigation.

MAIN TEXT

The authors carried out special studies (started back in 2017 [2]) of 1735 dry-cargo vessels which have been built from 1956 to 2000. The analysis showed that 831 vessels are operating of these ones with an average age of 39.8 years by of April 2020. 766 vessels (44%) were written off, 95 (12%) of which were lost in accidents with an average age of 31.2 years and 671 were scrapped with an average age of 36.5 years. There are 138 vessels berth-anchored with an average age of 44.2 years. For example, 66 vessels, 54.4%, of "Sormovsky" type 1557 project (built in 1967-1986) were written off (17% - 11 vessels were lost in accidents, 55 vessels were scrapped) from total amount of 121 vessels. There are 47 vessels in operation with an average age of 41.2 years. The average write-off age is of 39.4 years. The main vessel write-off schedule has a pronounced exponential feature after 2008, recycling continues, for example, in 2017-2019, 21 vessels were written off. There are 8 vessels berth-anchored with an average age of 45.1 years - they are likely to be scrapped as well.

Undoubtedly, vessels of the Volga-Don Max class are in demand even more than vessels of the "Omskiy" type. Such example is the dry-cargo vessels of the Volzhsky type of project 05074 (built in 1981-1999). 2 vessels were lost in accidents, and 7 ones were converted into tankers of total 63 dry-cargo vessels of this type. There are now 50 vessels in operation with an average age of 30.5 years, and 4 ones are berth-anchored with an average age of 29.8 years (mainly due to bankruptcy of operators). There are 108 dry-cargo vessels of the Volga-Don type of project 1565 (built in 1968-1990). 20% of them or 22 vessels were decommissioned (5 ones were lost in accidents, and 17 were scrapped with an average age of 37.6 years). 70 vessels with an average age of 42.4 years are currently in operation, 16 ones with an average age of 44.5 years are berth-anchored.

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Forecast of decommission of river-sea dry-cargo vessels of "classic" projects up to April 2020

Table 1

Project	Decommission forecast, year	Number of vessels 2019, un.	Number of vessels 2020, un.	Number of vessels forecast by 2025, un.	Number of vessels forecast by 2030, un.
"Volgo-Don max"					
507A, B	2031	53	53	34	8
1565	2034	81	70	61	31
05074*	2036	46	50	40	27
19610, 19611	2036	43	43	35	27
Total for the section		*223*	*216*	*170*	*93*
"DWT3000"					
92-040	2033	32	34	25	5
791	2022	3	3	0	0
2-95	2030	86	79	55	4
1557	2029	50	47	18	0
488	2033	33	34	25	17
1743, 1743.1	2032	116	115	86	40
16290, 16291	2034	10	10	7	4
292, 0225	2031	30	30	25	7
17310	2038	8	8	8	7
Total for the section		*368*	*360*	*249*	*84*
"First" series					
21-88, 21-89	2031	53	47	29	4
576	2028	51	50	20	0
Phin1000	2030	14	14	10	4
Total for the section		*118*	*111*	*59*	*8*
Restricted sea navigation					
1588	2022	3	3	0	0
16510	2035	3	3	3	2
1572	2023	3	3	0	0
Total for the section		*9*	*9*	*3*	*2*
"DWT 2000"					
613, 620	2027	8	8	2	0
781, 781E	2023	5	4	0	0
285, 289, 787	2025	8	3	1	0
Total for the section		*21*	*15*	*3*	*0*
ST and STK					
037	2022	1	1	0	0
326, 326.1	2029	38	35	16	0
191, R-168, 19620, 19621	2030	42	41	19	3
Total for the section		*81*	*77*	*35*	*3*
Platform vessels and bunker vessels without hatch covers					
D-080, D-080MK	2025	7	7	3	0
R-32, R-32A, R-32K	2035	36	36	30	18
Total for the section		*43*	*43*	*33*	*18*
Total for the dry cargo vessels		**863**	**831**	**552**	**208**
* - in the statistics of 2019, 3 tankers of project 05074T converted into dry cargo vessels under the RSD22 project are taken into account.					

There are 119 dry-cargo vessels of the Volgo-Don type of project 507, 507A, 507B (built in 1960-1980). 45% of them or 53 vessels were written off, (4 ones were lost in accidents, and 49 ones were scrapped with an average age of 37 years). 53 vessels with an average age of 45.6 years are currently in operation, 13 ones with an average age of 46 years are berth-anchored. Vessels are most commonly in the river operation now.

It is possible to forecast write-off of river-sea vessels for the whole fleet, but this will be a very rough estimate, since the patterns of decommission for vessels of various projects differ significantly from each other.

The decommission dates were obtained for each project based on the data obtained above and based on the selected write-off model, (excluding the impact of the BWM 2004 convention), which are indicated in Table 1.

The forecast of the Marine Engineering Bureau, based on the received distributions of write-off, is that 552 vessels from the "Soviet" series will be in operation in 2025, and 208 vessels - in 2030.

30 dry cargo vessels were decommissioned in 2017 only, 23 ones - in 2018, 26 ones - in 2019, and 5 ones (incomplete data) - in 2020. Vessels of "DWT3000" type continue to prevail among the decommissioned ones: 21 vessels of the Sormovsky type project 1557, 18 vessels of the Volgo-Balt type projects 2-95, 2-95A / R and 791, 3 vessels of the Amur type project 92-040, and 9 vessels of ST and STK type. Also, over the past three years, 12 vessels of the Volgo-Don type projects 507 and 1565 were decommissioned (and another 17 units were scraped). Three vessels of the Omskiy type project 1743, according to earlier estimates, are related to the objects that will be repaired "to the last ", which is a sign of physical aging of the hull and mechanisms, since the type of such vessels itself is in demand on the market.

Today, there are about 1052 dry-cargo vessels in operation, 79% of which are the "old" ones, and the remaining 21% of them were built in the 21st century. Moreover, the operating cargo fleet is not only "Soviet" series of vessels. 221 dry-cargo vessels of river-sea going, inland and sea restricted navigation have been built or bought on the market since 2000 (10 new dry-cargo vessels were received per year in average - see Table 2). Interestingly, that 15 vessels were purchased and not specially ordered for Russian way conditions. Moreover, there are three vessels of Chinese construction, five of the Dutch, four of the Bulgarian ones, two of the German ones, and one of the Polish ones. The data is given without taking into account the DCV36 concept coasters (10 vessels) specially built in China for the NWSC and a number of similar projects.

113 dry cargo vessels (51% of total number) have been built in Russia since 2000, 32 ones in China, 42 ones in Ukraine and Turkey (by 21 each), 14 ones in Romania and 8 ones in Vietnam (see Figure 1). The number of newly built dry cargo vessels incoming from the industry has exceeded the corresponding building of tankers since 2017. Now 59 dry cargo vessels are under construction at various stages: 48 ones or 81% of the total order in Russia, 8 ones in China and Ukraine (by 4 each), and 3 ones in Turkey.

The most demanded vessels are the "Volgo-Don Max" class now [3]. These vessels satisfy the dimensions of the Volga-Don Canal (VDSC) and are intended to replace the well-known Soviet series "Volgo-Don", i.e. these vessels' dimensions are universal for the operation at the European part of the inland Russian waterways with deadweight in the river from 4600 to 5400 tons, at sea - up to 8000 tons.

71 vessels (32%) have been already built since 2000, and 55 new vessels or 93% are among the ordered ones.

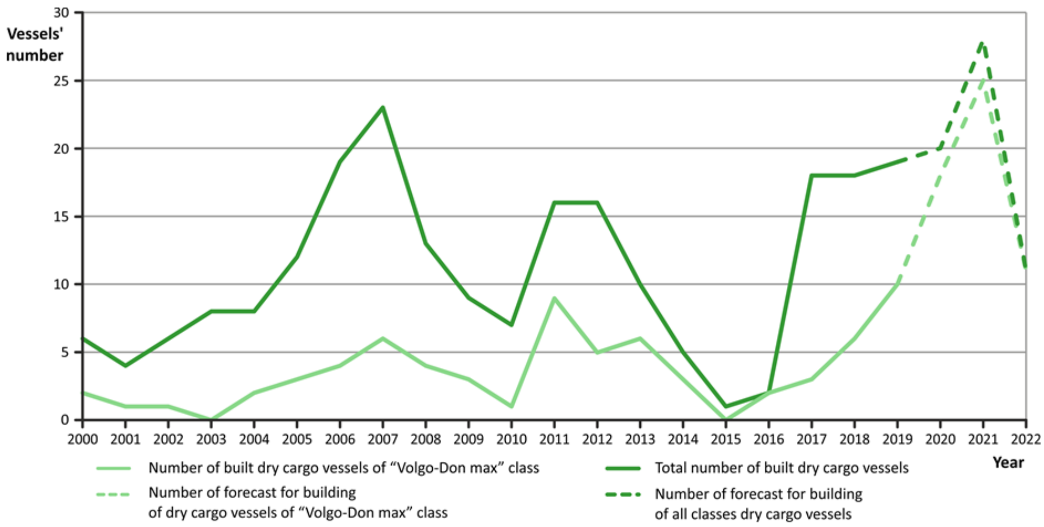

Fig. 1. Construction schedule for new dry cargo vessels

The Royal Institution of Naval Architects RINA included the Volgo-Don Max vessel of the "Pola Makariya" type of RSD59 project, the first dry-cargo vessel with "super-full" hull shape, among the best vessels of the year in the world in 2018 [4]. As by October 2020, 27 such vessels have been already in operation and 60 vessels of this project have been ordered in total. A version of the RSD59 project using natural gas-engine fuel has been worked out (see Figure 2).

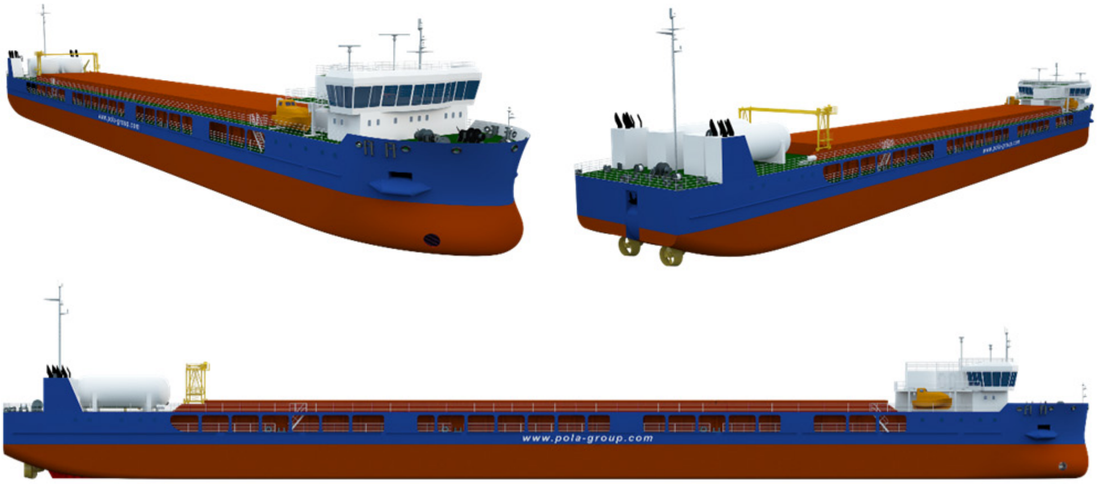

Fig. 2. General view of a dry-cargo vessel of RSD59 project running on gas-engine fuel

Summary statistics for new dry cargo vessels for the period 2000-2019 with a forecast up to 2022. 221 built vessels and 59 more vessels under construction

Table 2

Project	Number of built vessels																				Forecast			Built + under construction
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	
Dry cargo vessels of "Volgo-Don max" class	2	1	1		2	3	4	6	4	3	1	9	5	6	3		2	3	6	10	18	26	11	71 + 55 Russia 54 + 47, Ukraine 11 + 4 China 4 + 3, Turkey 2 + 1
Dry cargo vessels of other classes	4	3	5	8	6	9	15	17	9	6	6	7	11	4	2	1		15	12	9	2	2		150 + 4 Russia 59 + 1, China 28 + 1, Turkey 19 + 2, Romania 14, Ukraine 10, Vietnam 8, Netherlands 5, Bulgaria 4, Germany 2, Poland 1
Total number of dry cargo vessels	6	4	6	8	8	12	19	23	13	9	7	16	16	10	5	1	2	18	18	19	20	28	11	221 + 59 Russia 113 + 48, China 32 + 4, Ukraine 21 + 4, Turkey 21 + 3, Romania 14, Vietnam 8, Netherlands 5, Bulgaria 4, Germany 2, Poland 1

Source: Marine Engineering Bureau

However, it should be clear that we are talking about the philosophy of the "super-full" vessel, and not about the details, since it is hardly worthwhile for everyone to build only two-hold vessels with a long 80-meter hold with Russian Maritime Register of Shipping class notation, which is necessary for operation around Europe. Probably, the grain cargo base requires a vessel in the same "super-full" hull shape and with the preservation of the most complex parts of the vessel (stern, engine room, superstructure, fore end), but with lighter hulls and lower depth in the middle part. This will add about 200 tons of cargo on draft from 3.60 to 4.00 m (development of the RSD59 project RSD62 concept), with the usual number of holds – 3-4, as is done, for example, at RSD79 project, possibly with a different type of hatch covers (folding, piggy back).

In addition, there is a significant interest of medium and small ship-owners to the RSD34 project vessels replacing the vessels of "Omskiy" projects, but the next step to "launch" such series requires operational leasing. The issue of building vessels, and especially pushed tug-barge combinations with a carrying capacity of 2000-3000 tons, is becoming more and more urgent, but it is not yet clear how to finance such new orders, because their profitability is lower than "Volgo-Don Max" vessels ones, but at the same time such vessels and combinations transport a significant part of cargo on the river.

Finally, the Volga Shipping Company has been successfully operating ten new dry-cargo vessels of the RSD44 project of the "Geroi Stalingrada" type for almost ten years, including operation at the RTC of the roadstead of the Caucasus seaport ("M-PR" class). The RSD44 project vessels' deadweight with a draft of 3.60 m in the river is about 100 tons higher than that of the RSD59 one, and building cost is less (they are lighter in weight and simpler in terms of class requirements).

The air draft of the RSD44 project vessel in ballast is only 5.4 m (and even less in cargo condition), which allows it to pass under bridges across the Neva River, under the Rostov railway bridge without raising them unlike all the others projects. As a result, the vessel will save time waiting for the queue to bridges' raising, that is up to 20 days per navigation.

A completely different situation is in Siberia, and the North of the European part. Moreover, it is necessary to consider the issue of amount's increasing the fleet for the northern rivers on the basis of the available and prospective cargo flows of a particular region, its national economic needs. Accordingly, the projects of the new generation vessels for the Far East and Siberia will differ from the concepts of the European part.

It has been practically established that it is possible to reduce the vessel's lightweight due to lighter materials only [5].

CONCLUSIONS

Since 2017, the number of new dry-cargo vessels delivered from the shipyards has exceeded the corresponding shipments of tankers. Now another 59 dry-cargo vessels are under construction at various stages, and 48 of them or 81% have been ordered in Russia.

The main factor that determines the parameters of water transport cargo vessels is undoubtedly the cargo base. It is the cargo flows that determine the number and type of vessels required.

The pace of construction of new vessels should be coordinated with the actual cargo base and the actual decommissioning of old competitioner vessels.

The dry-cargo vessels "Volga-Don max" class were and remain the most popular vessels that meet the dimensions of the VDSC and are intended to replace the well-known "Volgo-Don" Soviet series, i.e. vessels of universal dimensions for operation on the European part of the inland waterways of Russia.

An increase in carrying capacity for case of limited vessels' dimensions and river depths is possible only by increasing the overall fullness and reducing the lightweight of the vessel.

The "super-full" hull shape, used by the Marine Engineering Bureau currently at such projects as RSD59, RSD62, RSD79, are the quite final answer to the first question. All attempts to improve the MEB solutions in other design bureaus' projects have only led to the opposite result like growth of metal consumption and a corresponding reduction in carrying capacity.

Thus, it has been practically established that it is possible to reduce the light weight of a vessel only due to lighter materials.

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INVESTIGATION OF HULL CONTOURS OF NEW GENERATION RIVER-SEA CRUISE PASSENGER SHIPS

Alexander EGOROV

Abstract. *Research of operational experience, including risk analysis and reliability of Ukrainian and Russian river and river-sea cruise passenger ships is carried out. The analysis of failures with PS hulls occurred since 1983 is executed. Technical recommendations from the position of navigation and ecological safety for design of PS are given.*

New PS are necessary for the following reasons: limited possibilities of modernisation of available ships because of outdated design; unsatisfactory indicators of comfort of passenger cabins and public spaces on ship; impossibility of river-sea cruises. The forthcoming write-off of PS fleet will cause essential damage to internal river passenger traffic; conception of river cruise can disappear.

For avoiding of such scenario it is recommended on medium-term perspective to build new fleet: PS projects of "Dnipro / Volga-Don max" class of PV300, PV300VD, "Volga-Balt max" class of PV500VB, "BBK max" class of PV09, PV11 as the most fully corresponding to market tendencies.

Key words: *concepts, cruise market, passenger ships, prognosis, river and river-sea cruises.*

INTRODUCTION

The new generation of river and river-sea cruise passenger ships (PS) differs significantly from the classic river and modernized to river-sea class cruise passenger ships both in their technical equipment and conceptually - other approaches of determination of main dimensions, contours, formation of passenger and public spaces [1, 2].

Application of principle of maximal usage of dimensions of inland waterways for which the vessel is designed, as well as implementation of new propulsion complexes (rudder propellers - RP and azimuthal propellers, propeller with rotary symmetric two-way rudder ("gate rudder" system), wheeled propulsion and steering complexes), by analogy with cargo ships, led to the need of creation of new effective hull contours. At the same time, the contours themselves are created and optimized in software packages that simply did not exist at the time of design of existing PS.

Hull contours and running characteristics of PS directly affect the economy and efficiency of the ship in operation, therefore, it is extremely important to obtain the possibility of qualitative estimation of running characteristics of new generation PS at design stage.

AIM OF THE PAPER

Estimation of running characteristics of new generation PS developed by Marine Engineering Bureau.

MAIN TEXT

New generation line-up of PS developed by the Bureau includes all main classes: "PostDnipro max" / "Volga-Balt max" (dimensions are determined by the conditions of the Volga-Baltic route or the Dnieper river, passenger capacity is about 500 people, project PV500); "Dnipro max" / "Volga-Don max" (dimensions are determined by the travel conditions of the Volga-Don shipping canal or the Dnieper river, taking into account the optimization of the navigation area, passenger capacity is about 250-350 people, projects PV300, PV300VD, PV250); Danube Max (dimensions are determined by the way conditions of the Danube River and

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the Danube-Main-Rhine inter-basin connection, passenger capacity about 200 people, project PV200D); “BBK Max” (dimensions are determined by the way conditions of the White Sea-Baltic Canal, passenger capacity is about 150-200 people, projects PV09, PV11, PV150, PV200BB).

As noted in [2], for our operating conditions, the most suitable is the traditional mono-hull type of passenger ship. Let’s stop on some main projects in more detail: - PV300VD PS of “Dnipro max” / “Volga-Don max” class; - PV250 PS of “Dnipro max” / “Volga-Don max” class (passenger tug-barge combination); - PV150 PS of “BBK max” class (classic contours and propulsion); - PV09 PS of “BBK max” class (modern contours and rudder-propellers).

PV300VD PS is steel self-propelled three-screw (in the original version, during building phase it was replaced by 3 RP) vessel with inclined stem and transom stern end, with excess freeboard, with extended forecastle superstructure, poop superstructure, with middle location of four-tier superstructure, with fore location of wheelhouse, with engine room in aft part.

PV250 PS (passenger tug-barge combination) is steel integrated vessel with excess freeboard, with forecastle superstructure on main section (passenger barge), poop superstructure on power section (tug), with middle location of three-tier superstructure on main section, with fore location of lifting (for visibility) steering deckhouse on power section, with engine room in aft part of power section with 2 fixed pitch RP in nozzles. The hull of passenger section has bow end with inclined stem and transom stern end with simplified contours. The hull of power section has simplified bow contours, designed for joint flow with passenger barge, and transom aft end with shallow half-tunnels and skeg.

PV150 PS is steel self-propelled three-screw vessel with inclined stem and transom stern end, with excess freeboard, with forecastle and poop superstructure, with middle allocation of three-tier superstructure, with fore located wheelhouse, with engine room in aft part.

PV09 PS is steel self-propelled vessel with excess freeboard, with vertical stem and transom stern end, with middle allocation of two-tier superstructure, with fore located wheelhouse, with engine room in aft part, with diesel-electric power plant, with two full-rotated fixed pitch RP and bow thruster.

Hull contours of new generation PS were created in Rhinoceros and CAESES (Friendship Systems) software packages and were optimized using CFD methods in FlowVision program. Modeling of towing tests of studied PS in FlowVision is carried out by solving Reynolds equations by finite-volume method in computational domain. 3D model of the ship's hull is placed inside the domain. Calculations were carried out on physical scale with intention of avoiding the influence of scale effects and recalculation procedures from model to real object, taking into account operating conditions of real ships.

Lines drawings of new generation PS are shown in Table 1. The geometric characteristics of underwater part of hulls of new generation PS are presented in Table 2. For towing resistance data of new PS see Figure 1. Visualization of resistance calculations for speed of 14 knots (PV300, PV250, PV150) and 12,5 knots (PV09) is shown on Figure 2.

Selection of optimal characteristics of propellers and calculation of running characteristics of ships with classical propulsion complex were carried out using the results of systematic model tests of M 4-65 series, with rudder propellers were carried out using hydrodynamic characteristics of serial Ka 4-70 propellers in nozzles of 19A type.

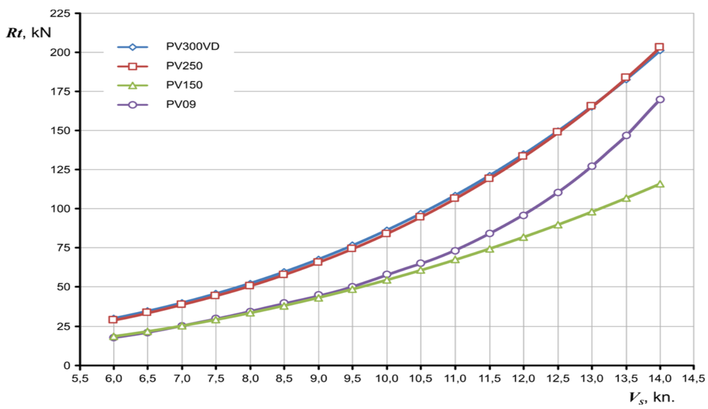
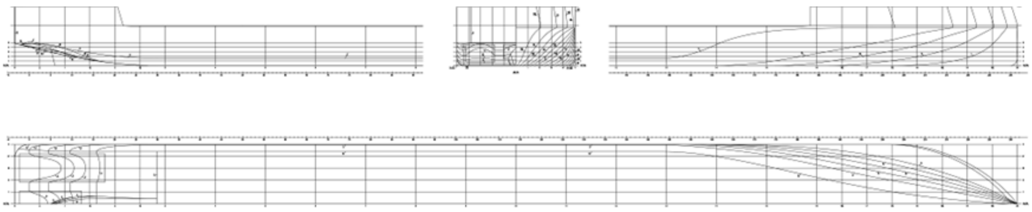
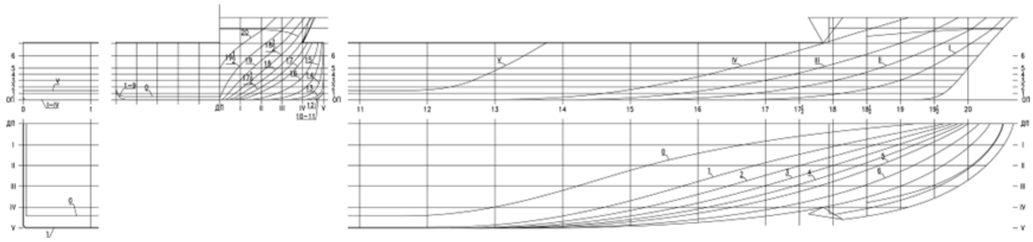
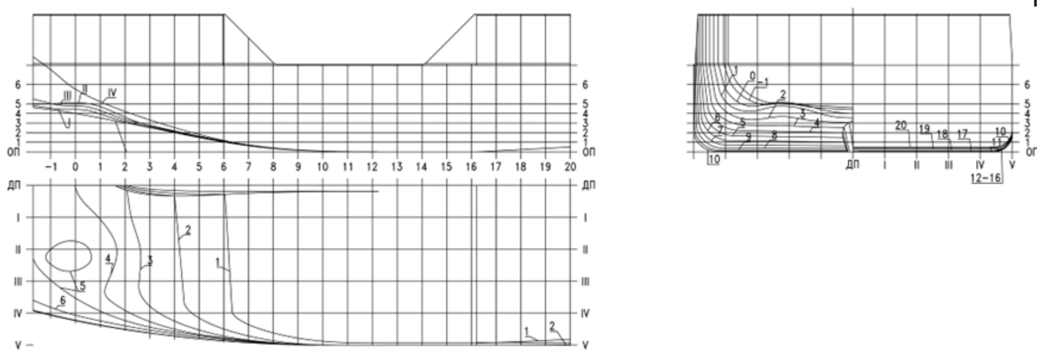
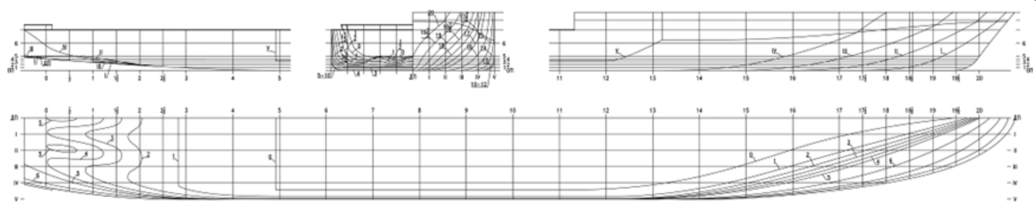
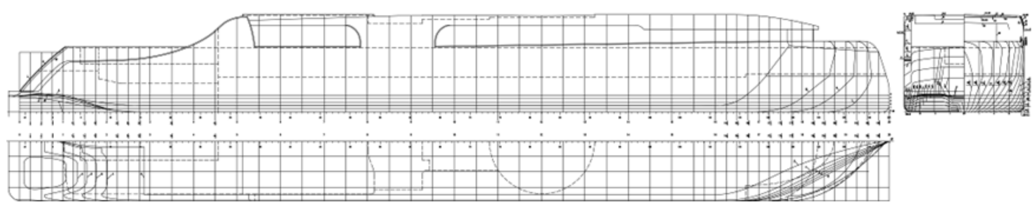


Fig. 1. Towing resistance of new generation PS

Lines drawings of new generation PS

Table 1

Projects	Lines drawings
PV300VD «Petr Velikiy»	
PV250 (passenger section)	
PV250 (power section)	
PV150	
PV09 «Shtandart»	

The geometric characteristics of underwater part of hulls of new generation PS

Table 2

Characteristics	Notations	Metric unit	Values					
			PV300VD	PV250			PV150	PV09
				Passenger section	Power section	Combination		
Length by waterline	L_{WL}	m	135,000	108,000	28,000	136,200	95,000	94,300
Length overall	L_{OA}	m	138,870	110,600	28,000	138,800	97,800	94,300
Breadth	B	m	16,600	16,600	16,600	16,600	16,200	13,000
Draught at fore perpendicular	T_F	m	2,900	2,500	2,500	2,500	1,400	1,800
Draught at aft perpendicular	T_A	m	2,900	2,500	2,500	2,500	1,400	1,800
Draught amidships	T	m	2,900	2,500	2,500	2,500	1,400	1,800
Bilge radius	R	m	0,950	0,950	0,950	0,950	0,950	0,700
Volume displacement	∇	m^3	4902,1	3601,6	816,5	4418,2	1548,4	1855,3
Weight displacement	Δ	t	5024,6	3601,6	816,5	4418,2	1548,4	1855,3
Wetted surface area	S	m^2	2484,6	1943,0	569,6	2512,6	1434,2	1391,4
Waterline area	S_{WL}	m^2	1966,5	1535,9	433,3	1969,1	1292,9	1131,6
Area of center line plan	S_{CL}	m^2	377,6	267,4	59,7	327,1	115,9	162,1
Area of midship plane	S_M	m^2	47,8	41,1	41,1	41,1	22,3	23,2
Water-line entrance angle	i_E	deg.	28,0	21,0	90,0	21,0	21,5	28,0
Longitudinal center of buoyancy (from mid of L_{WL})	x_C	m	-0,376	-9,347	3,586	-5,461	-1,657	-0,230
Longitudinal center of buoyancy (relative)	ℓ_{CB}	%	-0,28	-8,65	12,81	-4,01	-1,74	-0,24
Immersed transom area	A_{TR}	m^2	0,063	36,015	1,492	1,492	0,874	-
Absciss of parallel middle body center (from mid L_{WL})	x_{PMB}	m	-3,000	-27,375	6,600	-13,275	-7,500	-2,357
Length of parallel middle body	L_{PMB}	m	51,000	52,750	5,200	52,750	30,000	61,295
Length of parallel middle body relative (L_{PMB} / L_{OA})	ℓ_{PMB}	%	36,7	47,7	18,6	38,0	30,7	65,0
Block coefficient	C_B	-	0,754	0,804	0,703	0,782	0,719	0,841
Waterplane area coefficient	C_{WP}	-	0,878	0,857	0,932	0,871	0,840	0,923
Coefficient of midship-section area	C_M	-	0,992	0,991	0,991	0,991	0,983	0,991
Longitudinal coefficient	C_P	-	0,760	0,811	0,709	0,789	0,731	0,848
Length to breadth ratio	L_{WL} / B	-	8,133	6,506	1,687	8,205	5,864	7,254
Breadth to draught ratio	B / T	-	5,724	6,640	6,640	6,640	11,571	7,222

Correspondences between speed of new generation PS, main engine power load and number of revolutions of propeller shafts are shown graphically on Figure 3.

For PV09 project calculation of ship's performance was carried out using the data of RP manufacturer Rolls-Royce US 155P14 CRP (2 x 1100 kW). According to the results of calculations cruising speed in calm deep water with US 155P14 CRP RP is 13.7 knots at 100% power of main engines.

Estimated speed in quiet and deep water of PV300VD PS - 14.24 knots at 85% (3 x 825 kW) load of main engines, PV250 PS - 12.93 knots at 85% (2 x 989 kW), PV150 PS - 14.63 knots at 85% (3 x 577 kW).

PS of PV300VD project “Petr Velikiy” was launched in May 2019 and now is under construction (see Figure 4), sea trials have not yet been carried out.

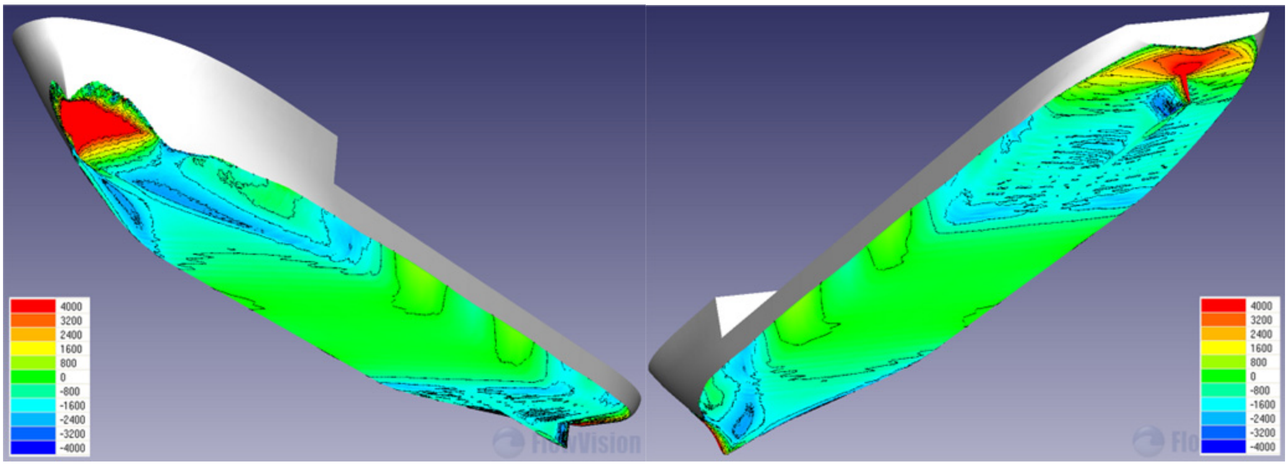
PS of PV300 project “Mustai Karim”, hull contours of which are close to those of PV300VD project (difference in aft end and propulsion complex - 2 RP with capacity of 1200 kW each were installed instead of the same three) was launched in September 2019, put into operation in August 2020, sea trials confirmed (with margin) contract speed of the vessel.

PV09 PS “Shtandart” was put into operation in 2017. During building process, it was decided to replace RP on SCHOTTEL STP 550 (2 x 1000 kW) and design speed decreased accordingly. Sea trials confirmed seaworthiness of PS “Shtandart”. The vessel on measured mile achieved maximal speed of 23.8 km/h (12.85 kn).

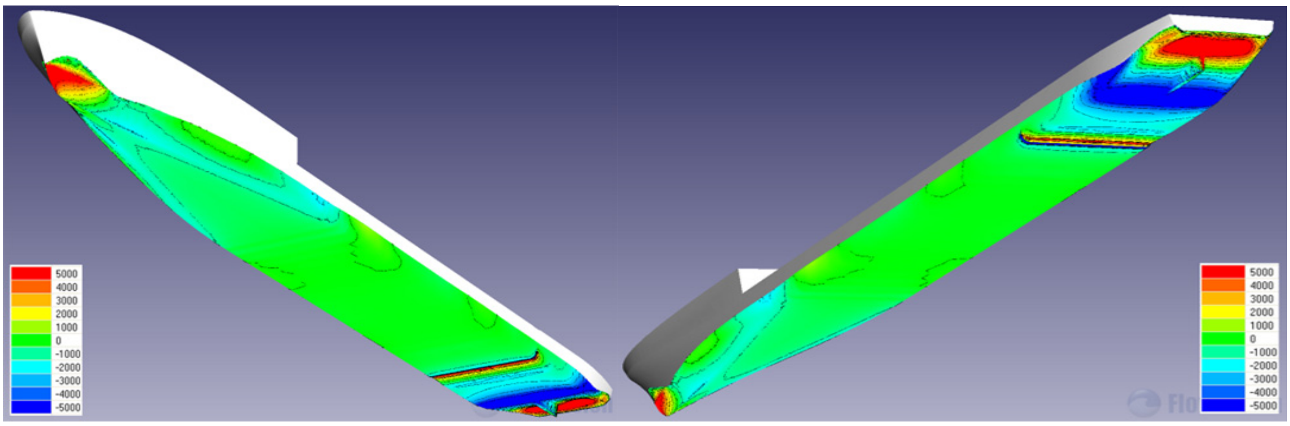
In 2019 extended sea trials of “Shtandart” were carried out in order to confirm the fulfillment of conditions of river-sea class M-PR 2.5 of Russian River Register.

Trials were carried out at value of revolutions 1500 rpm of main engines at five values of wave-direction angles (WDA): 0°, 45°, 90°, 135° and 180° (0° corresponds to movement against wave). When maneuvering the ship turned to the wave with both starboard and port sides.

During trials at each stage the ship moved in straight course with constant main engine speed; holding time of the ship on each course was 9-12 minutes.



a)



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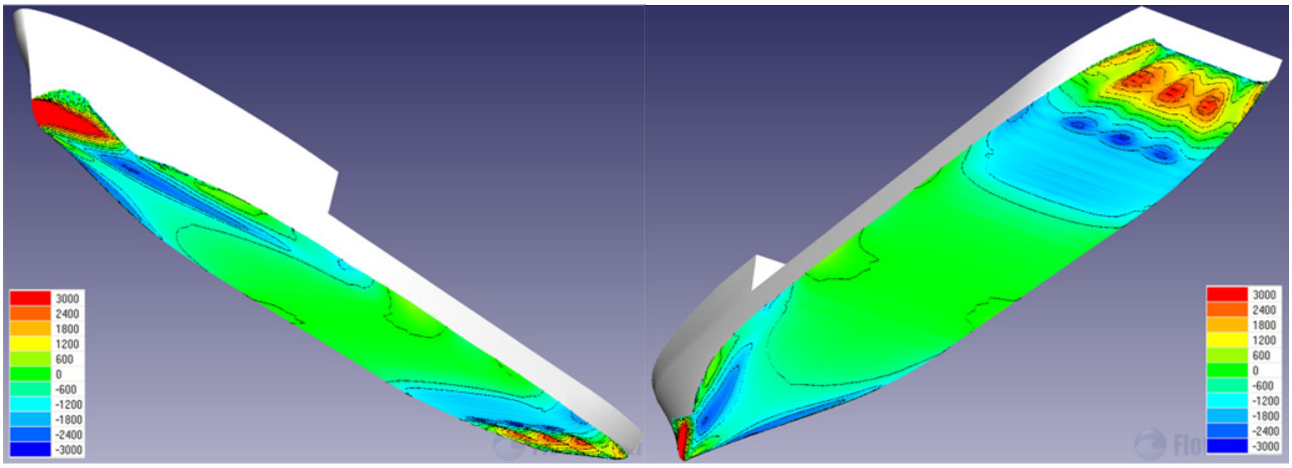

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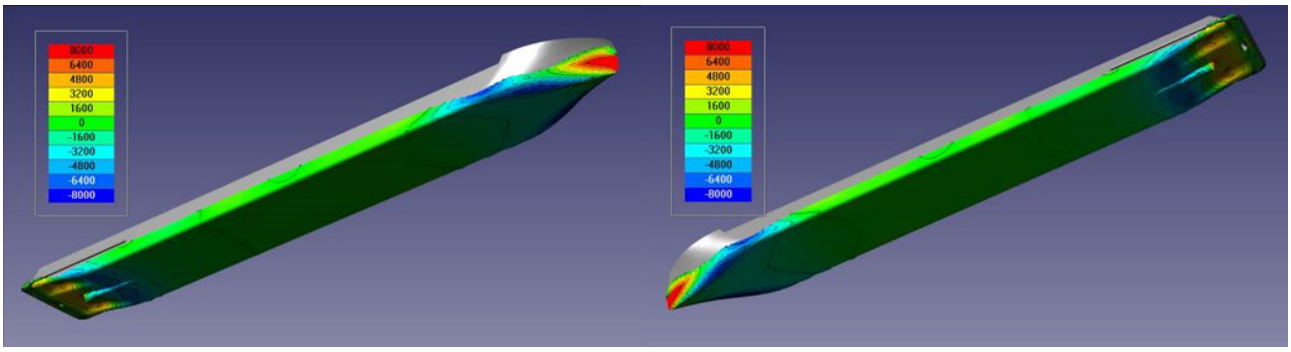

d)

Fig. 2. Visualization of calculations for maximal speeds of new generation PS. Water pressure distribution:
a) PV300VD, b) PV250, c) PV150, d) PV09.

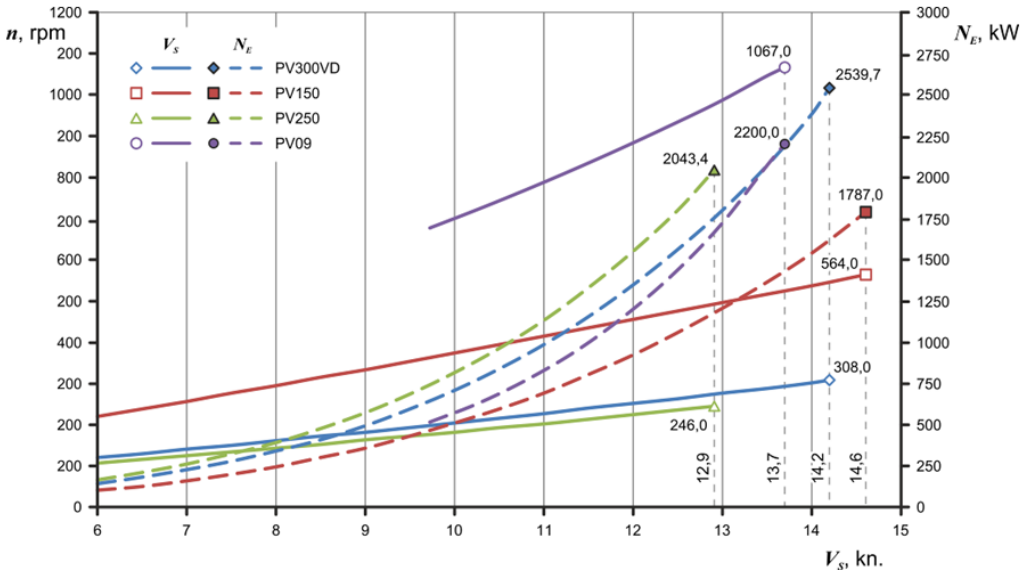

Fig. 3. Calculation of running characteristics of new generation PS

Fig. 4. Fore and aft ends of PV300VD PS "Petr Velikiy"

Based on results of trials it was found that PV09 PS "Shtandart" had shown good seaworthiness: steady controllability in forward motion, moderate pitching, moderate splashing, crinoline flooding (at stern) at WDA 90-180° (that was quite expected according to chosen architectural-constructive type of the ship), loss of forward speed at WDA 0° from 21.0 to 18.8 km/h (actual waves $h_{3\%}$ = 2.32 m), normal habitability. Breakdowns in operation of ship power plant, emergence of bottom, rising on the wave and plunging were not observed. The ship cut through the wave with no apparent effort or effects. There were no comments relating to any faults on shipbuilding elements.

Full-scale seaworthy tests carried out in 2019 under the conditions of designed wind-wave regime confirmed that the seaworthiness of PV09 PS "Shtandart" meets specification requirements. The seaworthiness of the ship corresponds to RRR class M-PR 2.5, which is assigned to the ship.

CONCLUSION

Study of running characteristics of new generation PS has been carried out. These ships differ from classic PS built in Soviet era by *L / B* ratio - for the most part ("Dnipro max" / "Volga-Don max" and "PostDnipro max" / "Volga-Balt max" classes) new PS are longer, fore and aft contours are optimized using CFD methods, and also new PS designed with taking into account installation of thrusters and rudder propellers.

Satisfactory convergence of results of model and full-scale seaworthy tests on the example of PV09 PS "Shtandart" shows the effectiveness of used tools.

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RESEARCH OF CHANGING OF COMPARTMENT AREAS ON MODERNIZED RIVER CRUISE PASSENGER SHIPS

Alexander EGOROV

Abstract. *Despite increase in number of modernizations, not all working river cruise passenger ships (PS) fitted modern cruise requirements. Therefore, when developing modernization projects and projects of new PS, it is extremely important to have information about real situation with passenger cabins and public spaces. Any PS modernization or conversion, if there are no problems with technical conditions of the ship, is carried out in order to increase comfort level. On such ships, increase of comfort level and fit to modern standards of service are achieved by reducing passenger capacity unlike to sea cruise passenger ships and liners, for which foremost changes in overall dimensions are possible. At the same time distribution of areas and layout of compartments are also subjects to change. Correlations received during the work will simplify the design process of basic projects, including design works on modernization and conversion of PS.*

Key words: *comfortableness, conversion, correlation, modernization, river cruise passenger ship.*

INTRODUCTION

Fleet of domestic river cruise passenger ships (PS) is aging. Moreover, as studies show [1], first of all, morally. In recent years, travel requirements for comfort on board increased significantly, which affected pace and volume of modernization works. Over the past five years, more than 30 PS have been modernized of which 13 - significantly, with increase in comfort level.

Trends at domestic market are quite consistent with European one, where since 2013 there has been an increase in number of cruises, primarily due to American tourists [2].

Despite increase in number of modernizations, not all working river cruise passenger ships (PS) fitted modern cruise requirements. Therefore, when developing modernization projects and projects of new PS, it is extremely important to have information about real situation with passenger cabins and public spaces.

AIM OF THE PAPER

Determination of dependencies of changing of distribution of PS compartment areas as a result of modernizations and conversions for estimation at initial stages of design.

MAIN TEXT

Any PS modernization or conversion, if there are no problems with technical condition of the ship, is carried out in order to increase comfort. On such ships increase of comfort level and lead to modern service standards [1] are achieved by reducing passenger capacity, in contrast with sea cruise passenger ships and liners for which, for the most part, it is possible to change the overall dimensions. Herewith distribution of areas and layout of compartments are also changing.

Author carried out corresponding analysis of change of distribution of deck areas (see examples in tables 1 and 2). The most suitable for modernization ships from the first (projects 785, 26-37, 588, 305, 646, 860) and the second (projects 301, 302, Q-040, Q-056, Q-065, 92-016) PS groups have been chosen as research objectives [3].

Changes in the areas and layout of passenger cabins are shown on Figure 1.

Changes in the areas and layout of restaurant complex (increase of total area as well as number of restaurants)

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on the example of 302 project ship and its modifications (PV12, PV17 projects of Marine Engineering Bureau) is shown on Figure 2.

Such modernizations of restaurant complex are typical for European river cruise market. For example, one of the segment leaders, cruise company Nicko Cruises, has been expanding its restaurant complex in recent years at the expense of passenger capacity, offering 3 different restaurants on board.

Table 1

Example of calculation of changing of distribution of deck areas (the second PS group, 301 and Q-065 projects)

№	Compartments	301 project								Q-065 project					
		301 basic project		PV17 (301 modernization)		Knyazhna Viktoria (301 modernization)		St. Petersburg (301 modernization in 2019)		Q-065 basic project		PV08 (Q-065 conversion)		Sergey Esenin (Q-065 modernization in 2019)	
		m²	%	m²	%	m²	%	m²	%	m²	%	m²	%	m²	%
1	Passenger cabins	1445	20,7%	1597	22,3%	1472	20,6%	1338	19,2%	675	17,2%	920	21,1%	767	19,6%
2	Balcony of passenger cabins			458	6,4%	500	7,0%					290	6,7%	27	0,7%
3	Restaurants	231	3,3%	359	5,0%	476	6,7%	231	3,3%	114	2,9%	446	10,2%	138	3,5%
4	Bars, saloons, cinemas	391	5,6%	246	3,4%	354	5,0%	391	5,6%	273	7,0%	86	2,0%	181	4,6%
5	Other public compartments	42	0,6%	41	0,6%	206	2,9%	42	0,6%	28	0,7%	25	0,6%	28	0,7%
6	Corridors	331	4,7%	317	4,4%	219	3,1%	302	4,3%	110	2,8%	104	2,4%	106	2,7%
7	Halls, elevators	306	4,4%	291	4,1%	440	6,2%	306	4,4%	79	2,0%	100	2,3%	79	2,0%
8	Deck galleries	1161	16,7%	803	11,2%	650	9,1%	1161	16,7%	652	16,6%	348	8,0%	625	16,0%
9	Solarium	356	5,1%	250	3,5%	151	2,1%	356	5,1%	234	6,0%	446	10,2%	234	6,0%
10	Crew cabins	495	7,1%	722	10,1%	500	7,0%	602	8,6%	367	9,4%	350	8,0%	367	9,4%
11	Public compartments (c)	101	1,4%	101	1,4%	114	1,6%	101	1,4%	38	1,0%	38	0,9%	38	1,0%
12	Corridors (c)	233	3,3%	265	3,7%	133	1,9%	262	3,8%	118	3,0%	112	2,6%	118	3,0%
13	Engine room compartments	877	12,6%	890	12,4%	901	12,6%	877	12,6%	513	13,1%	457	10,5%	513	13,1%
14	Stores	133	1,9%	66	0,9%	163	2,3%	133	1,9%	47	1,2%	57	1,3%	43	1,1%
15	Auxiliary	25	0,4%	20	0,3%	25	0,4%	25	0,4%			5	0,1%		
16	Provision stores (p)	95	1,4%	95	1,3%	95	1,3%	95	1,4%	66	1,7%	66	1,5%	66	1,7%
17	Provision stores (c)	29	0,4%	29	0,4%	29	0,4%	29	0,4%						
18	Catering facilities (p)	191	2,7%	191	2,7%	191	2,7%	191	2,7%	131	3,3%	136	3,1%	131	3,3%
19	Catering facilities (c)	35	0,5%	35	0,5%	35	0,5%	35	0,5%	8	0,2%	8	0,2%	8	0,2%
20	Laundry, ironing (p)	89	1,3%	89	1,2%	89	1,2%	89	1,3%	13	0,3%	13	0,3%	13	0,3%
21	Laundry, ironing (c)														
22	Medical	32	0,5%	32	0,4%	57	0,8%	32	0,5%	17	0,4%	17	0,4%	17	0,4%
23	Operational posts	72	1,0%	72	1,0%	85	1,2%	72	1,0%	57	1,5%	43	1,0%	57	1,5%
24	Anchor and mooring gear	135	1,9%	135	1,9%	125	1,8%	135	1,9%	105	2,7%	105	2,4%	105	2,7%
25	Others	164	2,4%	55	0,8%	130	1,8%	164	2,4%	273	7,0%	189	4,3%	257	6,6%
26	*Total area of passenger cabins*	*1445*	*20,7%*	*2055*	*28,7%*	*1972*	*27,6%*	*1338*	*19,2%*	*675*	*17,2%*	*1210,4*	*27,8%*	*794*	*20,3%*
27	*Total area of public spaces for passengers*	*2900*	*41,6%*	*2334,5*	*32,6%*	*2561*	*35,9%*	*2871*	*41,2%*	*1625,55*	*41,5%*	*1648,7*	*37,8%*	*1518,55*	*38,8%*
28	*Total useful area*	*4345*	*62,3%*	*4389,5*	*61,3%*	*4533*	*63,5%*	*4209*	*60,4%*	*2300,55*	*58,8%*	*2859,1*	*65,6%*	*2312,55*	*59,1%*
29	*Total area of services spaces*	*2624*	*37,7%*	*2769,5*	*38,7%*	*2607*	*36,5%*	*2760*	*39,6%*	*1614,75*	*41,2%*	*1502,4*	*34,4%*	*1602,75*	*40,9%*
30	**Total decks area**	**6969**	**100%**	**7159**	**100%**	**7140**	**100%**	**6969**	**100%**	**3915**	**100%**	**4362**	**100%**	**3915**	**100%**

Note: (p) - passenger compartments; (c) - crew compartments

Example of comparison of specific areas and correlation of number of passengers and crew (the second PS group, 301 and Q-065 projects)

Table 2

№	Compartments	301 project								Q-065 project					
		301 basic project		PV17 (301 modernization)		Knyazhna Viktoria (301 modernization)		St. Petersburg (301 modernization in 2019)		Q-065 basic project		PV08 (Q-065 conversion)		Sergey Esenin (Q-065 modernization in 2019)	
			%		%		%		%		%		%		%
1	Number of passenger on boards, pas	360		196		206		210		180		112		136	
2	Specific living area, m²/pas	4,0		10,5	161,2	9,6	138,5	6,4	58,7	3,8		10,8	188,2	5,8	55,7
3	Average area of cabin, m²	8,0		21,0	161,2	19,1	138,5	12,7	58,7	7,5		21,6	188,2	11,7	55,7
4	Specific public area, m²/pas	8,1		11,9	47,9	12,4	54,3	13,7	69,7	9,0		14,7	63,0	11,2	23,6
5	Specific useful area, m²/pas	12,1		22,4	85,6	22,0	82,3	20,0	66,1	12,8		25,5	99,7	17,0	33,0
6	Specific service area, m²/pas	0,04		0,03	-15,3	0,04	19,9	0,04	0,1	0,03		0,04	21,2	0,04	17,2
7	Number of crew and staff, pas	94		84		112		99		55		62		64	
8	Correlation between number of crew and staff to number of passengers	0,26		0,43	64,1	0,54	108,2	0,47	80,5	0,31		0,55	81,2	0,47	54,0

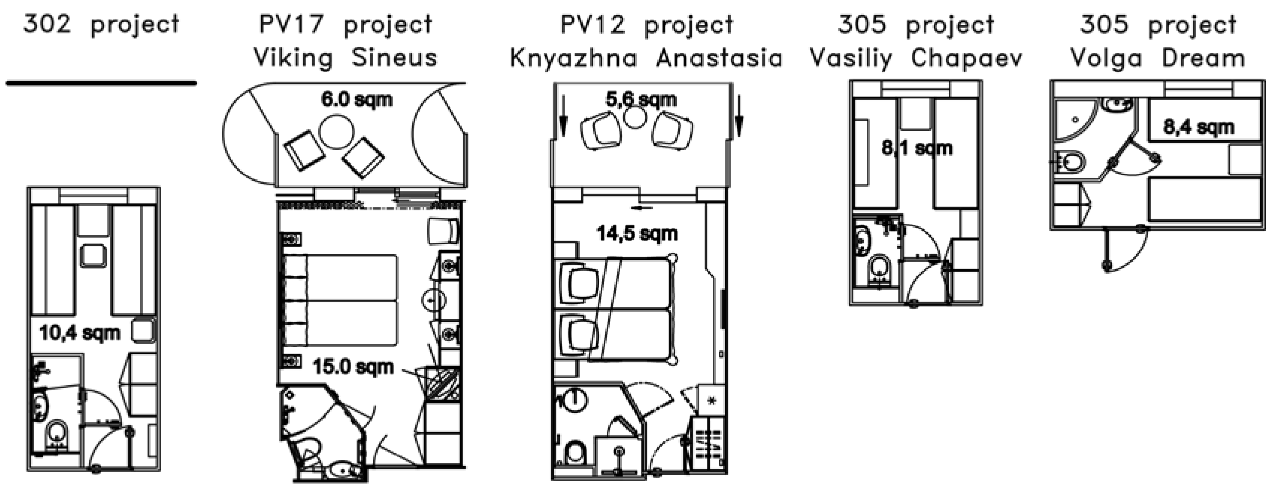

Fig.1. Changing of areas and layout of passenger cabins on PS of the first (305 project) and the second groups (302 project)

Number of all decks n on designed or modernized PS, including decks for crew and service rooms, as well as sun deck, can be determined depending on B, m² (where L and B are PS overall length and breadth respectively) as follows: three decks (n = 3) at B = 1100 ÷ 1250 m², four decks (n = 4) at B = 1250 ÷ 1500 m², five decks (n = 5) at B = 1500 ÷ 2350 m² and six decks (n = 6) at B = 2350 ÷ 2400 m².

The average area of passenger cabin on PV06 conversed PS increased by 196.7% (from 4.1 m² to 12.2 m²) in comparison with the original 588 project PS, by 170.8% on Rus Velikaya conversed PS (up to 11,2 m²), and on I. A. Krylov modernized PS by 121.8% (up to 9.2 m²).

On modernized Sergei Obraztsov PS in comparison with the original 305 project PS increased by 104.8% (from 3.3 m² to 6.7 m²).

On modernized PV17 PS Viking Sineus in comparison with the original 301 project PS increased by 161.2% (from 8.0 m² to 21.0 m²), on Princess Victoria modernized PS - by 138.5% (up to 19.1 m²); on St. Petersburg PS - by 58.7% (up to 12.7 m²).

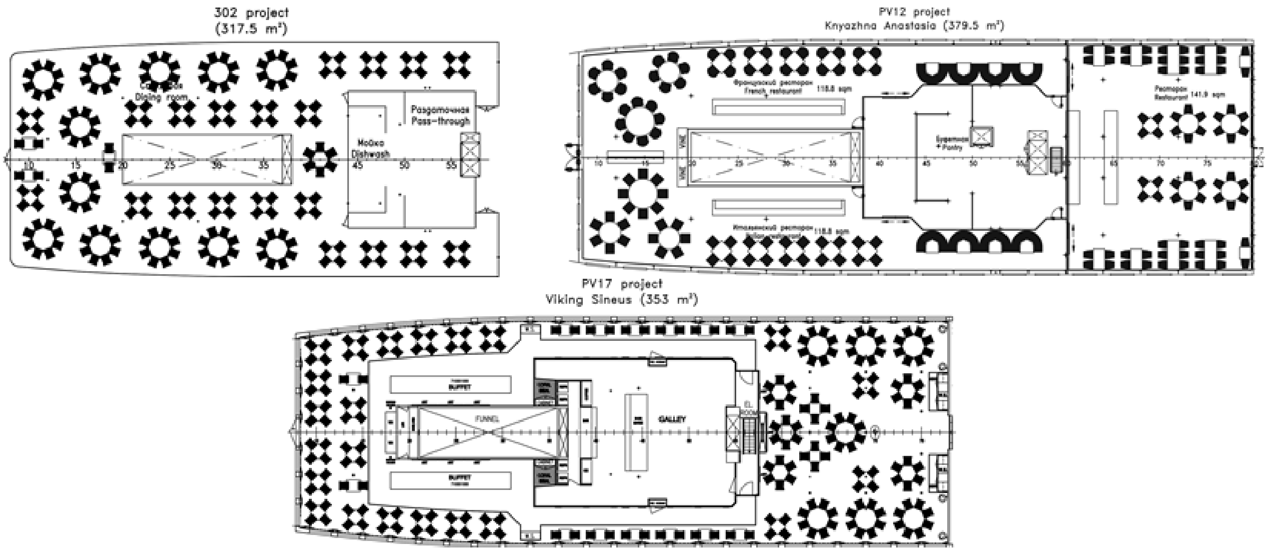

Fig. 2. Changing of areas and layout of restaurant complex on the example of 302 project PS and its modernizations

For determination of utilization coefficient of total area of decks on PS $S_{deck} = S_{deck} / LBn$ (for all ships, basic and modernized), dependence $S_{deck} = 3{,}5583 \cdot (LBn)^{-0{,}18}$ was obtained (see Figure 3).

On conversed PV08 PS Alexander Grin in comparison with the original ship of Q-065 project increased by 188.2% (from 7.5 m² to 21.6 m²), on modernized Sergey Esenin - by 55.7% (up to 11.7 m²).

On modernized PV12 PS in comparison with the original 302 project PS increased by 120.5% (from 9.5 m² to 21.0 m²), on modernized PV15 PS - by 101.8% (up to 19.2 m²), on Rus PS - by 6.7% (up to 10.1 m²).

On Mstislav Rostropovich modernized PS in comparison with the original 92-016 ship increased by 160.7% (from 8.7 m² to 22.8 m²), on Sergei Kuchkin PS - by 18.2% (up to 10.3 m²).

Dependencies for average values of areas of passenger cabins for basic and modernized projects are shown on Figure 4.

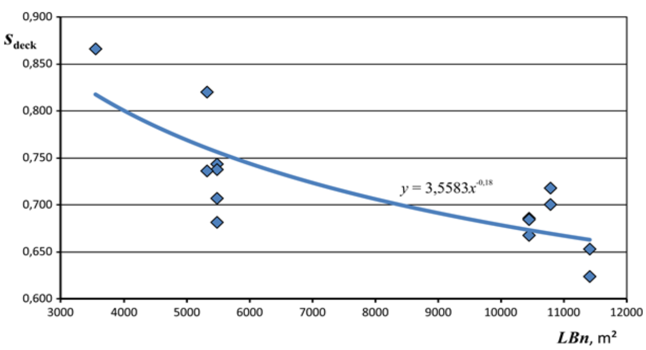

Fig. 3. Determination of total area$_k$ utilization coefficient S_{dec}

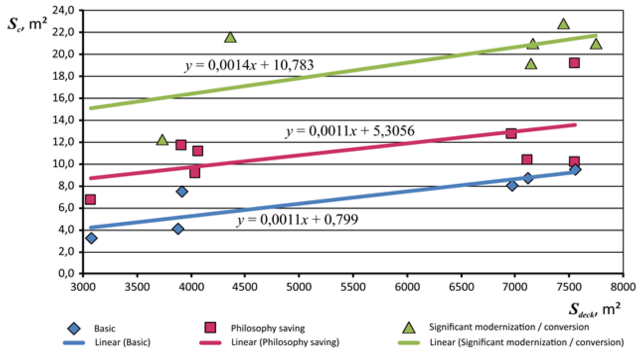

Fig. 4. Determination of average value of areas of passenger cabins S_c, m²

For basic projects this dependence can be represented as $S_c = 0{,}0011 \cdot S_{deck} + 0{,}799$, m², for philosophy saving modernized projects - $S_c = 0{,}0011 \cdot S_{deck} + 5{,}3056$, m², for significant modernizations and conversions - Sc = 0,0014·Sdeck + 10,783, m².

Values of specific area (relative to the number of passengers) of passenger cabins for all ships, basic and modernized, are shown on Figure 5 and can be determined from the dependence

$S_c^{/} = 0{,}0069 \cdot (S_{deck} / N_{pas})^2 - 0{,}033 \cdot \frac{S_{deck}}{N_{pas}} + 1{,}8688$, m²/pas.

Values of specific area of public compartments $S_p^{/}$ for all ships, basic and modernized, are shown on Figure 6 and can be determined from the dependence $S_p^{/} = 0{,}306 \cdot \frac{S_{deck}}{N_{pas}} + 2{,}5933$, m²/pas.

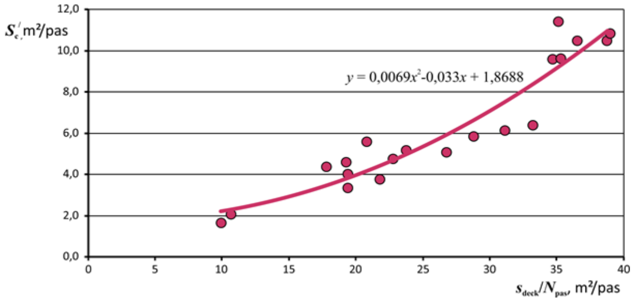

Fig. 5. Determination of values of specific area of passenger cabins $S_c^{/}$, m²/pas

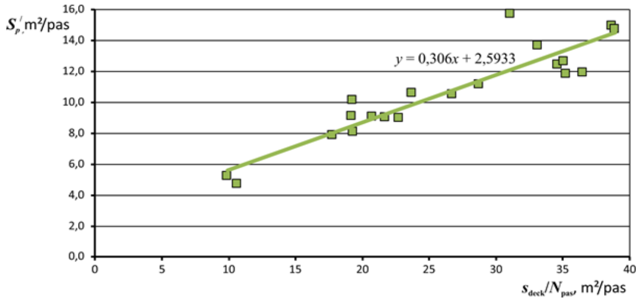

Fig. 6. Determination of values of specific area of public compartments $S_p^{/}$, m²/pas

Values of specific useful (passenger cabins and public spaces) area $S_{useful}^{/}$ for all ships, basic and modernized, are shown on Figure 7 and can be determined from the dependence $S_{useful}^{/} = 0{,}6225 \cdot \frac{S_{deck}}{N_{pas}} + 0{,}5468$, m²/pas.

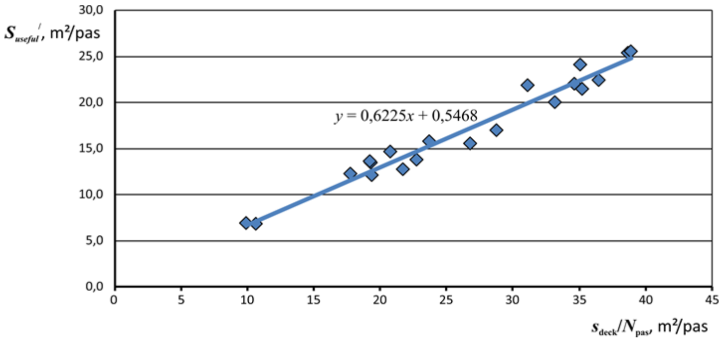

Fig. 7. Determination of values of specific useful area $S_{useful}^{/}$, m²/pas

It was found that values of specific areas (Figures 5-7) are characterized by the following values of the ratios $S_{deck} / N_{pas} = 9 \div 22$ m²/pas for basic PS projects, $S_{deck} / N_{pas} = 22 \div 35$ m²/pas for modernized projects with philosophy saving, $S_{deck} / N_{pas} = 35 \div 40$ m²/pas for significant modernizations and conversions.

Analysis of distribution of deck areas also made it possible to obtain utilization coefficients for areas of passenger cabins $s_c = S_c / S_{deck}$, public spaces $s_p = S_p / S_{deck}$, useful spaces $s_{useful} = S_{useful} / S_{deck}$ and service spaces $s_{ser} = S_{ser} / S_{deck}$ both for basic and modernized projects.

Utilization coefficient of areas of passenger cabins for basic projects $s_c = 0{,}0131 \cdot (S_{deck})^{0{,}3175}$, for modernized projects with philosophy saving $s_c = 0{,}0344 \cdot (S_{deck})^{0{,}2166}$, for significant modernizations and conversions $s_c = 0{,}0162 \cdot (S_{deck})^{0{,}3242}$.

Utilization coefficient of areas of public spaces for basic projects $s_p = 2{,}0662 \cdot (S_{deck})^{-0{,}182}$, for modernized projects with philosophy saving $s_p = 3{,}3845 \cdot (S_{deck})^{-0{,}243}$, for significant modernizations and conversions $s_p = 6{,}2251 \cdot (S_{deck})^{-0{,}321}$.

Utilization coefficient of areas of useful spaces for basic projects $s_{useful} = 0{,}8379 \cdot (S_{deck})^{-0{,}032}$, for modernized projects with philosophy saving $s_{useful} = 1{,}0655 \cdot (S_{deck})^{-0{,}058}$, for significant modernizations and conversions $s_{useful} = 1{,}3861 \cdot (S_{deck})^{-0{,}086}$.

Utilization coefficient of areas of service spaces for basic projects $s_{ser} = 0{,}2078 \cdot (S_{deck})^{0{,}0639}$, for modernized projects with philosophy saving $s_{ser} = 0{,}1825 \cdot (S_{deck})^{0{,}0758}$, for significant modernizations and conversions $s_{ser} = 0{,}0867 \cdot (S_{deck})^{0{,}1573}$.

In process of modernization or conversion of PS increase of number of crew and staff per passenger is observed. This is also normal if level of service is increasing.

Average ratio n_{crew} / n_{pas} for basic projects is 0.24, for modernized projects with philosophy saving - 0.38. For significant modernizations and conversions n_{crew} / n_{pas} = 0.51, which is in the line with modern ideas about cruises.

CONCLUSIONS

Detailed analysis of distribution of areas on PS basic projects, as well as on modernized and conversed ships, was carried out.

Modernization and conversion works on such ships are carried out primarily to increase comfort of river cruises. Considering impossibility of changing the overall dimensions of PS the only possible option is to reduce the passenger capacity.

At the same time distribution of areas and layout of compartments are also subjects to change. Specific area of passenger cabins is increasing from 2.0-4.5 m^2/pas to 9.0-12.0 m^2/pas, specific area of public compartments - from 4.5-9.0 m^2/pas to 11.5-16.0 m^2/pas.

The number of crew and staff per passenger increases up to 0.51, which increases the level of service on board.

Correlations received during the work will simplify the design process of basic projects, including design works on modernization and conversion of river cruise passenger ships.

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DETAILED ANALYSIS OF HULL DAMAGES OF RIVER AND RIVER-SEA CARGO VESSELS

Vladimir NILVA

Abstract. *Statistical data of accidents of river and river-sea cargo vessels for period since 1991 is analyzed. Classification of hull's damages is proposed. Statistical probabilities of accidents' types are defined. Compared to sea-going vessels, the feature of operation of river and river-sea vessels is contacts with walls of canals and locks. Based on obtained results it can be concluded that the most likely types of damages of river vessels are fires and explosions (0.0000901 cases per year), grounding (0.0000744 cases per year) and ice damage (0.0000529 cases per year).*

Key words: *accident, classification of hulls' damages, river-sea vessel, statistical data.*

INTRODUCTION

Special operational feature of river and river-sea vessels in comparison with sea going ones is significant operational term in the conditions of rivers, canals, sluices, narrow water. That's why the probability of collisions, grounding and other accidents is increased essentially. Statistical data of Russian River Register and database "Fleet", additional sources [1-2] was analyzed to get mean dimensionless values. These values can be used for probability assessment of accidents' occurrence and reasons.

AIM OF THE PAPER

To analyze and treat data concerning accidents of river and river-sea vessels for the period of 1991-2012, to classify types of hull damages, to get mean values of probabilities of accidents' types.

MAIN TEXT

Prof. Gennadiy Egorov proposed the classification of main groups of identified casualties [1] when processing statistical data for discussed problem (as the first step on the way to formal assessment of risk during vessels' operation). Main three sections of this classification are as follows:

- the dangers connected with technical condition of the hull, machinery, mechanisms and systems of the vessel;
- the dangers connected with incorrect technology of cargo transportation;
- the dangers connected with actions of the ship-owner, coastal operators and crew.

Such approach allows analyzing and sorting the whole range of input data if array of known emergency situations is considered.

Single part is sorted from input data that connects partly 1 and 3 sections of mentioned classification, that is the dangers connected with technical condition of the hull, machinery, mechanisms and systems of the vessel and the dangers connected with actions of the ship-owner, coastal operators and crew.

The reasons of hull damage are divided into following groups in accordance with following classification (see Figure 1): collisions, ice damages, grounding, excess of the wind-wave mode, explosions and fires, other. Also this classification considers damage localization along the vessel and/or depth of damage (breach or deformation).

List of emergency accidents during 1991-2012 is shown in Table 1 (examples). 246 cases are chosen among considered accidents that caused vessel hull damage. Distribution by types of damages and localization along the vessel is shown in Table 2.

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Index of conditional probability is defined as $\mu = \sum_{i=1}^{T} \left(\frac{n_i}{N_i} \right) \Big/ T$

where

n_i - cases' quantity of certain type of damage in the considered year,

N_i - total number of vessels in operation in the considered year,

T = 22 years - the time period which is considered when processing input data.

Also in Table 2 the probability $k = n_{cat} / n_i$ is defined, where n_{cat} - cases' quantity of each category of damage taking into account localization along the vessel.

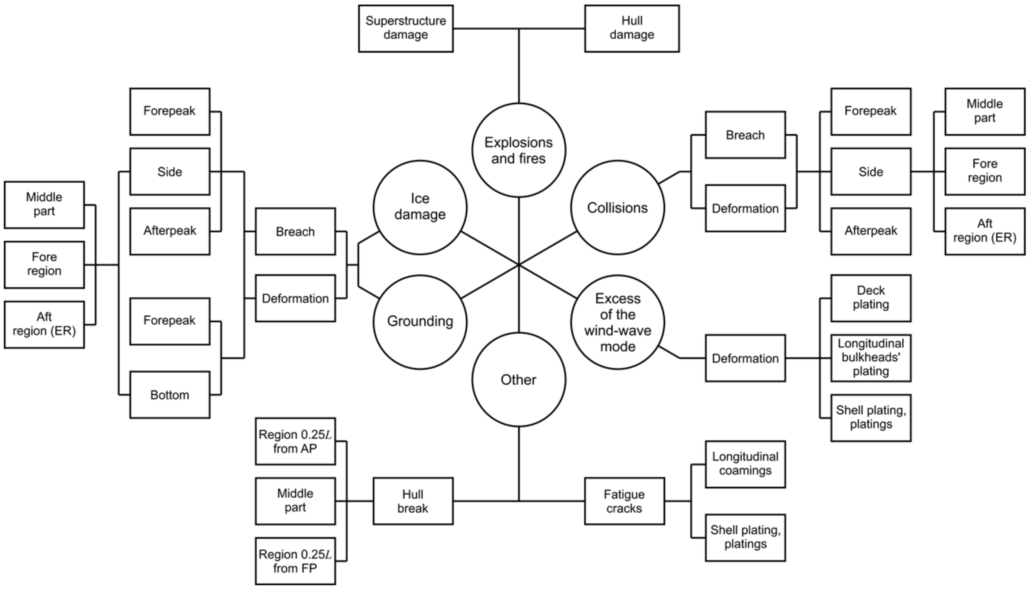

Fig. 1. Classification of hull damages

Emergency accidents of inland and river-sea going vessels during 1991-2012 (examples)

Table 1

No.	Project	Vessel's name	Date of accident	Damage description	Vessel's type	$L_{суд}$
Groundings						
1	Pr. 944	MP-285	13.10.2012	Bottom breach (fore region)	Barge for deck cargo	46
2	Pr. 795	Sborshchik -2	07.10.2012	ER bottom breach (aft region)	Oil tanker	50
3	Pr. 550A	Volgoneft-152	17.07.2012	Bottom breach (fore region)	Oil tanker	133
4	Pr. 942	1251	11.07.2012	Bottom breach (fore region)	Barge for deck cargo	66
5	Pr. 1565	Kapitan Skachkov	15.06.2012	Bottom deformation (fore region)	Dry cargo vessel	138
6	Pr. 550A	Volgoneft-162	14.06.2012	Bottom breach thruster room (fore region)	Oil tanker	133
7	Pr. 942	584	28.05.2012	Bottom deformation (fore region)	Barge for deck cargo	66
8	Pr. 21-88	Mezhdu-rechensk	24.05.2012	Bottom deformation (aft region)	Dry cargo vessel	104
9	Pr. 576	Tver'	10.05.2012	Bottom deformation (fore region)	Dry cargo vessel	94
10	Pr. 1743	Moskva	03.05.2012	Bottom breach MO (aft region)	Dry cargo vessel	108
Cracks						
1	Pr. 507B	Volgo-Don167	12.05.2009	Crack of bilge plating PS (middle part)	Dry cargo vessel	138
2	Pr. 507B	Volgo-Don103	30.01.2008	Coaming's crack (middle part)	Dry cargo vessel	138
3	Pr. R-85	3201	14.04.2003	Coaming's crack (middle part)	Barge for deck cargo	88
4	Pr. R-85A	3264	14.04.2003	Coaming's crack (middle part)	Barge for deck cargo	88
5	Pr. 05074M	Vladimir Filkov	07.02.2003	Coamings' crack (middle part)	Dry cargo vessel	138
Hull break						
1	Pr. 459T	NS-1523	22.03.2011	Middle part hull break	Oil barge	78
2	Pr. 866	TN-6-206	13.08.2009	Middle part hull break	Oil tanker	66
3	Pr. 795	TNM-22	14.01.2005	Middle part hull break	Oil tanker	50
4	Pr. 05074M	Strelets	03.02.2003	Hull break in the region 0.25L from FP	Dry cargo vessel	138
5	Pr. 558/550	Volgoneft-26	16.07.2002	Middle part hull break	Oil tanker	133
6	Pr. P-56	MP-3338	24.01.2002	Middle part hull break	Barge for deck cargo	86
7	Pr. P-56	MP-3063	14.05.1999	Middle part hull break	Barge for deck cargo	86
8	Pr. P-56	MP-2829	28.10.1999	Middle part hull break	Barge for deck cargo	86
9	Pr. 942A	886	23.06.1998	Middle part hull break	Barge for deck cargo	66
10	Pr. P-29	BO-23	11.06.1998	Middle part hull break	Open hold barge	86

Table 1 (continuation)

No.	Project	Vessel's name	Date of accident	Damage description	Vessel's type	$L_{суд}$
Ice damage						
1	Pr. 507B	Volgo-Don 167	12.05.2009	Side deformations at the WL level (fore region и middle part)	Dry cargo vessel	138
2	Pr. 1565M1	Volgo-Don 5021	02.04.2006	Side breach (fore region)	Dry cargo vessel	138
3	Pr. 507B	Solikamsk	27.02.2006	Side deformations at the WL level (fore region и middle part)	Dry cargo vessel	138
4	Pr. 621	Lenaneft-2057	24.10.2005	Side deformations at the WL level (fore region и middle part)	Oil tanker	123
5	Pr. 11	Voronezh	06.12.2004	Breach in the forepeak region	Dry cargo vessel	93
6	Pr. 621	Lenaneft-2057	12.10.2004	Side deformations at the WL level (fore region и middle part)	Oil tanker	123
7	Pr. 621	Lenaneft-2064	12.10.2004	Side deformations and breaches at the WL level (along the entire vessel's length)	Oil tanker	124
8	Pr. 550A	Volgoneft-135	28.04.2004	Side breach (fore region)	Oil tanker	133
9	Pr. 1565	Zircon	09.03.2003	Side deformations at the WL level (along the entire vessel's length)	Dry cargo vessel	138
10	Pr. 1565	Evgeniya 3	25.02.2003	Side deformations at the WL level (along the entire vessel's length)	Dry cargo vessel	138
Excess of the wind-wave mode (deformations)						
1	Pr. 507B	Volgo-Don179	10.01.2008	Deformation of the deck plating (middle part)	Dry cargo vessel	138
2	Pr. 507B	Volgo-Don199	11.01.2008	Deformation of the deck plating (middle part)	Dry cargo vessel	138
3	Pr. 507B	Volgo-Don101	15.01.2008	Deformation of the deck plating (middle part)	Dry cargo vessel	138
4	Pr. 507B	Volgo-Don103	30.01.2008	Deformation of the deck plating (middle part)	Dry cargo vessel	138
5	Pr. 621	Lenaneft-2068	02.02.2008	Deformation of the deck plating (middle part)	Oil tanker	123
6	Pr. 550A	Volgoneft-123	15.11.2007	Deformation of the deck plating (middle part)	Oil tanker	133
7	Pr. 05074M	Volzhsky-44	15.03.2007	Deformation of the deck plating (middle part)	Dry cargo vessel	138
8	Pr. 05074M	Volzhsky-40	09.04.2007	Deformation of the deck plating (middle part)	Dry cargo vessel	138
9	Pr. 1565	Volgo-Don5021	02.04.2006	Deformation of the deck plating (middle part)	Dry cargo vessel	138
10	Pr. 1577	Volgoneft-233	14.11.2005	Deformation of the double side plating (middle part)	Oil tanker	133
Collisions						
1	Pr. 942	1241	13.08.2012	Forepeak breach	Barge for deck cargo	66
2	Pr. R-56	MR-2844	29.04.2012	Forepeak breach	Barge for deck cargo	86
3	Pr. R-89	7407	16.07.2012	Shell plating breach StB (middle part)	Barge for deck cargo	63
4	Pr. 1577	Komsomol Volgograda	09.11.2011	Shell plating breach, region of fr.168(aft region) Shell plating breach	Oil tanker	133
5	Pr. 1745	3810	16.11.2011	Shell plating breach (middle part)	Cement carrying barge	110
6	Pr. 576	Kerch	13.08.2010	Shell plating breach PS (middle part)	Dry cargo vessel	94
7	Pr. 21-88	Yalta	13.05.2010	Forepeak breach	Dry cargo vessel	104
8	Pr. P-79A/ R-79A-SP	Barzha 3072	12.11.2010	Shell plating breach (fore region) Shell plating breach. Dimensions - 2,0 x 0,4 м	Hold barge	98
9	Pr. P-97T	Okskiy-62	15.10.2009	Shell plating breach of ER PS (aft region)	Vessel for deck cargo	93
10	Pr. 05074T	Volga-Flot 5	15.10.2009	Forepeak breach	Oil tanker	139
Fire and explosions						
1	Pr. 1557	Jul	01.09.2012	Superstructure damage	Dry cargo vessel	114
2	Pr. 1577	Inzhener Nazarov	28.02.2012	Superstructure damage	Oil tanker	133
3	Pr. 765	ST-6-40	22.09.2012	Superstructure damage	Dry cargo vessel	66
4	Pr. 3164	BAM-4	04.08.2011	Superstructure damage	Bunkering tanker	52
5	Pr. 82651B	NZS-321	31.03.2011	Hull damage (pump room)	Oil spill cleanup plant	126
6	Pr. P-32A	Nevskiy -18	21.02.2011	Superstructure damage	Dry cargo vessel	97
7	Pr. 1577	Volgoneft-266	24.06.2010	Hull damage	Oil tanker	133
8	Pr. 21-88	Orekhovo-Zuyevo	27.07.2010	Hull damage (hold No.4)	Dry cargo vessel	104
9	Pr. 558/550	Volgoneft-37	23.07.2010	Hull damage (engine room)	Oil tanker	133
10	Pr. 585	Velta	28.07.2010	Hull damage (engine room)	Bunkering tanker	60

Definition of index of conditional probability

Table 2

Damage description		n_i	μ	n_{cat}	n_{cat} / n_i
Grounding		47	0,0000744		
Breach					
bottom	-			1	0,021
bottom	fore region			30	0,638
bottom	middle part			5	0,106
bottom	aft region			5	0,106
Deformation					
bottom	fore region			5	0,106
bottom	aft region			1	0,021
Fatigue cracks		17	0,0000258		
shell plating and horizontal plating				6	0,353
coaming				11	0,647
Hull break		24	0,0000308		
region 0.25 *L* from AP				1	0,042
middle part				20	0,833
region 0.25 *L* from FP				3	0,125
Ice damage		40	0,0000529		
Breach					
bottom	-			1	0,025
side	fore region			2	0,050
bottom	fore region			4	0,100
Deformation					
side	fore region + mid. part			27	0,675
side	whole length			2	0,050
bottom	+side			1	0,025
Breach and deformation					
side	whole length			3	0,075
Excess wind-wave mode		25	0,0000368		
deck plating				16	0,640
longitudinal bulkheads' plating				7	0,280
shell plating				2	0,080
Collision		33	0,0000521		
Breach					
forepeak	-			8	0,242
side	fore region			13	0,394
side	middle part			6	0,182
side	aft region			2	0,061
side	fore and aft region			2	0,061
side	+inner side (mid. part)			1	0,030
side	bilge region			1	0,030
Explosions and fires		60	0,0000901		
superstructure damage				22	0,367
hull damage				35	0,583
superstructure and hull damage				3	0,050

Ratio of n_i to N_{acc} for every accidents' types is shown in Figure 2.

Probabilities of accidents' types according to the offered classification during 1991-2012 are shown in Figures 3-9.

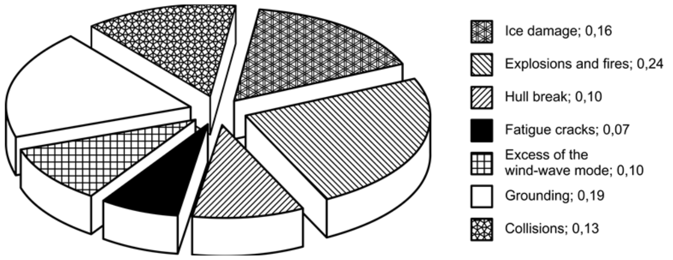

Fig. 2. Relative distribution of accidents' types

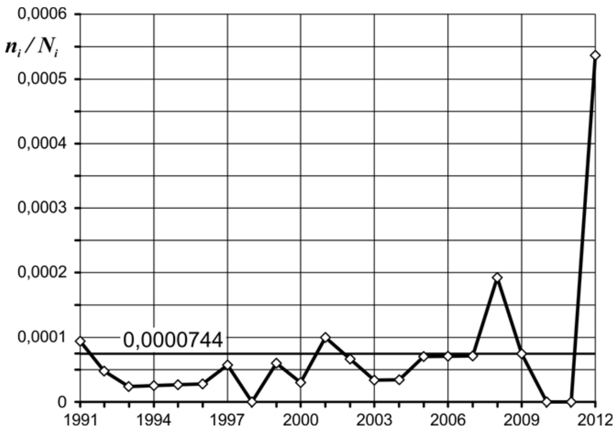

Fig. 3. Probability of grounding

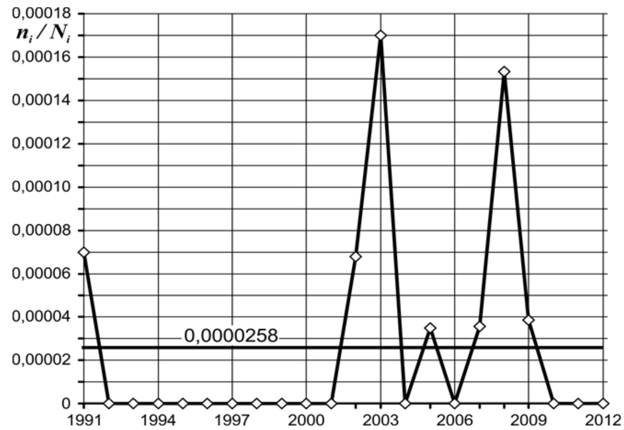

Fig. 4. Probability of fatigue cracks initiation

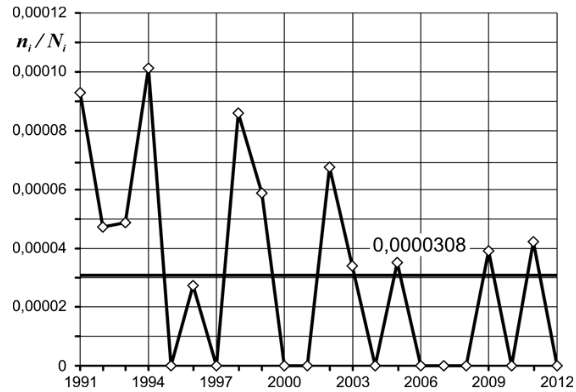

Fig. 5. Probability of hull break

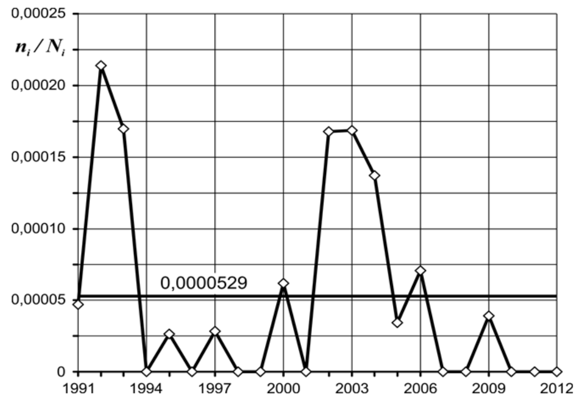

Fig. 6. Probability of receiving the ice damage

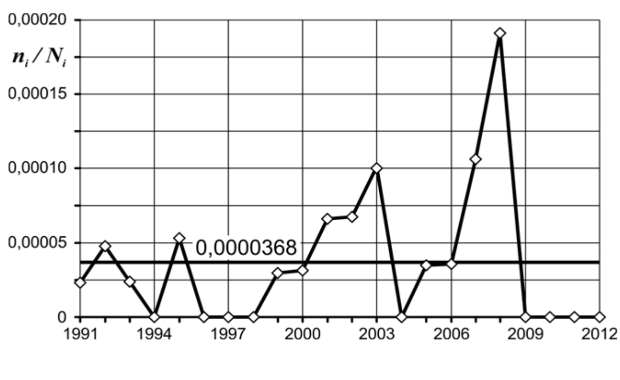

Fig. 7. Probability of receiving the ice damage

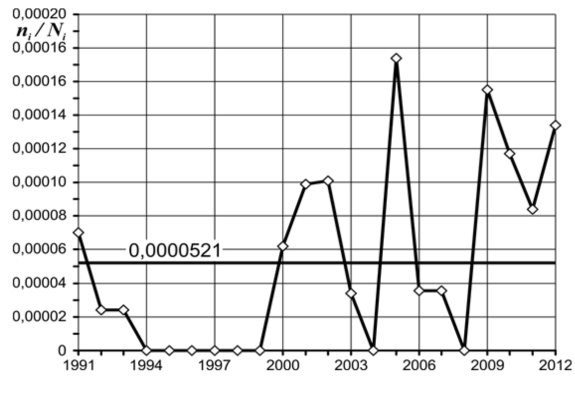

Fig. 8. Probability of vessels' collision

The mentioned statistics cannot be considered absolutely reliable. Firstly, decrease of accident rate can reflect the economic situation in the considered year, change of number of the operated cargo vessels at inland waterways, change in fleet structure, etc. Secondly, the bigger quantity of sources, probably, would allow to fill gaps in the specific types accidents. Thirdly, lack of some accidents in the corresponding years does not mean 100% probability that they did not occur actually. Information about accidents is held back by the ship-owner for a number of reasons, for example because of their insignificant effects. The inaccuracies connected with accounting order in the organizations which are responsible for collecting statistical data are possible also.

Distribution of mean values of probabilities by types of accidents is shown in figure 10.

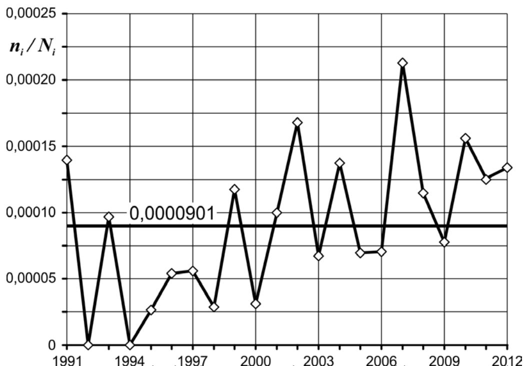

Figure 9. Probability of explosions and/or onboard at the vessels.

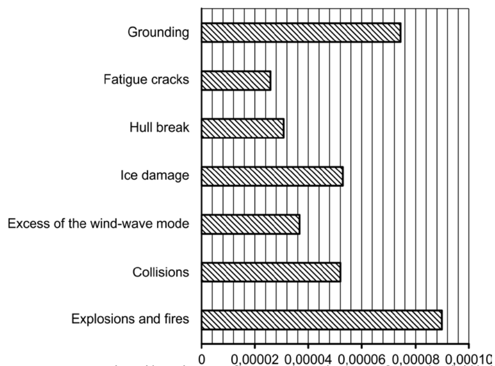

Figure 10. Distribution of mean values of probabilities by types of accidents.

CONCLUSIONS

The analysis of statistical data of vessels' casualties of river and river-sea vessels' types for the period of 1991-2012 is carried out in the article. The idea of defining of conditional probabilities for concrete types of hull damage is initially put.

Therefore more detailed classification of hull damages that takes into consideration damage localization along the vessel is proposed. Such classification does not include damages of gears, systems and mechanisms of the vessel.

By the received results it is possible to make a conclusion that the most probable types of damage of inland waterways vessels are the fires and explosions (μ = 0.0000901 cases a year), groundings (μ = 0.0000744 cases a year) and ice damages (μ = 0.0000529 cases a year).

Results can be used for obtaining mean dependences for length, breadth and depth of damages, damage's arrangement along the vessel and, further, for the program of damage strength assessment of the vessel with use of probabilistic methods.

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ANALYSIS OF POSSIBILITY OF LAUNCHING OF RIVER-SEA PASSENGER SHIP WITH SIGNIFICANT OVERHANG OF FORE PART

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Abstract. *Justification of possibility of safe launching of river-sea passenger ship of PV300VD project with significant overhang of fore part, which is almost 30% of the length of the vessel is executed. When estimating strength of a ship's hull, launching from slip with significant overhang, next main strength problems were solved: - whether the slip itself will withstand (wooden bedding and launching trolley strength); - will framing, web framing and plates of the bottom and upper deck in the overhang area withstand (questions of local strength); - whether the ship itself can withstand (question of overall longitudinal strength of the ship).*

Key words: *overhang, passenger vessel, safety, strength, traversing unit.*

INTRODUCTION

On August 15, 2016 a solemn keel laying ceremony of PV300VD prj. river-sea cruise passenger vessel for Moscow River Shipping Company took place at "Lotos" Shipyard. By mid-2018, the shipyard completed the formation of the vessel's hull, and at the same time, the question about the possibility of launching of such an object from a slip had arosed. The length of the slip was almost 1/3 less than the overall length of the vessel. And if the launch of river-sea going cargo vessels of "Volgo-Don Max" class took place at the shipyard "Lotos" in the normal mode, then the launch of a passenger vessel with a significant number of cutouts in the sides of the developed superstructure caused justified concerns.

AIM OF THE PAPER

To prove the safety of launch taking into account the limited slipway-deck and the number of traversing units.

MAIN TEXT

A feature of passenger vessels with a developed superstructure is that, due to their length, decks must be included in the hull girder when calculating the longitudinal strength. However, in order to reduce the weight of the vessel, the upper part of the superstructure is made of aluminum with such a minimum thickness that it cannot contribute to the longitudinal strength.

Expansion joints along the entire length of all decks of the superstructure are used to exclude it from the hull girder (see Figure 1).

It was necessary to solve the main strength problems in making an assessment of vessel's hull strength during the launch from a slip with a significant overhang:

- whether the slip itself will withstand (a wooden pillow and a traversing unit);
- whether ordinary, web framing and bottom and upper deck platings will withstand in the area of overhang (local strength questions);
- whether the vessel herself will withstand (overall longitudinal strength of the vessel will be saved);

Initial data for the calculation:

Length overall - 141.15 m;

Length (at design waterline) - 141.0 m;

Breadth - 16.60 m;

Depth (to MD) - 5.5 m;

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Displacement of the vessel during launch - 2697.5 t;
Weight of stem overhang - 514.8 t;
Length of overhang - 33.59 m.

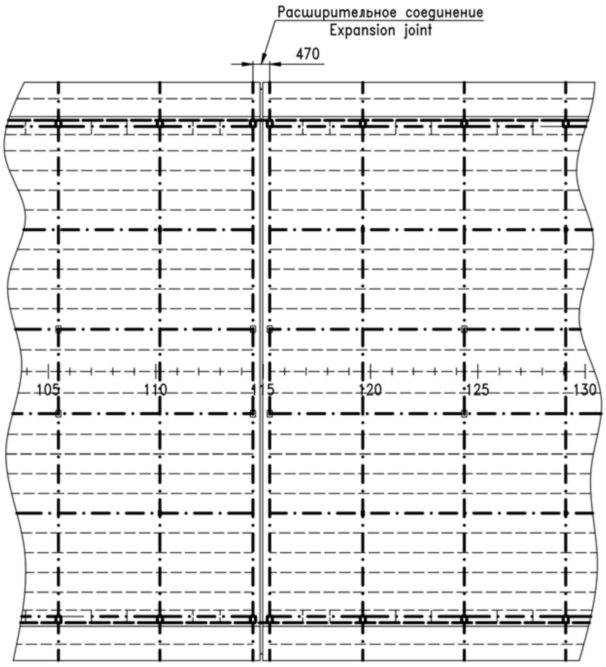

Fig. 1. Expansion joints along the entire length of all decks of the superstructure

Main characteristics of traversing unit:
Length - 100.0 m;
Load carrying capacity - 6000 t;
Number of traversing unit - 21;
Number of wheels of traversing unit - 16;
Permissible load on one wheel of traversing unit - 28 t;
Permissible load on all wheels of traversing unit - 28 x 16 = 448 t;

Vessel's hull was considered as a prismatic beam with a moment of inertia of ≈ 8.876 m^4 on 21 independent elastic supports. This value of the moment of inertia is taken according to the document [1] and corresponds to the section along the 160th frame. The calculation was carried out by the finite element method (FEM) using the FEM-94 program in accordance with the installation scheme of PV300VD prj. on the traversing units (see Figure 2). The design scheme, including 39 elements and 40 nodes, is shown in Figure 3.

Stiffness coefficients of elastic supports are determined taking into account the location of the pedestals with wooden filler on the support table of traversing unit. Installation scheme of pedestals on traversing units №№1, 2, 21 (in the CL of traversing units) and №№3-20 (above the hinges of the support table) is shown in Figure 4.

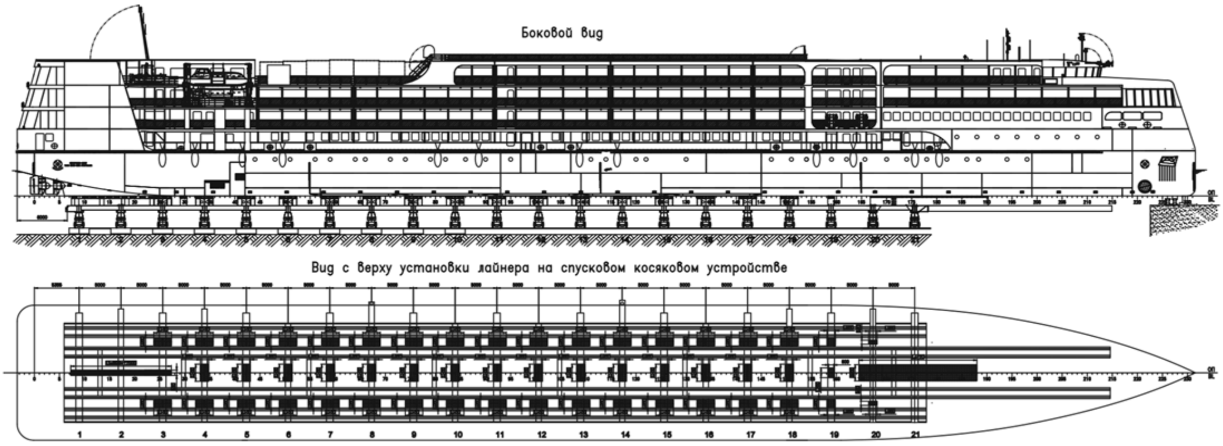

Fig. 2. Installation scheme of wooden keel blocks on a traversing table with their dimensions

Stiffness coefficients of elastic supports №№ 1, 2, 21 are determined in accordance with the scheme that takes into account the deflection of the support table in the form of a beam with a cross section. Other pairs of pedestal supports with pine stripes are located above the steel supports of the traversing table and their elasticity is not taken into account. Value of the stiffness coefficient of 1 m² of a wooden layer is = 294300 kN / m.

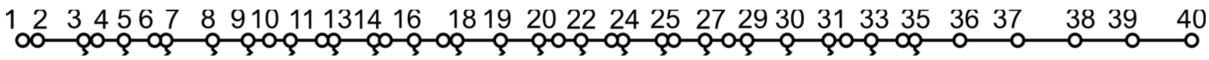

Fig. 3. Design scheme of the vessel on traversing units

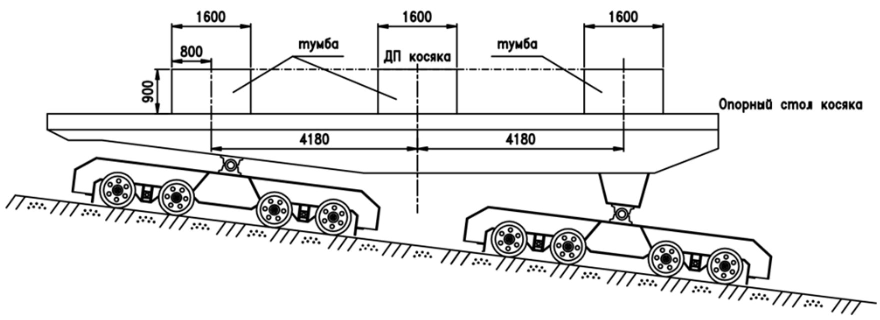

Fig. 4. Installation scheme of pedestals on traversing units №№ 1, 2, 21 (in the CL of traversing units) and №№ 3-20 (above the hinges of the support table)

Summary stiffness coefficient of traversing units №1, 2, 21 is determined as

$$K_\Sigma = \frac{K_1}{1+\left(K_1/K_2\right)},$$

where

E_p = 6000 т/м² (for pine);

h = 0,2 м (height of wooden strip).

For example, for traversing unit №1:

$$K_1 = \frac{F_g \cdot E_q}{h_q} = \frac{2{,}21 \cdot 6000}{0{,}2} = 66300 \text{ t/m}$$ - stiffness of the wooden strip.

$$K_2 = \frac{48{,}28 E I_0}{L^3\left(1+31{,}36\dfrac{I_0}{w_c L^2}\right)}$$

E_w = 2,1·107 t/m², at a = 3,75 m, b = 4,18 m.
I_0 = 825825 cm⁴; w_c = 256 cm².
(according to the reference book [2]).

$$K_2 = \frac{48{,}28 \cdot 2{,}1 \cdot 10^7 \cdot 825825 \cdot 10^{-8}}{7{,}93^3 \left(1 + 31{,}36 \dfrac{825825}{256 \cdot 793^2}\right)} = 14474{,}3\, t/m$$

Therefore

$$K_\Sigma = \frac{66300}{1 + \dfrac{66300}{14474{,}3}} = 11880{,}6\, t/m = 1{,}165 \cdot 10^5\, kN/m$$

i.e. less than stiffness of a wooden layer in 5.58 times.

Shear forces' and bending moments' diagrams were made to assess the overall longitudinal strength of vessel's hull. The maximum deflection of the fore end was 70 mm.The overall longitudinal strength of vessel's hull was calculated with M_{max} = 95830,0 kNm and N_{max} = 5050,3 kN. Section modulus of the upper deck W_{min} = 1.776 m³, web area of hull girder F_{web} = 0.11 m². Material of upper deck is steel with a yield stress of 315 MPa.

$$\sigma_{\max} = \frac{M_{\max}}{W_{\min}} = \frac{95830}{1{,}776} \cdot 0.001 = 54 \text{ MPa} \approx 0{,}171\sigma_{yield} << \sigma_{per} = 0{,}6\sigma_{yield}$$

$$\tau_{\max} = \frac{N_{\max}}{F_{web}} = \frac{5050{,}3}{0{,}11} \cdot 0{,}001 = 45{,}9 \text{ MPa} \cong 0{,}256\tau_{yield} << \tau_{per} = 0{,}6\tau_{yield},$$

where

σ_{yield} - 315 MPa, τ_{yield} ≅179,6 MPa are tension and sheer yield stresses, respectively, for the material of upper deck of PV300VD prj. vessel.

Thus, calculations of longitudinal strength have shown that there is no danger for the vessel on the traversing units with the large console. Maximum normal and sheer stresses in the hull are much less (in 3.5 ÷ 3.9 times) than the permissible ones, which are not less than $\sigma_{per} \cong 0{,}6\sigma_{yield}$ and $\tau_{per} \cong 0{,}6\tau_{yield}$ in this situation.

The most loaded was not the nose support, but the traversing unit No. 19 in terms of stresses in wooden strips (stresses in wooden pillows were 129.1 t / m² or 80.1% of the allowable 160 t / m²), and with permissible loads on all traversing units $P_{per} \leq 448$ t.

Local strength of structures in the most stressed section was also assessed. Bottom grillage, longitudinal stiffeners' (LS) and bottom platings' strength in the area of traversing unit №19 (161-177 frames) was calculated. Calculations were made using "MKE-94" and "ISPA" programs.

The design scheme of strength of the bottom grillage that includes 34 elements and 29 nodes is shown in Figure 5. The grillage is considered as rigidly fixed on the transverse bulkheads on 161, 177 frames and freely supported at the side. CL symmetry of the structure and the load is taken into account.

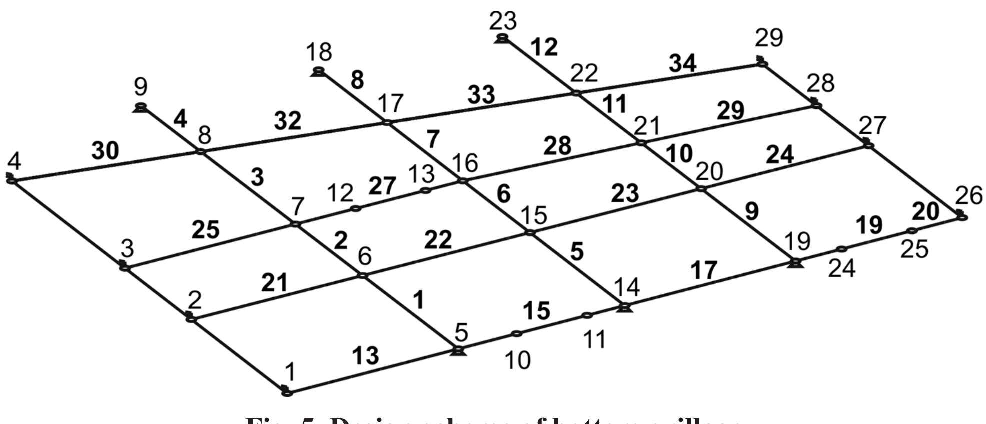

Fig. 5. Design scheme of bottom grillage

The value of the maximum shear force arising in the bottom stringer in the area of traversing unit № 20 is 790.5 kN and shear stresses $\tau = 90$ MPa, or 84% of the allowed 107.2 MPa. The value of the maximum bending moment in the bottom stringer in the area of traversing unit № 20 is 1250 kNm. The value of the normal stresses is $\sigma = 64$ MPa, that is significantly lower than the permissible ones.

LS is considered as freely supported on floors and on fixed brackets. The value of the maximum shear force arising in the bottom longitudinals n the area of traversing unit № 19 is 146.64 kN and the shear stresses are equal to the permissible 107.2 MPa. The value of the maximum bending moment in the bottom girder in the area of the traversing unit № 19 is 15.117 kNm. The value of normal stresses $\sigma = 150$ MPa, or 67.3% of the allowable ones.

The bottom plate is modeled as a plating on an elastic base. The stiffness of 1 m² of pine pillow of 0.2 m high is 294,300 kNm. The considered section of the plating has an area of $0.55 \cdot 0.6 = 0.33$ m², so the total stiffness of the elastic base is $0.33 \cdot 294300 = 97119$ kNm. The load on the section of plating is $3444.8 / 2.72 \cdot 0.33 = 417.9$ kN. The pressure on the plating is $417.9 / 0.33 = 1266$ kN / m² = 1.266 MPa. The maximum value of normal stresses on the plate was 102 MPa that is noticeably lower than the permissible ones.

Bottom grillage, stiffeners' and bottom platings' strength with temporary reinforcement structures is ensured.

Following recommendations for the launch were given based on the results of the calculations:

- Vessel's hull and superstructure should be reinforced (see Figure 6);
- Glasses of all windows above the main deck should be dismantled in the fore from 145 fr.;
- Vessel should be installed on traversing units.

It is necessary to install temporary keel blocks in the area of the stem overhang of the vessel with a step not more than 5 m. They should be dismantled immediately before the launch of the vessel.

There should be no open holes in the outer side of the vessel below the main deck.

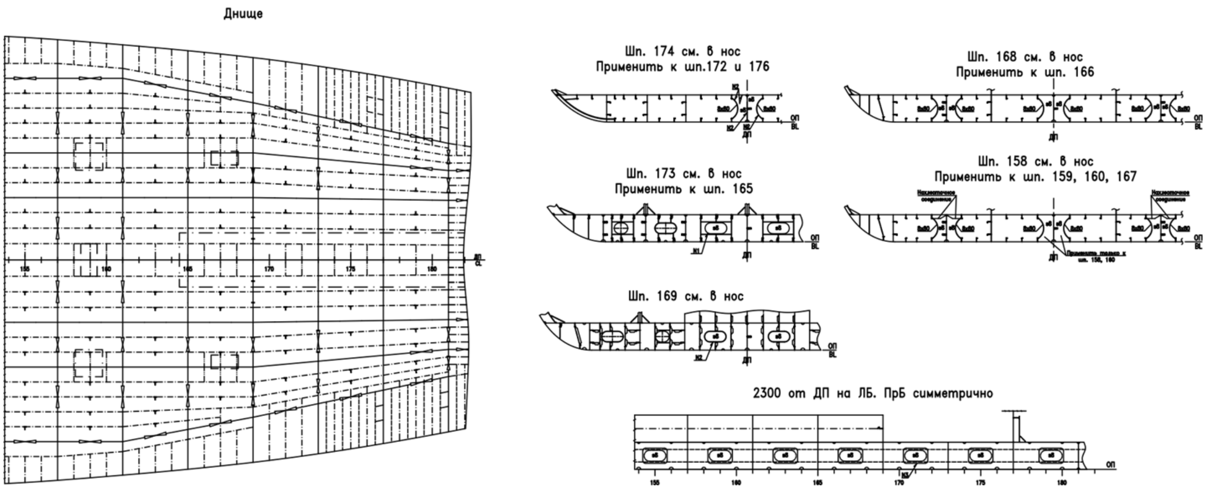

Fig. 6. Scheme of bottom reinforcement during launch of PV300VD prj. vessel (158-173 frames)

CONCLUSIONS

Successful launch of PV300VD prj. river-sea passenger vessel was carried out in 2019 on the basis of calculations and proposed installation scheme on traversing units (see Figure 7).

Fig. 7. Launch of PV300VD prj. passenger vessel "Petr Velikiy"

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ABOUT DESIGN OF MODERN FISHING VESSELS

Gennadiy EGOROV*, Nickolay AVTUTOV**

Abstract. *The important place of the fishing fleet is underlined. Under RS class mean age of fishing vessels is 30.9 years, of transport refrigerators - 29.5 years. As of July 2020, there were 271 catching vessels with RS class with length more than 60 m, 827 with length less than 60 m (excluding small size), refrigerated transport - 163.*
The existing large vessels of "Soviet" projects are also undergoing modernization with the replacement of factories and redevelopment with significant increase in productivity in the field. However, the physical wear and obsolescence of the fleet require real measures to update it. Fishing vessels of new generation differ significantly from those built in Soviet time with similar or smaller sizes higher productivity, modern factories, equipment for fishing and significantly higher level of automation.

Key words: *cargo gear, crabber, construction, design, trawler.*

INTRODUCTION

Consumption of fish, fish products and seafood in North America is about 24 kg/person per year, 22 for Europe, 21 for Asia, 9-10 for Africa and Latin America. In 2019, according to the RF Federal Agency for Fisheries, fish consumption in Russia was 12.9 kg/person (in 2012 it was 17.1). Catch in the same year amounted to almost 5 million tons (98.6% of 2018). 2.1 million tons from this amount were exported (94.6% of 2018) with 3.9% increase of revenues from sales abroad (5.38 billion USD only). Almost 70% of fish is caught in the Far East, about 16% in the Northern Basin. In general, there are pollock and herring in the Far East, cod and haddock are in the Northern Basin.

In general, the export of fish is an essential item of foreign currency incoming to the country. It occupies for an average of 17% of the export of all agricultural products and ranks second (the first is grain, the third is vegetable oil). It is interesting to note that in general the sale of fish and seafood occupies the fifth place in the country's exports. There is quite a steady export growth, i.e. there were 2 million tons of fish and 4.5 billion USD - in 2017 and 2.1 and 5.38 in 2019 respectively. Already by May 1, 2020, 0.828 million tons of fish were exported (for 1.65 billion USD). The main buyers in Asia are South Korea (34%), China (31%), Japan (7%).

The main product by weight (90%) is frozen fish. A significant part of the sold frozen fish (more than 800 thousand tons) is pollock. Fillet, if taken by weight, is approximately 5%. At the same time, pollock fillet costs 1.3 times more than a headless and frozen semi-finished product, and surimi - 3.2 times more. Accordingly, in terms of income, frozen fish contributed 58.5%, fillets and other fish products 27%. That is why on the new ships, which are now being built for Russia, conditions have been created for the production of products with a higher added value than "freezing", for example, fillets, forcemeat, portions, fish sticks, etc.

Crabs play a very unique role. It is catched 8 times less, and the cost is 14-15 times higher than for frozen pollock. Russian fishermen today catche up to 100 thousand tons of various types of crabs per year, mainly kamchatka crab (44%), opilio crab (23%) and blue crab (10%). For example, 91.3 thousand tons in 2019, 96 thousand tons in 2018. 73.4 thousand tons were exported (South Korea - 60%, the Netherlands - 21%, China - 16%) in 2019. Crab catching is now done using crab traps. They are rectangular, tapered or pyramidal cages made from a sturdy steel frame, over which a metal or nylon net is stretched. The trap has a trap hole, a feeder that holds the bait (a piece of fresh or frozen fish), and an opening bottom. Before launching into the water, a cable with a fixed signal buoy is connected to the row of cages. After that, the trap is dropped to a depth of

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100-200 m and left on the bottom for several days. Up to 200 such cages are installed at a time on an area of up to 100 km². After maximum of two days, the vessel returns and lifts from the bottom the trap with caught crabs [1].

AIM OF THE PAPER

Substantiation of characteristics of new generation fishing vessels.

MAIN TEXT

Vessels are the main tool for fish and seafood catching. Soviet fishing fleet consisted more than 4 thousand vessels of various purposes and types; they operated practically all over the world, not only in domestic economic zone.

From 1995 to 2014 the number of fishing vessels decreased by a third and continues to decrease.

At the same time, enough large fishing fleet remained in Russia; among the production vessels the large ones (over 100 m long) are of 25, big ones (65 - 100 m) are of 177, medium ones (34 - 65 m) are of 850 and small ones (24-34 m) are of 339. There are 71% of the fleet in the Far East and 16% in Northern Basin.

In the RS class, fishing vessels have average age of 30.9 years, and transport refrigerator vessels have mean age of 29.5 years. As of July 2020, there were 271 catcher vessels of more than 60 m length with the RS class, 827 ones of less than 60 m length (excluding small-sized crafts), and 163 transport refrigerator vessels.

In the RRR class there were 114 vessels with average age of 37.1 years and 4687 small-sized vessels with average age of 21.7 years (2334 in suitable condition).

There are 12 companies that owned 11 or more vessels. For example, in the Russian Fishery Company (RFC) there are 14 large-capacity big autonomous freezing trawler (BAFT) of the "Pulkovskiy meridian" type (1288 prj.) and transport refrigerator vessel. Northwestern Fishery Consortium (NWFC) has 17 large and big trawlers and crabbers (modernized from medium trawlers), FOR Group has 11 large and big and 4 medium trawlers.

Most of the companies operate 1-2 vessels.

According to Yu. F. Kuranov, 224 fishing vessels (11 large, 9 big, 143 medium, 71 small a) operated in the Northern Basin in 2016. It is interesting to note that in 1990 there were 416 units of these vessels, i.e. there was a reduction of 46%. The part of large, big and medium-sized vessels over 20 years old is 96.0%. There are 17 ships built after 1995 (one large, 11 medium-sized of foreign construction, as well as 4 small-sized of Russian construction) [2].

69 operated before vessels were purchased in Europe, which were in operation (6 big, 52 medium and 11 small ones), that noticeably surpass the characteristics of vessels of the "Soviet" type in terms of search and navigation equipment, productivity, automation of technological processes control and the level of labor mechanization, speed and total vessel's power-to-weight ratio.

The existing large and big vessels of the "Soviet" design are also undergoing modernization with the replacement of factories and redevelopment with a significant increase in productivity in the field.

As a result, the specific catch per vessel and per 1 kW of power increased by an average by 1.6 times, and per 1 ton of displacement and one crew member increased by an average by 1.8 times.

However, the physical deterioration and obsolescence of the fleet require real measures to renew it.

New generation fishing vessels. As part of the "investment" approach adopted by the government of the Russian Federation, 43 trawlers and longliner trawlers will be built at Russian shipyards by the end of 2025, including 25 ones for the Northern Basin and 18 ones for the Far East Basin (11 ones of over 108 m long). The total amount of private investments will be over 166 billion rubles. 35 vessels for crab catching were added the mentioned amount.

In total, 78 vessels have been ordered for the moment.

Marine Engineering Bureau is actively involved in the fishing vessels building program (see Figure 1).

The head crabber-processor "Zenith" of the KSP01 prj. is put into operation already (see Figure 2), and another 27 vessels are under construction, namely 11 large-capacity ST-192 trawler-processors the Far East, 4 big KMT01 trawler-processors, 4 big KMT02 trawler-processors, 5 KSP01 crabber-processors and 3 KSP02 crabber-processors (all for the Northern Basin).

In addition to the Russian shipyards, Turkish ones are actively involved, i.e. Tersan Shipyard in Yalova is responsible for "Zenith" crabber-processor, ST-192 trawler, ST-191L two trawlers; Ozata Shipyard in Yalova is responsible for three crabbers.

In 2018, the Spanish shipyard Zamacona converted a supply vessel (2009 built) into catcher vessel "Rem Star" for crab catch and salmon processing; company Luntos (Petropavlovsk-Kamchatskiy) was a Customer.

Several vessels are being constructed by orders of Russian fishermen, namely one vessel "Vard 8 02" (length of 80.4 m, frozen products productivity of 170 t/day) in Vietnam, 4 vessels in China.

"Zenith" became the first vessel in the world that was specially built for catching and deep processing of crab with boiling and freezing by brine. The ST-184 (aka KSP01) vessel "Zenith" arrived in Murmansk on April 22, 2020.

During the voyage from Turkey around the Europe, the vessel demonstrated excellent seaworthiness especially in stormy conditions. She was hit by serious storms for three times. In front of the Kola Bay the wind reached 30 m/s.

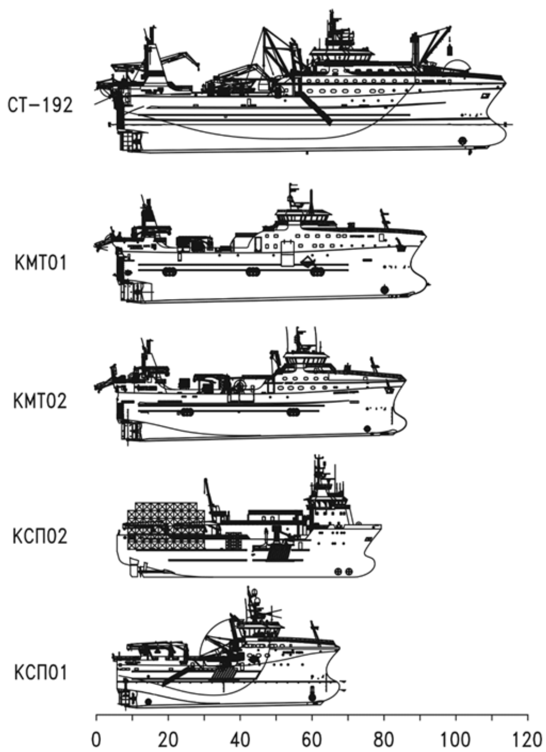

Fig. 1. Line-up of MEB fishing vessels

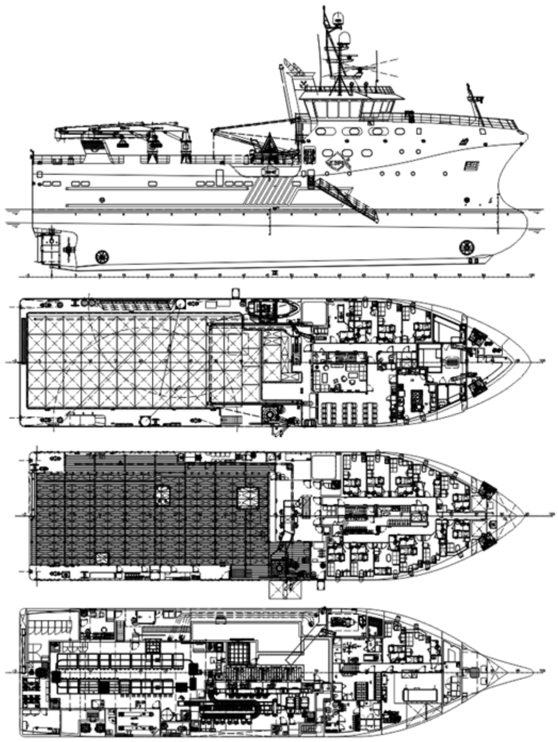

Fig. 2. General arrangement scheme for crabber-processor "Zenith"

The main purpose of the vessel is:

- catching kamchatka crab and opilio crab with help of cage traps of cone, trapezoid or rectangular form at the depth 20-400 m;
- processing of the caught crabs into boiled-frozen products;
- products storage in the freezing cargo hold;
- handing over of the frozen products ashore or to refrigerated transport vessels by cargo booms using "telephone" scheme while sea is up to force 5.

The main types of gathered crab are kamchatka crab and opilio crab (snow crab), as well as other crab types.

The processing capacity of raw materials is 30 tons per day for snow crab and 60 tons per day for the kamchatka crab. Productivity for completed frozen products is 20 tons per day for snow crab and 40 tons per day for the kamchatka crab.

Vessels characteristics:

Length overall about - 61.9 m;

Breadth - 15.0 m;

Depth till main deck - 9.25 m.

RS class notation is KM ✪ Ice3 AUT1 BWM(T) (REF) Fishing Vessel.

Navigating region is of unrestricted one; autonomy is 50 days.

The planned areas of operation are the North Atlantic including the Barents Sea, the Norwegian Sea, the Greenland Sea and the Arctic seas.

The crab processing complex provides the manufacture of boiled and frozen walking and claw-nosed limbs of brine freezing. In addition to the cargo freezer hold, the vessel has a freezer hold for storing bait and compartments for storage of packages and salt. The vessel is equipped with an electro-hydraulic crane of a rising complex with three independent booms, namely the upper telescopic one for working with traps, an intermediate one for the main power rising unit when working with liners, and the lower one for the rising unit for work with single traps.

There are two electro-hydraulic cargo cranes with folding boom and a specialized gripper with a bumper for traps aor handling traps, unloading products and loading bait in the port. Each crane has lifting capacity of 1.0 t at the maximal outreach of 20 m and 3.0 t at the outreach of 10 m. The cranes are controlled from the operator's cab of the crane as well as remotely using a portable radio remote control panel. The products are transferred to a transport refrigerator vessel or ashore in cardboard boxes.

Trawlers of the new generation, the construction of which began under the state program "Keel Quotas", significantly differ from those built in Soviet times, with similar or smaller sizes, by higher productivity, by modern factories and equipment for fishing, and by significantly higher level of automation.

For example, a trawler-processor with length of more than 105 m for the Far Eastern fisheries basin (investment object type A) with gross tonnage of at least 5000, according to the Government Decree tablmust have the production at least 75 t/day for fillets and (or) forcemeat from pollock and (or) herring; at least 40 t/day for fish meal and (or) fish oil or other products from production wastes; also there should be freezing equipment with a total products capacity of at least 150 t/day.

In fact, the ST-192 vessel that is being under construction for the RFC has length of 108.2 m, gross tonnage of 9065, displacement of 13600 t, the capacity of freezing holds 4500 m³, the capacity of the fishmeal hold 1000 m³, daily productivity of 80 t for pollock (herring) fillets (forcemeat), 250 t for fish meal and fish oil, 260 t for frozen products.

For comparison, the well-known BAFT of the "Pulkovsky Meridian" type (1288 prj.) built by the Black Sea Shipyard (which are currently operated by RFC) have length of 104.5 m, displacement of 5720 t, the capacity of freezing holds of 2140 m³, the capacity of the fishmeal hold 370 m³, daily productivity of 35 t for fish meal, fish oil, 60 t for frozen products.

Being under construction for the RFC ST-192 super-trawlers are the largest and most technologically advanced Russian fishing vessels. Each new vessel is designed for an annual catch of more than 60 thousand tons of fish, that is 2.5 times higher than the productivity of the vessels that currently form the basis of the fishing fleet in the Russian Far East. Investments in the construction of a series of 10 vessels exceed RUB 65 billion.

It is interesting to note that, according to A. I. Solomin, recoupment of such a new large-tonnage vessel is provided in about 9.8-13.4 years [3]. The calculations were carried out for two scenarios of the operation of the perspective BAFT of a new generation (that is very closed to the type A investment object in terms of parameters):

I. The vessel is used for the pacific pollock fishery. She specializes in the production of various products: healess pollock, fillets (for the Bering Sea), caviar (seasonal) and fish meal.

II. The vessel fishes for pollock during the period of the most stable accumulations, combining with the fishery for feeding herring in the period permitted by the fishing rules, receiving salmon in July-August, fishing for squid and greenling during favorable periods in July-September.

A trawler-processor of length of more than 80 meters for the Northern Fisheries Basin (investment object type 3) with gross tonnage of at least 3500, according to the Government Decree must have the production at least 21 t/day for fillets and (or) forcemeat from cod and (or) haddock; at least 7 t/day for fish meal and (or) fish oil or other products from production wastes; also there should be freezing equipment with a total products capacity of at least 60 t/day.

In fact, the KMT01 vessel that is being under construction at the Vyborg Shipyard has length of 68 m, gross tonnage of 5079, displacement of 7116 t, the capacity of freezing holds 2500 m³, the capacity of the fishmeal hold 350 m³, daily productivity of 40 t for fillets (forcemeat), 60 t for fish meal and fish oil, 100 t for frozen products, 5 thousand conventional cans for canned food.

The Vyborg Shipyard also constructs KMT02 vessel. They have length of 80.4 m, gross tonnage of 3786, displacement of 5694 t, the capacity of freezing holds 2650 m³, the capacity of the fishmeal hold 200 m³, daily productivity of 40 t for fillets (forcemeat), 48 t for fish meal and fish oil, 80 t for frozen products, 4 thousand conventional cans for canned food. Both the KMT01 and KMT02 vessels, with smaller dimensions, have a much higher functionality than the classic vessels of the 1288 prj. The characteristics of the new generation trawlers are presented in Table 1.

Of course, over the years, while the Russian industry did not build fishing vessels, the approaches to their design and equipment have changed; increase in productivity with decrease in size took place. Besides, the requirements of the Regulations often reflect, for example, the requirements of international conventions, in particular SOLAS, which don't apply to fishing vessels in principle. Considering that the fish processing plant is located below the freeboard deck and has a length of more than 80% of the ship's length, and the length of the freezing hold is 48-55% of the ship's length, it's became clear that it isn't possible to provide the same number of transverse bulkheads as for cargo vessels, and some of them, due to the length of the factory, cannot be extended to the freeboard deck. Therefore, this is not done at on modern Western fishing vessels.

Technical characteristics of the new generation trawlers

Table 1

Parameter	Project		
	ST-192	KMT01	KMT02
Length overall, m	108.20	86.00	80.40
Breadth overall, m	21.80	19.48	18.07
Breadth at the middle, m	21.00	17.00	15.40
Depth to the trawl deck,	11.55	10.10	9.10
Draught mean, m	8.35	7.10	6.55
Displacement, t	13600	7116	5694
Deadweight, t	5700	2844	2154
Speed, kn	15.0	15.0	15.0
Crew, pers	139	49	46
Capacity (kW) and type of ME	8120 (14V32/44CR)	6000 (10L32/44CR)	4640 (8L32)
Frozen products productivity, t/day	260	100	80
Fish meal and fish oil production (due to raw material), t/day	250	60	48
Canned food production, ths.conv.cans/day	-	5	4
Total freezing holds capacity, m³	4500	2500	2050
Fishmeal hold capacity, m³	1000	350	260

The requirements for emergency escape from ER compartment are also implemented rationally at modern concepts; they are made where it is really necessary, not by formal requirements, for example, as for incinerator room. Stationary local fire extinguishing systems inside machinery spaces are also not used onboard new fishing vessels.

On modern fishing vessels, footboards in the ER are made of aluminum because of less weight, comfort handling, DW increasing etc. RS rules require steel manufacture of such elements (requirements are taken from SOLAS which does not apply to fishing vessels). There are peculiarities in design of hull structures. For example, in view of the presence of bulbous fore end, definition of the effective hull length requires a special approach.

Today for the vessels mooring at sea, structures that formally are located in the area that requires reinforcement, category D steel have to be used. However, studies carried out by the Marine Engineering Bureau show, that at refrigerated vessels and tankers waves doesn't reach to the constructions of the area "C" located above the waterline; so requirement for category D steel is clearly excessive and the use of steel of category A is quite acceptable. Such hard requirements for the high-located constructions have appeared in connection with frequent mooring to high-depth bases; this moment this is no longer so relevant for new vessels.

At the fishing vessels due to the reduction in size of compartments and high equipment saturation, cutouts are made in the structures adjacent to the outer shell for passage of systems and cable routings. Taking into consideration that the upper zone of ice reinforcement is located between the main and trawl decks, analysis of the structural strength and justification of cutouts in areas of ice reinforcement is required. Steel is the main shipbuilding material. High-strength wear-resistant steels (with yield point above 390 MPa) are in demand for the construction of new generation fishing vessels, including projects ST-192, KMT01, KMT02. These are trawl decks and slip (steel such as Strenx 700, Hardox 450). The acting RS Rules do not allow the strength calculations for the structures made of these steels (500 MPa, 690 MPa, etc.), that, in turn, does not make it possible to realize the noticeable advantages that they give.

Another feature of the modern fishing vessel is the variable frequency of the power plant (50/60 Hz). As a rule, the power plant consists of one main diesel connected to the shaft and an variable pitch propeller in fixed nozzle through reducer and elastic coupling. The main engine is medium-speed (for example 750 rpm), with a smooth (limited combinatorial) continuous mode of operation (for example, from 750 till 620 rpm), while the current frequency produced by the shaft generator is variable in the range from 60 Hz till 50 Hz.

Vessel's electric power plant includes (at KMT01, for example):

1. Main generator unit of 900 kW at 1200 rpm, voltage 3 x 440 V, 60 Hz;
2. Main generator unit of 500 kW at 1200 rpm, voltage 3 x 440 V, 60 Hz;
3. Emergency generator unit of 120 kW at 1800 rpm, voltage 3 x 440 V, 60 Hz;
4. Shaft generator unit of 3200 kW at 1200 rpm, voltage 3 x 440 V, 60 Hz and 2222 kW at 1000 rpm, voltage 3 x 400 V, 50 Hz;
5. Rotary transformer, providing undistorted stabilized electricity 230 V, 60 Hz at a supply voltage of 400-440V, 50-60 Hz.

Fuel of more than 600 m³ is stored in tanks without double bottom and double sides. Fulfillment of the requirements of Regulation 12 A of MARPOL is ensured through the calculated justification of the outflow of oil products and comparison with the normative value.

For information, the total capacity of fuel tanks is (about): - 1780 m³ > 600 m³ st ST-192; - 980 m³ > 600 m³ st KMT01; - 905 m³ > 600 m³ st KMT02.

On June 23, 2020, JSC "Admiralty Shipyards" launched the second 108-meter large-capacity ST-192 trawler-processor "Mekhanic Maslak". Vessel's keel was laid down on 08.04.2019. A series of ten vessels is being built for the RFC under the quotas for the Far East. Main aim of the vessel is catching pelagic and near-bottom pelagic type fish, also manufactory of frozen production during the voyage; with full cycle of take processing onboard vessel directly. The main types of catching fish: pollack, herring, mackerel. The main types of products are: headless and gutted fish, fillets, pollock roe (frozen), surimi, as well as fish meal and fish oil.

Production storage is provided in the main refrigerating hold (capacity 4250 m³) after processing and freezing. Fishmeal and other frozen production are stored in 2 holds (capacity 400 and 600 m³). Also 300 m³ hold is foreseen for storage of carrying carton, fish meal and other production. Storage of fish oil is provided by 2 tanks of 100 m³ summarized capacity made from food stainless steel. The vessel is equipped for work with single trawl. Fully equipped fish processing system provides water pumping through refrigerated fish tanks, sorting, processing, freezing, packing, storage and unloading of production. production freezing will be carried out in horizontal automatic plate freezers of summarized capacity 260 t/day. Equipment for surimi production with separate laboratory is foreseen, it capacity is 80 t/day. There is also fish meal plant with daily processing of 250 t of raw material.

Transportation of prepared production and packaging material through the vessel is carried out with help of two cargo elevators and special cargo conveyor within freezing holds.

Arrangement of 40 crewmembers is provided at comfortable single or double cabins, and factory staff (max. 99 people) is arranged at single, double or four-bed cabins. Onboard the vessel there are separate mess-rooms for officers and other crew with self-service zone, crew recreation room, all necessary medical, sanitary-common and sanitary-hygienic rooms in accordance with requirements of Sanitary Regulations for Fishing Vessels. Additionally, there are cinema hall, sport complex including the gym, saunas.

Passive roll damping system is foreseen for providing comfortable conditions at non-fully loading conditions. Diesel oil is used as working liquid in the roll damping system.

CONCLUSIONS

The existing large and big vessels of the "Soviet" design are also undergoing modernization with the replacement of factories and redevelopment with a significant increase in productivity in the field. However, the physical deterioration and obsolescence of the fleet require real measures to renewing it. Such process has recently begun and must bring the fishing fleet to a fundamentally different level of productivity, processing depth, increased added value and, in general, the role in the country's economy as a powerful export tool.

For the moment, 78 new generation vessels have been ordered.

Marine Engineering Bureau is actively involved in the fishing vessels building program: the head crabber-processor "Zenith" of the KSP01 prj. is put into operation already (see Figure 2), and another 27 vessels are under construction, namely 11 large-capacity ST-192 trawler-processors the Far East, 4 big KMT01 trawler-processors, 4 big KMT02 trawler-processors, 5 KSP01 crabber-processors and 3 KSP02 crabber-processors (all for the Northern Basin).

Each fishing vessel is custom-built and this is a normal world practice. There are no large series abroad, especially for large-capacity trawlers. They are very expensive; the comfort effect is a very important factor in technological terms because efficiency of fishing depends on comfort. Non-serial production in fishing shipbuilding is inevitable and corresponds to world experience.

As the experience of building a new fleet under RS supervision has shown, the imperfection of RS Rules led to the need to adjust them directly during the construction process, which was reflected in the design process itself: the use of high-strength steels, the requirement for emergency escapes from ER, material for footboards, meeting the requirements of Regulation 12A of MARPOL, etc.

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SDS18 MULTIFUNCTIONAL DIVING VESSEL - CATAMARAN AS EFFECTIVE ALTERNATIVE OF EXISTING DIVING FLEET REPLACEMENT

Gennadiy EGOROV*, Dmitriy CHERNIKOV**

Abstract. *The analysis of native diving fleet in operation is executed. 60% of diving vessels are in operation with exceeded life term, the oldest vessel "Diver-5" is 62 years old. The further operation of old vessels is associated with risk increase of ensuring maritime safety and high cost of funds for their maintenance and repair. Most vessels are outdated. Necessity of building of new generation multifunctional diving vessels with large open deck with fastening equipment, dynamic positioning, well for divers and equipment, special personnel accommodation is shown. The concept of diving catamaran is developed, basic characteristics are defined. Comparison with existing diving vessels is made. Hull contours of multifunctional diving catamaran vessel by means of model trials in experimental tank and CFD modelling have been created and optimized. Basic functions and equipment installed on the vessel are described.*

Key words: *catamaran, design, equipment, diving complex, hull contours, multi-functionality, salvage vessel.*

INTRODUCTION

According to the FBE "Morspassluzhba" [1], for 2019, the rescue fleet of the Russian Ministry of Transport includes 41 diving vessels, the average age of the vessels is 25 years. 60% of diving vessels are in operation with exceeded life term, the oldest vessel "Vodolaz-5" is 62 years old. The further operation of old vessels is associated with risk increase of ensuring maritime safety and high cost of funds for their maintenance and repair. Most vessels are outdated.

In connection with the problems mentioned above, it is necessary to update the diving fleet to replace the technically outdated diving vessels.

AIM OF THE PAPER

Justification of the main characteristics of modern multifunctional vessel.

MAIN TEXT

Analysis of the characteristics of existing rescue vessels and functions that they actually fulfill in Russia and other countries, as well as modern analogues, shows that the general trend is building of multifunctional vessels with the possibility of using of modular removable equipment (and, accordingly, the presence of an open deck of sufficient area with fastening means), increasing the power of the power plant and the device for dynamic positioning [2].

A consequence of this interest was the design of the project of a new SDS18 multifunctional diving catamaran vessel (MDV) by Marine Engineering Bureau.

On December 1, 2016, at the Navashinskaya Oka shipyard, a solemn laying of the keel of the SDS18 sea diving catamaran "Igor Ilyin" took place, the launch took place on July 26, 2017. On October 12, 2017, i.e. in less than 11 months, the lead vessel was put into operation (see Figure 1).

SDS18 (see general arrangement on Figure 2) vessel is a single-deck steel double-hull catamaran with cross-structure, with deck-house and wheelhouse made of aluminum-magnesium alloy, with an elongated forecastle, with deck-house and wheelhouse located fore, with aft open cargo deck, with 2 full-turn rudder propellers and 2 bow thrusters, with engine rooms located in the side hulls of the catamaran. Navigation zone includes marine regions matching to R1 area. Radio equipment provides operation in areas A1, A2, A3.

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Functions of MDV SDS18 project:
- providing of diving and underwater works on depth till 60 m and at sea state up to force 3;
- participation in rescue and ship-raising operations;
- placing and providing work of the research parties in accordance with installed technical means;
- inspection of a sea-bottom, sink objects, underwater part of ship's hull and waterside structure's;
- providing of remote operated deep-water vehicle using at sea state up to force 3.

Fig. 1. The lead vessel of the SDS18 series "Igor Ilyin" on the slipway before the launch

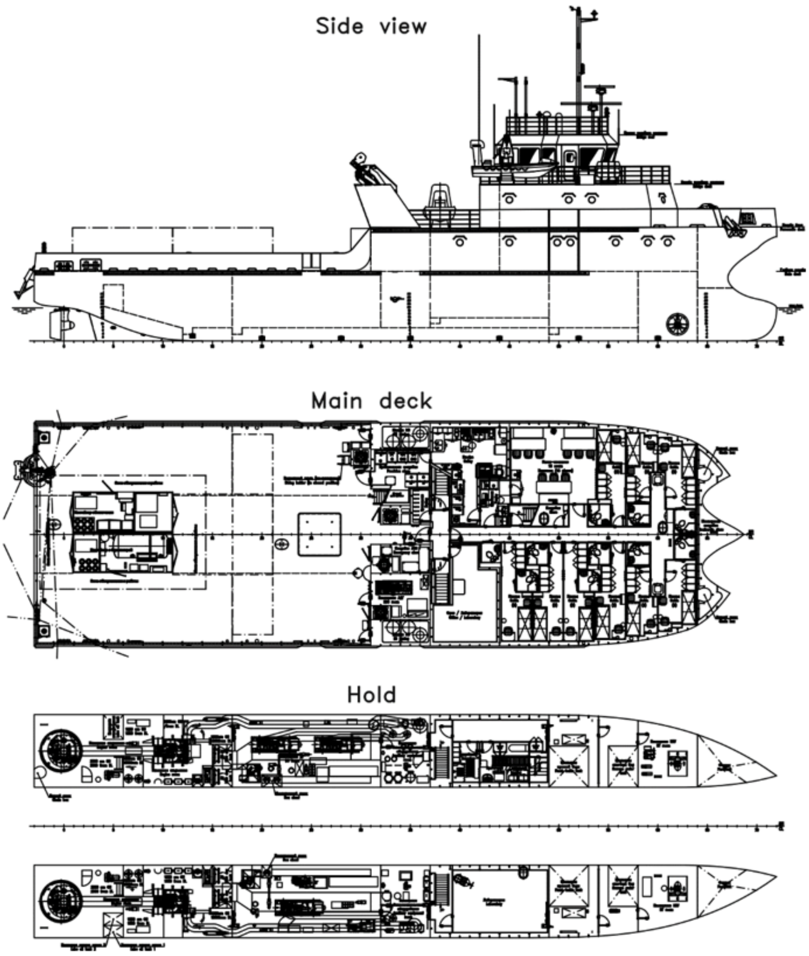

Fig. 2. General arrangement of the MDV SDS18 project

Therefore, when determining the main dimensions of the catamaran vessel and the shapes of the hulls, the following factors were decisive:

- the choice of the length and total width of the catamaran vessel is due to the need to provide an open working deck with large dimensions to accommodate equipment;
- based on the running characteristics of the catamaran, the width of each hull should be minimal, while it is necessary to ensure the arrangement of the main mechanisms with safe areas for their servicing;
- the choice of vertical clearance is influenced by the need to reduce the probability of wave impacts on the lower surface of the connecting bridge, while the significant depth should not interfere with the carrying out of diving works, which is the main function of the vessel;
- it is necessary to ensure the optimal values of the horizontal clearance at the same time, when choosing the total width of the vessel and the width of the hulls;
- the sea conditions of the SDS18 project require the creation of a vessel that has good ship seaworthiness.

Based on this, the main dimensions were determined (the main characteristics of the vessel, see Table 1), while the vessel was made with an elongated forecastle extending to the midship, which provided a high freeboard in the bow and a low freeboard in the area of the working platform for descent of divers.

The vessel is a catamaran with symmetrically located hulls, united in the freeboard part. Fore ends of the hulls have a stem shape that is specific for bulbous contours, and pointed waterlines. An overhanging fairing with a sharpened stem in the CL is located in the freeboard part between the hulls. In the bow, the stem is displaced towards the CL. The stern ends are transom, adapted for the installation of full-turn rudder propellers, have a simplified bottom shape formed by straight waterlines and a skeg-stabilizer before the propellers.

Model tests of the MDV were carried out in the experimental gravity pool of the Odessa National Maritime University named after prof. A.A. Kostyukov to assess the running characteristics of the vessel during designing. 1:20 scale model was used (see Figure 3).

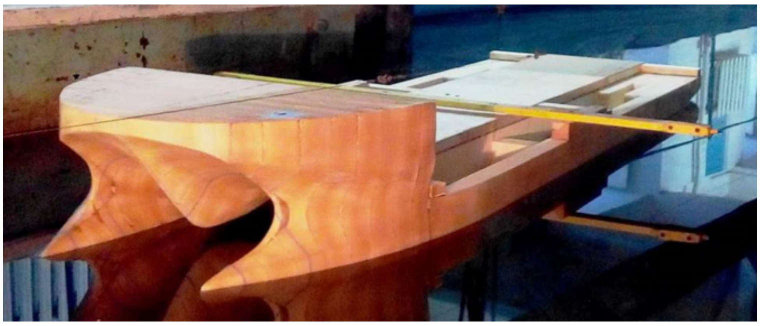

Fig. 3. Model before harnessing to the pool towing system

The results of numerical, model and full-scale tests confirmed the accepted dimensions of the vessel and the shape of the hulls to achieve the contract speed of 11.5 knots with a propulsion power of 2 x 634 kW and a draught of 2.0 m.

Visualization of the water flow around the vessel's hull at a speed of 11.5 knots (= 0.288) is shown on Figure 4.

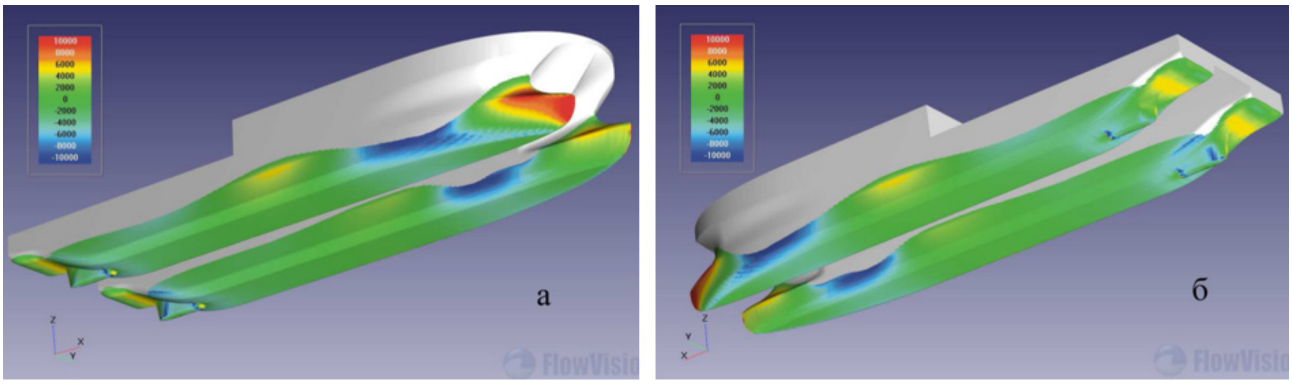

Fig. 4. Pressure distribution based on CFD modeling results

Main characteristics of the SDS18 project marine diving catamaran vessel in comparison with similar vessels

Table 1

Parameter	SDS18 project	SDS08 project	535 project
RS Class	KM ★ Ice1 R1 AUT3-ICS OMBO DYNPOS-1 Catamaran Special purpose ship	KM ★ Ice2 R2 AUT3-C OMBO SDS≥60	KM ★ Л4 II
Length overall, m	46,20	38,35	40,90
Breadth overall, m	13,72	7,90	8,00
Depth, m	4,20	3,20	3,50
Draught, m	2,50	2,35	2,07
Displacement, t	810	455	306
Full speed, kn	11,5	12,0	12,0
Vessel economic speed, kn	10	8,0	-
Range of sailing, mm	4500	500	1500
Autonomy, days	25	4	10
Power of ME, kW	2 x 634	2 x 442	2 x 220
Crew/ places (special staff)	7/12 (18)	12 (7)	20 (7)
Diving complex	- modular diving complex for diving operations at depths of up to 60 meters; - diving mine (mine can also be used for drilling); - diving ladder.	- HYTECH pressure chamber with an inner diameter of 1.6 m, two-compartment, flow-decompression, with a closed ventilation system, with a set of BIBS masks, with a water fire extinguishing system, for 4 divers; - monoblocks of cylinders with compressed helium - 6; - monoblocks of compressed oxygen cylinders - 2; - tanks for storing compressed air BK-100-250AB - 12; - Bauer KAP 150-11NH compressor with electric drive - 2; - Mariner 250-E compressor with electric drive; - compressed air supply system to the pressure chamber; - divers breathing compressed air system (post of the head of launches) for three divers with a communication system and television control; - diving half-cone with launching gauge; - diving ladder; - equipment for a working diver - 2; - equipment for a half-cone operator; - divers water heating means for three divers.	- modular diving complex for diving operations at depths of up to 60 meters.
Means for carrying out of UTO	- the main deck can accommodate various modular units, including diving complexes, underwater robots, remotely controlled underwater vehicles, etc.; - loading device with a lifting capacity of 1 t with an outreach of 25 m	- diving television complex; - means of underwater lighting; - hydraulic unit with a set of tools for underwater work; - loading device for lowering and lifting hydraulic tools, as well as lifting objects weighing up to 3 tons from a depth till 100 m; - means for underwater electric arc welding, electro-oxygen and exothermic metal cutting; - soil washing and drainage systems; - pontoon blowdown system; - remotely controlled underwater vehicle.	-
Maximum depth of the work	60	100	60
Absence and area of cargo deck	250	No	No

The vessel is equipped with modern equipment for diving and auxiliary rescue operations to carry out the main functions. A feature of the concept is the presence of an open part of the main deck with an area of 250 m². The arrangement of a diving complex for diving operations using compressed air for breathing at depths of up to 60 meters in a mobile container of 2 twenty-foot containers is provided on the deck. For fastening containers of the international standard (TEU), container pockets, as well as eyes and eyes-bolts are installed on the cargo part of the main deck. In total, it is possible to install 8 twenty-foot containers and other modular units (diving complexes, underwater robots, remotely controlled underwater vehicles, etc.) with a maximum mass of deck cargo of 141 tons.

Special mine and diving ladder on the main deck in the middle part of the vessel are foreseen for divers. The mine can also be used for drilling and launching of other equipment. The mine has hydraulic closing that opens outwards down to the connecting bridge.

Ship's motion and maneuverability provided by two aft full-revolving rudder-propellers with fixed-pitch ducted propellers. For improvement of controllability at low speeds, at passing narrow waters and at moorings the bow thruster of the "screw in a tube" type with a fixed-pitch propeller (FPP) is foreseen on the ship. Diving and other underwater technical works are provided by the DYNPOS-1 dynamic positioning system. The system is intended for reliable continuous keeping of the catamaran vessel relative to a given reference point and following the vessel in automatic mode along a predetermined trajectory. The system controls the rudder propeller and thruster using mathematical modeling of the vessel's maneuvering, which provides the required positioning accuracy for various operating modes. The dynamic positioning system is controlled from the bridge.

The sonar positioning system consists of positioning system with ultra-short base Ranger 2, transponder for dynamic positioning consisting of buoyancy device of 870-0251 type (up to 3000 m) and alkaline battery.

For search and rescue operations, the catamaran vessel is equipped with a search installation with an infrared camera, which allows detecting small floating objects and people at a distance of about 7 and 2 miles, respectively.

In order to provide the research party provides two laboratories (17 m² office / laboratory on the main deck on the starboard side, an area of 22 m² laboratory in the right catamaran housing).

Total places number is 31. The crew of 7 people is accommodated in two single block cabins (captain, chief mechanic), consisting of an office-salon, a bedroom and a bathroom, and five single cabins with individual bathrooms with a shower. The cabins have one additional berth for the crew (folding berth of the second tier). There is a single block cabin consisting of an office and a bedroom with an individual bathroom with shower on the deck of the tank for the ship owner. Special staff of 18 people are accommodated on the main deck in the bow in nine double cabins with individual bathrooms with shower. Saloon for 16 seats on the main deck on the port side is foreseen for crew and special staff.

The vessel hulls are designed on the Ice 1 ice class. Design service life of the vessel's hull is 24 years. As a material for main hull structures there is used the shipbuilding steel of D grade with yield strength of 235 MPa and 355 MPa. Transverse frame spacing is 600 mm. Longitudinal frame spacing is 550 mm. Cargo area of the main deck (along transom - 23 fr. and over the entire width except the way along of bulwark – 965 mm) is designed for intensity of the distributed load of 5,0 t/m². Bottom and double bottom in the middle part of the vessel are designed by the longitudinal framing system. Transverse framing system is in the ends. Main, Forecastle and Bridge decks, Bridge roof, bottom, side are designed by the transverse framing system.

The vessel is equipped with two bow higher holding power anchors with weight of 765 kg each and with one stern higher holding power anchor with weight of 585 kg. Mooring operations are provided with help of anchor-mooring winches and anchor-mooring capstan.

The rescue boat with 6 persons capacity is mounted on the bridge deck on the starboard side. The landing and launching of the boat is performed by davit. Vessel is equipped with work craft of RIB type. It has individual saving means, a portable communication facility and a portable projector. There are 4 life rafts with 16 persons capacity each (2 rafts on each side) at the vessel.

One hydraulic cargo crane-manipulator is installed on the portside with lifting capacity of 1 tons with outreach 25 m.

The main unit consisting of two diesel engines by the maximal continuous rate of 634 kW, working for 2 full revolving rudder propellers. Auxiliary plant consisting of three diesel-generators of electrical power about 300 ekW and emergency diesel-generator of electrical power about 50 ekW.

The scope and degree of automation of technical means of the vessel corresponds to the sign AUT3-ICS of automation in the ship class symbol in accordance with RS Rules.

The vessel started to work according to its purpose almost immediately after putting into operation.

According to Interfax, at the end of 2017 - beginning of 2018, multipurpose marine SDS18 diving vessel-catamaran “Igor Ilyin” takes part in preparations of the route for future gas pipeline “Nord-Stream-2”.

Advisor of the general director of the SPA Special Materials Yuriy Klenov told to Interfax that destruction of naval ammunition of Great Patriotic War time, found on the route of the future Nord Stream-2 gas pipeline, is carried out with help of the innovative Aquaschit technology for the first time.

The work was provided by the SDS18 catamaran vessel “Igor Ilyin”.

Usage of the Aquaschit technology has provided reliable protection of the ichthyofauna from the high-explosive impact during destruction of explosive objects”, Klenov said.

The search and destruction of the naval ammunition is being operated by undersea robot. “The newest technologies of underwater demining applied at the project “Nord Stream-2” provide maximum guarantees of quality and environmental safety” underlined Klenov.

He mentioned that the practical usage of the Aquaschit technology, developed by the SPA Special Materials and the Engineering and Technical Center for Special Works under the direction of Corresponding Member of the Russian Academy of Sciences, Sci.Dr., Professor Mikhail Silnikov, has a great future, as it provides minimum negative impact to the environment and avoidance of deth of marine life.

Table 1 shows a comparison of the main characteristics of SDS18 marine diving vessel with similar vessels. Combination of the equipment installed on the vessel, the ability to change mobile equipment in container design, a large open deck, as well as a powerful power plant with full - turn rudder propellers and dynamic positioning, allow vessel to solve almost any specialized tasks associated with underwater technical work at depths till 60 m (see Figure 5) and compares favorably with almost all vessel-analogs.

Fig. 5. The lead vessel “Igor Ilyin” of the SDS18 series. Author of photo: Ivan Borodulin

Project SDS18 of multipurpose marine diving vessel-catamaran “Igor Ilyin” has been named as the best innovative solution in the sphere of transport technology in the competition of innovative technologies among the transport firms “Motion Formula”. The results of the competition were summed up on December 7, 2017 at the XI International Forum “Transport of Russia - 2017”.

CONCLUSIONS

A modern SDS18 multifunctional diving catamaran vessel has been created, the characteristics of which have been confirmed by operation.

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ANALYSIS OF THE IMPACT OF THE UNIFIED MAIN DIMENSIONS ON THE PRODUCTIVITY OF SHIPBUILDING *SME*

Yordan DENEV, Petar GEORGIEV

Abstract. *The aim of the presented study is to evaluate the effect of the unified breadth and depth of a series of multi-purpose ships with deadweight 5000, 6000, 7000 and 8000 tDW, to build in the condition of an Small and Medium Enterprise (SME). The breadth of the ship is limited due to the available shipbuilding facilities. Accepting the depth of the biggest ship in the series leads to an increased freeboard for the rest. The paper presents the impact of the increased freeboard on steel mass, cargo capacity, intact stability and gross tonnage. For the listed qualities of the ship, qualitative and, where possible, quantitative assessments are presented. Finally, the productivity of construction of both individual and all ships in the series was estimated.*

Key words: *CGT, increased freeboard, MPV, productivity in shipbuilding, SME.*

INTRODUCTION

Currently, different approaches are being sought to reduce production costs, especially for such a large-scale and complex engineering product as the ship. “Design for Manufacturing” is one of the “Design for X” approaches applicable in ship design [1], [2] . The goal in this approach is to combine the design and production together in reducing production cost without sacrificing design performance or product quality. The main directions are simplicity in design; design based on shipyard facilities and other production considerations such as: simplified hull forms; avoidance of double curvature and large single curvature; developable surfaces; use of maximum plate sizes; transom stern; constant hold or tank length etc.

Modularization is a modern trend for which a significant number of applications can be identified. A detailed overview of the various examples of the application of modularization to ships is presented in [3]. This review also indicates the publication of Prof. Georgi Parashkevov (TU-Varna) related to the modular construction of bulk carriers[1].

In [4] authors proposed an estimation procedure for effectiveness of ship modular outfitting. In the paper, the cost savings are expressed in monetary units instead of working hour consumption. The reason for this is that in a group of workers engaged in the same work task, the man-hour cost for each worker is not identical, due to the education level, working skills and competence as well motivation of workers.

In the study [5], some improvements with regard to outfitting and piping assembly operations were carried out on the shipyard. The improvements were applied on the block assembly station. It was shown that if the outfitting and the piping assembly operations are carried out in earlier stations instead of the block assembly station, this may increase the throughput by 33%.

Recently, the study [6] presented a new method of modularization of the ship piping system inside the engine room. The method utilizes Design Structure Matrix (DSM) as a network modelling tool to represent elements that pervade a system and their interactions. The method is demonstrated by compressed air piping and seawater piping systems. With the evolution of ship size and technology in general in the shipbuilding they are more widely used for prefabrication, modularization and partitioning [7]. All these three modern approaches lead to decreasing of the construction hours and shortening the delivery time while maintaining high quality.

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The "design for modularity" [8] is defined as explicit actions towards sub-dividing the ship into well-defined parts and components that can later be recombined according to given rules and procedures. The approach can be applied at all phases of a ship's life cycle. In design the modularity may be used to configure an efficient ship towards specific customer needs. In the construction it will allow for the attraction of turn-key suppliers, enabling a high degree of pre-outfitting. During the operation the modularization supports flexibility towards missions, markets, and technical and regulatory changes.

Hull Form Modularization [1] means that portions of the shape of the hull form can be modularized with the standard shape. If these modules can have variations, it is possible to generate different overall hulls. A good example for this is the utilization of the following three modules - aft body, midship and fore body for design of a product mix for a medium-sized shipyard consisting of a 500-700 TEU container feeder vessel for short sea operations, a products tanker of about 10,000 dwt for coastal and short sea voyages, and a 10,000 dwt bulk carrier and a multipurpose cargo vessel. The variation in the mid body area includes length, bilge radius (midship area) and prismatic coefficient.

The aim of the presented study is to evaluate the effect of the equal depth and breadth for a series of four multi-purpose ships with deadweight 5000 - 8000 tDW. The design of these ships is part of a bigger investigation concerning development of a method for ship design and construction, taking into account the conditions of shipbuilding SMEs [9], [10]. The vessels are designed to take into account the limitations of the construction rail slipway of the SME, which limits the width of the ships to 16 m. The study answers the question what will be the effect of equal depth of the ships. With equal depth and breadth, the cylindrical part of the ships will have the same cross section and different length. Accepting the depth of the biggest ship will result in an increased freeboard for the rest of the series.

The next chapters consecutively present the evaluation of the increased freeboard, and corresponding influence of steel weight, cargo volume, intact stability and gross tonnage of the ships. Finally, the productivity of construction of both individual and all ships in the series was estimated.

INCREASED FREEBOARD FOR SERIES OF *MPV*

The main dimensions of the series of four multi-purpose vessels (MPV) are presented in Table 1 [9], [10] and the hull of one of the ships is shown in Figure 1.For all ships in the series the same percentage from length between perpendiculars (Lpp) and height is assumed, for superstructures (forecastle and poop) (Figure 2). The height of the double bottom and the double side is the same for all ships. The smaller ship in the series is with one hold, the second one with two and the last two ships are with three cargo holds.

The free board calculation is carried out according to the International Convention on Load Lines (ICLL [11]). For actual sheer, a percentage from the standard values was accepted as follows: fore and aft terminal 60% and 45 % from the standard one; for ordinate of 1/6L 35% and 0.5% respectively. The summary of the results is presented in Table 2. The value of dFb_0 means that the obtained from the software system *Expert* optimum design solution is with greater depth [9]. One reason for this is limitation in the breadth and the need to provide the required cargo volume without significantly increasing the length of the ship.

Main characteristics of series of an MPV

Table 1

DW, t	5,000	6,000	7,000	8,000
L, m	88,63	106,60	120,62	135,06
B, m	16,00	16,00	16,00	16,00
d, m	7,08	6,88	6,67	6,57
D, m	8,81	8,93	9,03	9,17
L / B	5,54	6,66	7,54	8,44
B / d	2,26	2,33	2,40	2,44
L / D	10,06	11,93	13,36	14,73
Cb	0,69	0,721	0,772	0,812

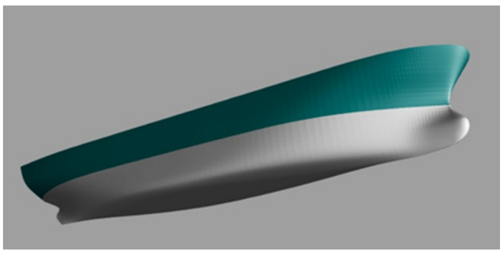

Fig. 1. Hull of one of the ships in the series [10]

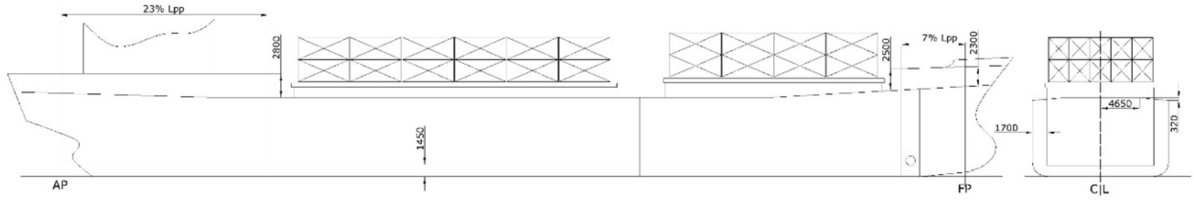

Fig. 2. Side view of a ship from the series

Summary table from free board calculation

Table 2

Item	Values			
Deadweight, t	5000	6000	7000	8000
Depth (D_0) ,m	8.81	8.93	9.03	9.17
Length of the ship acc. To ICLL (L_{ICLL}),m	90.046	107.924	121.312	136.573
Increased Freeboard (initial design)-dFb_0, m	0.084	0.138	0.229	0.267
Increased freeboard at unified depth, dFb_1 m	0.444	0.378	0.369	0.267
Actual increased freeboard - $\delta Fb = 9.17 - D_0$, m	0.360	0.240	0.140	0.000
Increased freeboard δF as percentage from, D_0	4.09%	2.69%	1.55%	0.00%

SHIP FEATURES AT INCREASED FREEBOARD

Steel structures

The influence of the increased freeboard on the steel structure is estimated based on models for the midship section (Figure 3) and transversal bulkheads (Figure 4) developed by MARS 2000 software [12]. The geometry characteristics of the framing are shown in Table 3. The relation between actual and rule Modulus (R_{mod}) for the deck and the bottom structures for all ships is presented in Figure 5.

The increase of the additional steel mass is estimated, taking into account the length of the cargo part of the ships (between the collision and ER bulkheads) and the mass of any additional structures per 1 meter. The extra mass for all bulkheads is also taken into account. Figure 5 presents the relation between the actual and required Modulus for midship while the increase of the steel structure mass is shown in Figure 6.

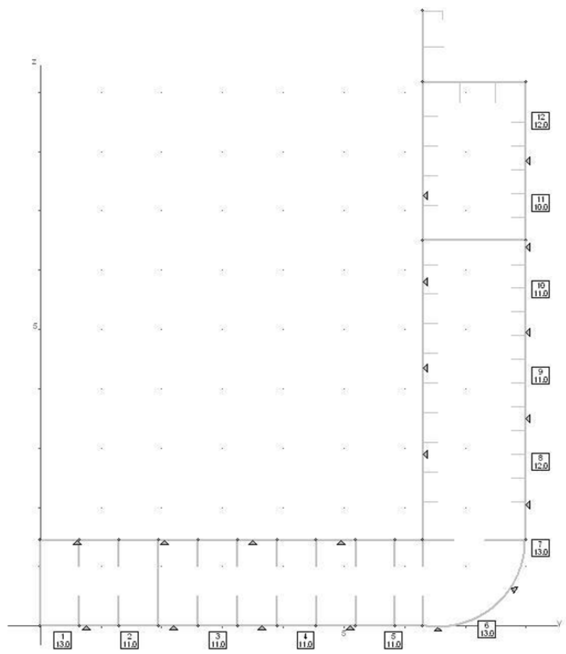

Fig. 3. Model of midship section in MARS 2000

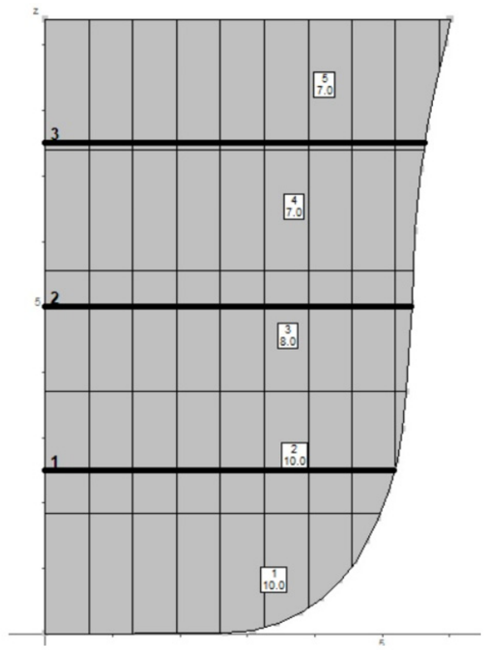

Fig 4. Model of the collision bulkhead in MARS 2000

Geometry of the hull structure

Table 3

Long. spacing in DB, mm	750
Transv. spacing in DB, mm	650
Long. spacing in inner side, mm	2250
Height of DB, mm	1450
Depth of inner side, mm	1700

Increased mass (kg) of transversal bulkheads

Table 4

DW, t	5000	6000	7000
ER Bhd	459	361	199
Coll. Bhd	133	132	210
Bhd No 1	-	316	211
Bhd No 2	-		209
TOTAL	592	809	829

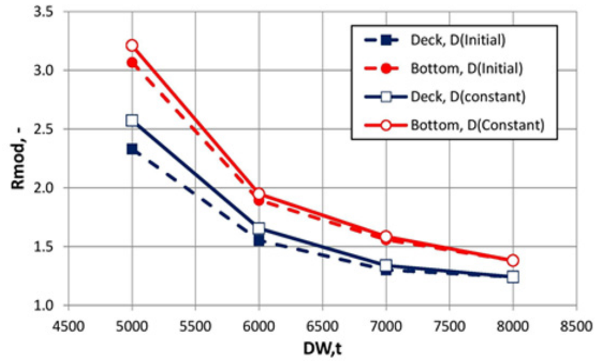

Fig. 5. Relation b/w actual and required Modulus for the ships

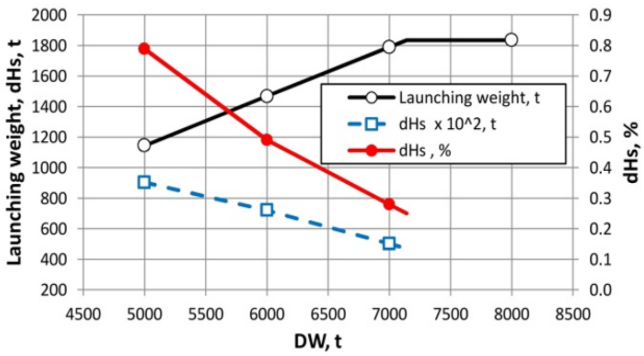

Fig. 6. Increased hull steel mass in t (left axis) and in % from the launching LW (right axis)

The relation between the actual and rule modulus for the variants with constant depth is a little bit higher but the thickness of the shear streak, and the plate from double side near the deck, is the same for both of the variants. The increased steel structure mass is less than 1 % from the launching LW of the ships, presented in Figure 6 as well. The launching weight is limited for ships greater than 7150 tDW by the permissible capacity of 1835 t of the available slipway of the SME. The extra steel structures due to the increased freeboard are in the range of 9 to 5 t for ships with 5000 - 7000 tDW respectively.

Cargo volume

The influence of the increased freeboard on the cargo capacity is positive. The cargo volume (CV) will increase without changing the number of container places (Figure 7). At this stage of the study, no detailed tank arrangement is provided. The definition of cargo volume takes into account the height of the double bottom and the double side. No special consideration for the forward (aft) part is made. The summary of results is presented in Table 5. The increase of cargo volume is in the range from 1.2% to 4.7% and the increase for vertical centre of gravity (ZG) is from 1.2% - 3.4%.

Summary for cargo volume

Table 5

DW, t	5,000	6,000	7,000
CV_0, m^3	5855.6	7176.9	8427.8
CV_1, m^3	6131.4	7390.3	8570.8
ZG_0, m	5.360	5.443	5.420
ZG_1, m	5.540	5.557	5.487
XG_0, m	50.788	61.158	70.121
XG_1, m	50.788	61.119	70.092
Increase CV,%	4.71%	2.97%	1.70%
Increase ZG,%	3.36%	2.09%	1.24%

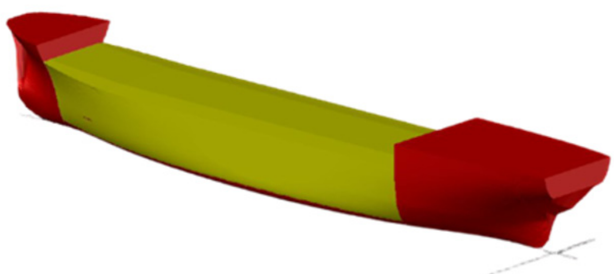

Fig. 7. Ship with DW = 5000 t and marked cargo area

Intact stability

It is known that increasing the depth of the ship has a positive effect on the reserve buoyancy and the parameters of the static stability diagram. The goal of this study was to estimate this effect quantitatively.

Recently, the impact of the freeboard on dynamic stability has also been analysed [13]. The probability of loss of stability of a small multi-purpose ship exposed to irregular transverse waves and random transverse wind is calculated in a series of numerical experiments in which the freeboard is changed systematically. The on-board effect is quantified by the range of metacentric heights, providing sufficient stability from a probabilistic point of view. The investigation showed that if the freeboard increases by 50 cm, i.e. 2.50 m, the probability of loss of stability drops from 10^{-3} to 10^{-8}, and the minimum metacentric height decreases from 0.4 to 0.2 m.

The influence of increased freeboard on intact stability is presented by the increase of the angle of deck edge immersion (q_{de}) and curve of maximum permissible vertical centre of gravity (KG_{max}) according to [14]. A scheme for increasing q_{de} after the change the depth is presented in Figure 8. The change of q_{de} at several draughts for three of the ships is shown in Figure 9. The increase of the angle of deck immersion for the ship with 5000 tDW at summer draught is about 20% but we must not forget that there is an increase in the angle of about 2.5°.

The value $\delta KG_{\max} = \frac{KG_{\max 1}}{KG_{\max 0}} - 1$ in percent due to increased depth is presented in Figure 10. In the formula, index 1 is for the ship with increased depth and index 0 for the initial depth.

In order to evaluate the effect of the increased KG_{max}, an estimation of the maximum possible additional cargo with vertical centre of gravity equal to that of the first tier of containers on the deck is provided. It is assumed that the ship whit initial value of the depth is loaded up to KG_{max0} and calculations do not take into account the increased VCG due to the additional steel structures. The additional cargo (w) is obtained from (1) by Solver from ExcelÒ. In (1) the value of KG_{max1} depends on the sum of the denominator (D_0+*w*) and Z_c is equal of 12.37 m.

(1) $$KG_{\max 1} = \frac{KG_{\max 0}.\Delta_0 + w.Z_c}{\Delta_0 + w}$$

The additional loaded cargo is possible from a draught about 5.5 m and there is a well-defined maximum for every one of the ships. In summer draught the value of *w* is zero. The maximum additional cargo for the three ships presented as number of 14 t TEU is 13, 9 and 5 respectively.

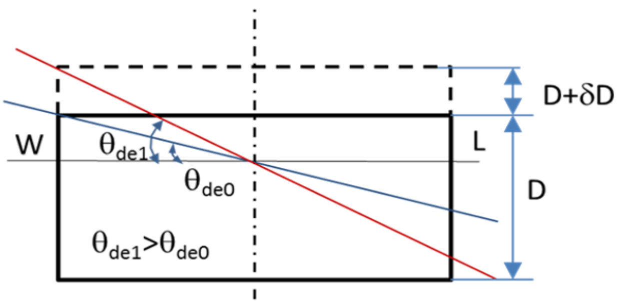

Fig. 8. Scheme of increase of angle of deck immersion $_{qd}$e

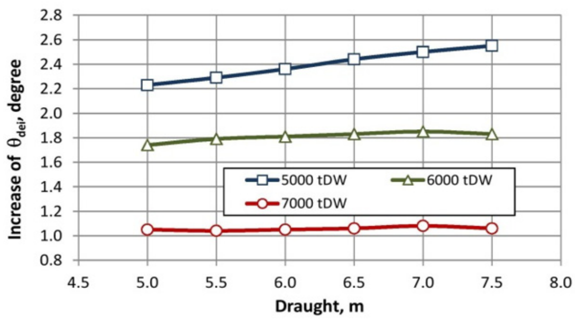

Fig. 9. Increase of θ_{de}, degree vs. draught for the ships

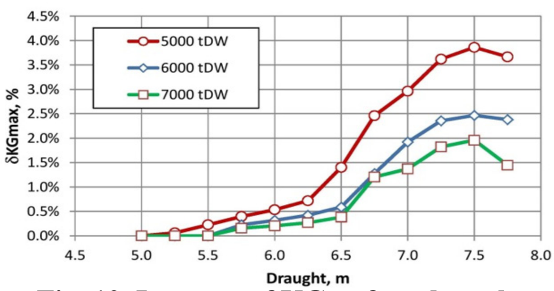

Fig. 10. Increase of KG_{max} f vs. draught

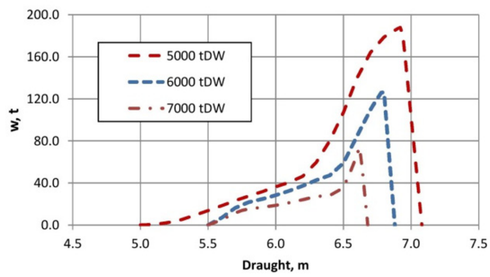

Fig. 11. Additional loaded cargo w, t due to the increased KG_{max}

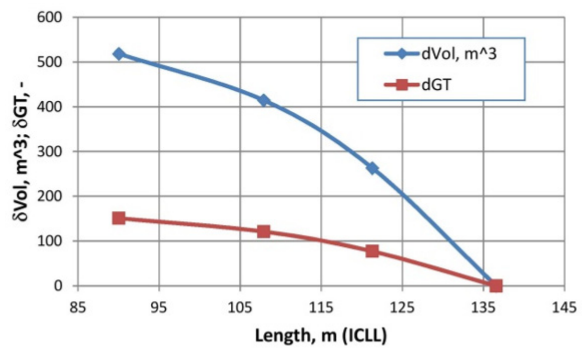

Fig. 12. Change of the additional volume and GT vs, L_{ICLL} of the ships

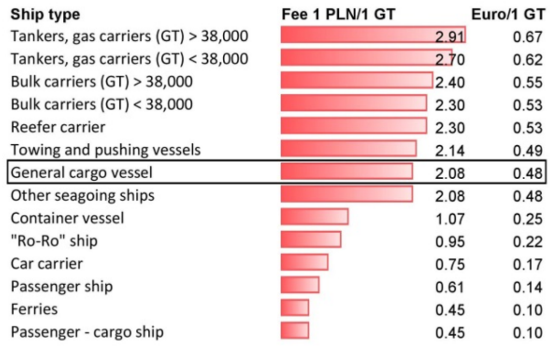

Fig. 13. Tariff for the services of the Port of Gdansk [15]

Gross tonnage

The tonnage of ships is calculated according to the International Convention on Tonnage Measurement of Ships 1969 [16]. The calculated volume of the hull includes the space below the main deck and the volume of the forecastle and the poop. To total volume for gross tonnage includes the volume of the superstructure, hatches and other closed volumes (if any) minus volumes like those of a bow thruster tunnel, sea chest boxes, hawse pipes etc. From similar ships, it can be evaluated that the volume of the superstructure is about 15% from the hull. The calculations show that the gross tonnage is not influenced by any additional volume of enclosed spaces in the range from 7% to 22.5% from the hull. The increased volume (dVol) and GT (dGT) due to increased depth of the ships is presented in Figure 12.

In order to evaluate the effect of the increased gross tonnage, an extra cost for services in the ports depending on GT is estimated. The calculations are based on the tariffs for three ports: Barcelona [17], Rotterdam [18] and Gdansk (Figure 13). The chosen ports propose a different kind of tariff and method for calculation. For example, in port of Barcelona the fee is constant for ships with GT up to 7000. This is applicable for the series of studied vessels.

Let's consider a hypothetical voyage on the route Rotterdam - Barcelona and assume a speed of 14 kn. At a distance of about 1900 nm the voyage will take about 6 days. If we accept a day for loading and unloading in each of the ports, it will take 10 days for one round trip. For 300 days of operation a year, we have 30 round trips. For each voyage we have two visits to Rotterdam and one to Barcelona. Therefore, for one year the maximum additional cost for port fees (for the smallest ship in the series) will be around € 3800. To get an idea of the amount of this extra cost, it is equivalent to about 17 tons of fuel (IFO380) in the port of Rotterdam[2].

PRODUCTIVITY ESTIMATION

Productivity for a process, a company or a group of production units, is defined as the relation between input and output [19]. This simple ratio raises a number of questions about shipbuilding and how to represent input and output. A recently presented study [20] summarizes the common input and output. For input these are: Dock area; Crane total load; Worker/CGT; Worker/ Hour; Worker; Total execution time; Waiting time; Erection area; ITech and IndEnv., where: CGT[3] = compensated gross tonnage; ITech = technological development index [19]; IndEnv = shipbuilding environment index. The last one cannot be changed by a shipyard decision [19]. The common output measures are: CGT; DWT; Type of vessel; Profit Labor productivity; Building time; No. of operations; Material amount.

After the definition of the Compensated Gross Tonnage by OECD, the shipbuilding productivity can be expressed by man-hours per CGT or CGT per employee per year:

(2) $$PD = \frac{mh}{CGT} \;;\; PD = \frac{CGT}{Employee/year}$$

[2] Heavy fuel oil price by 12.08.2020

[3] "*Compensated gross tonnage*, (cgt), is a unit of measurement intended to provide a common yardstick to reflect the relative output of merchant shipbuilding activity in large aggregates such as "World", "Regions" or "Groups of many yards" [21]

where
mh = man-hours.

The productivity of the shipyards is measured also by the relation of *mh* to steel weight (st.wt.) (Table 6). Additional shipyard characteristics could be added in the following form [21]:

(3) $$PD = a \times TE^{b} \times BP^{c} \times PR^{d} \times ST^{e} \times VI^{f} \times DP^{g}$$

where
PD = Productivity (mh/CGT); *TE* = Total number of employees; *BP* = Best Practice Rating; *PR* = Total/ Production Employees; *ST* = Number of ships delivered over three years divided by the number of ship types delivered over the same three year period; *VI* = Vertical Integration; *DP* = Dual purpose (commercial versus naval).

The CGT is calculated based on the GT according to the following formula [22]

(4) $$CGT = A \times .GT^{B}$$

where
for General cargo ships A=27 and B= 0.64.

To evaluate the productivity of the shipyard during the construction of a single or series of the studied ships with increased freeboard, it is necessary to estimate the additional man-hours required for steel structures and change in the CGT calculated by (4). Both of the variables will be larger but to different degrees. Table 7 presents the calculated variables. The last row includes percentage increase of the productivity after the unification of the breadth and the depth of the series of MPVs (Figure 14). For the smaller ship in series this increase is ab. 1.7% .The series effect strongly reduces the number of man-hours involved in the building of those ships. The effect can by estimated by [22].

(5) $$y = - 0.1483Ln (x) + 0.9995$$

where
x - is the number of the ships in the series.

Comparison of productivity measures [21]
Table 6

Ship type	mh/ st.wt.	mh/ cgt
VLCC	16	32
Suezmax tanker	19	22
Product tanker	27	20
Chemical tanker	46	36
Bulk carrier	19	20
Container ship 4,400 TEU	19	22
Container ship 1,800 TEU	28	22
Reefer	43	34
General cargo	56	29
Ferry	51	39
Ocean tug	105	31

Calculated variables for productivity of the SMEat construction of series of MPVs
Table 7

DW, t	5000	6000	7000	8000
GT_0, -	3707	4688	5468	6540
GT_1, -	3857	4809	5545	6540
CGT_0, -	5194	6037	6662	7470
CGT_1, -	5328	6136	6721	7470
$Mh_0.10^{-3}$,h	125.91	161.52	196.86	201.85
$Mh^1.10^{-3}$,h	126.90	162.32	197.41	201.85
PD^0,mh/cgt	24.2	26.8	29.5	27.0
PD^1 mh/cgt	23.8	26.5	29.4	27.0
δPD %	1.7%	1.1%	0.3%	-

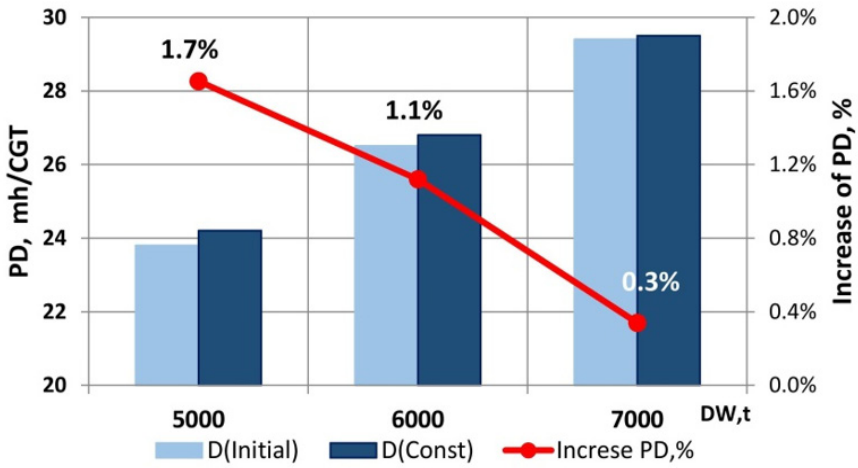

Fig. 14. Comparison of productivity after the unification of main dimnesions

According to formula (5) the reduction for a second ship is about 10%. A similar effect, though of a smaller degree, may also be present if a shipyard is building a ship with only limited size variations, as the workers then become more familiar with many of the details [22].

CONCLUSIONS

The building of ships in the conditions of SMEs, very often is accompanied by restrictions of the available facilities. The presented study deals with a series of multi-purpose ships with deadweight in the range of 5000 - 8000 tDW, designed with a limit of 16 m in width. The research question is what is the influence of the equal depth on the ship features and how will this change the productivity of the SME.

For the studied features, both the positive and negative effects are in the range of less than 5%. In order to give a clear answer to the overall appropriateness of this decision, it is necessary to sum up the monetary value for all effects.

Future studies should evaluate the series effect at construction of a series of ships with the same midship section and different length of the cylindrical part that will lead to a more significant increase in the productivity of SMEs.

ACKNOWLEDGMENTS

The presented study is carried out in the frame of National Science Program "Young Scientists and Postdoctoral Students" (Council of Ministers' Decisions No 577/17 August 2018) in which the first author participated.

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STATE OF SHIP RECYCLING AND THE EXPERIENCE IN BULGARIA

Petar GEORGIEV*, Mariana KOLEVA*

Abstract. *Every year, more than 1,000 ships are scrapped. Over 80% of these ships are transported to ship cemeteries in Bangladesh, India, Pakistan and Turkey. According to the European Commission, over 70% of ships end their lives on the beaches of South Asia in facilities that do not meet the safety standards. In most cases, these areas lack the environmental and safety measures needed to deal with hazardous materials contained in recycling vessels, such as asbestos, polychlorinated biphenyls, tributyltin and oily sludge. The international maritime community expects the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships (2009) to enter into force soon. The paper analyses the current state of the recycling industry and the experience in this field in Bulgaria.*

Key words: *Hong Kong Convention, Ship recycling, scrapped ships.*

INTRODUCTION

Ship recycling (also: ship breaking and ship demolition) is the final phase of a ship's life cycle. The scrapped steel is used for steel bars, billets, and rods for the construction industry, as well as electronic equipment and tools for homes and small businesses. [1]. The use of recycled steel has a positive effect on the environment due to the reduction of energy costs in the extraction of iron ore and hence steel. The usage of ferrous scrap is accompanied by less CO_2 emissions per ton of produced steel. On the other hand, ship recycling poses high risks to human health (Figure 1) and the environment (Figure 2) if it is not carried out in a proper and safe way, thereby leading to high levels of fatalities, injuries and work-related diseases.

Fig. 1. A typical view from the shores of South Asia [2]

Fig. 2. Scrapping of ships in Bangladesh [3]

The ship recycling centres in US and Europe, which were active from 1945 to 1980, today have shifted to Asia. Nowadays ship recycling is done mostly in Bangladesh, the Peoples' Republic of China (hereafter "China"), India and Pakistan, which together account for 91% of recycling volume in gross tons (GT), as of September 2017. [1]. Major reasons for the relocation of ship breaking businesses to these countries were the presence of lower labour costs due to accepted technology, lower safety and environmental standards and high local demand for recycled goods. According to The NGO Shipbreaking Platform [2] about 6616 ships were beached (demolished on the beaches of South Asia) with 399 deaths and 278 injuries since 2009.

The international maritime community is making coordinated efforts to regulate the processes. On 15 May 2009, IMO adopted the Hong Kong Convention that aims to ensure that recycling of ships does not pose any

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unnecessary risk to human health and safety or to the environment. The convention will enter into force once the following criteria is met: 24 months after ratification by 15 States, representing 40 per cent of world gross tonnage, combined maximum annual ship recycling volume not less than 3 per cent of their combined tonnage. India is the last country to join, making them 15with a total 29.62 % of World Tonnage versus required 40 % [4].

The goal of the presented study was to gather in one place and analyse the maximum amount of information, which will serve as a starting point for other research and scientific projects related to ship recycling. The research is part of a larger topic on the impact of environmental requirements on the various phases of a ship's life cycle.

THE SHIPBREAKING INDUSTRY

Organization of the shipbreaking industry

Shipping as a market activity includes four sub markets: freight market, shipbuilding, ship recycling and second hand ships [5]. These markets are interdependent. The level of freight depends on the balance between supply and demand of ships and any change in this balance affects the quantities of cargo transported. The ship breaking sale process is presented in Figure 3. A Cash Buyer buys a ship for dismantling, following two schemes: "as- is-basis" and "delivered basis". The difference is in the amount of cash payment and ship ownership. After this step, the Cash Bayer negotiates the sale of the ship to the shipbreaking yard, usually against a bank letter of credit. The shipowner also has two options: according to "as-is - basis" to sell the ship to the ship breaker, or according to the second option, to deliver the ship to the shipbreaking yard and to balance the deal with the Cash Buyer. The Cash Buyer acts as a financial facilitator and he bears a financial risk from exchange rates fluctuations.

The money flow is presented on Figure 4. There is both an input and output in the shipbreaker yard money flow. Both of them are in local currency or USD dollars.

Practically, all ship recycling sale and purchase transactions are quoted in USD per LT (long ton). Lightship displacement tonnage (LDT) is defined as the displacement of an unloaded ship with minimum liquid stores and water necessary for the last voyage.

The historic price data for five of the countries with the largest volume of recycled ships is presented in Figure 5. The graph clearly shows the impact of the global crisis in mid-2008. Scrap prices in China and Turkey are significantly lower, while for the countries of South Asia they are approximately the same. The dot in the figure indicates the current price (as of 2nd of October 2020). The price for tankers is as follows: Bangladesh USD$ 345/355 per LDT; Pakistan USD$ 355/365 per LDT; India USD$ 335/345 per LDT and Turkey USD$ 200/210 per LDT [6].

Current state of scrapped ships

In the period of 2005-2007 the total amount of scrapped ships was less than 0.5 MM CGT[1]. After that period, the amount of scrapped ships has increased, with a peak in 2012.

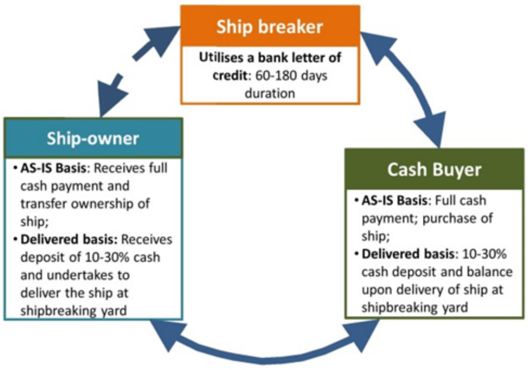

Fig. 3. Ship breaking sale process (adapted from [5])

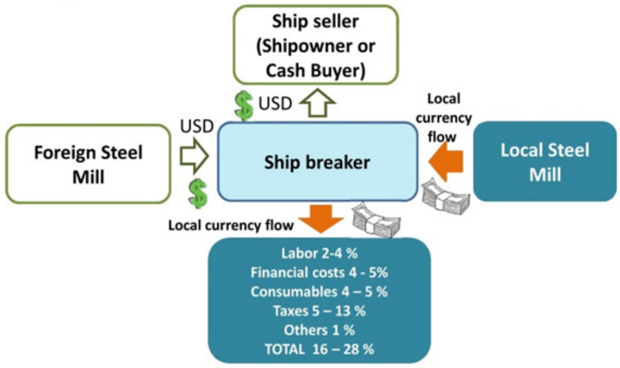

Fig. 4. The money flow in the shipbreaking process (adapted from [5])

[1] Compensated Gross Tonnage (CGT) is an indicator of the amount of shipbuilding work related to the gross tonnage (GT)

Fig. 5. Historic weekly price data (USD/LT (LDT) for tankers, adapted from [7]

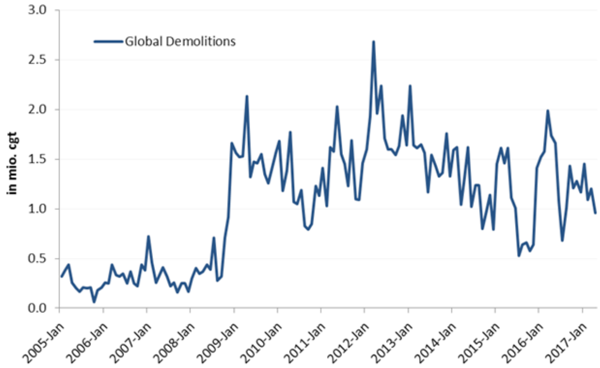

Fig. 6. Volume of global demolitions in CGT [8]

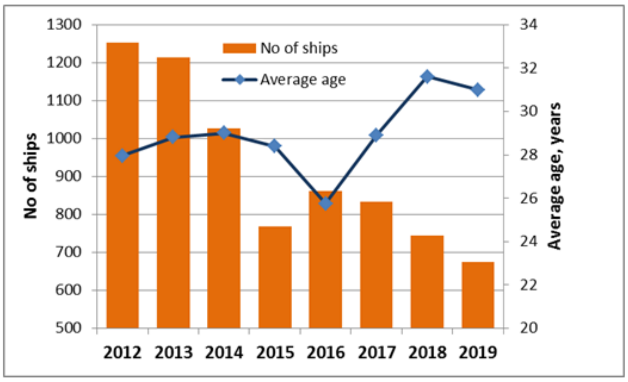

Fig. 7. Total number of ships and average age for the last 7 years (based on [2])

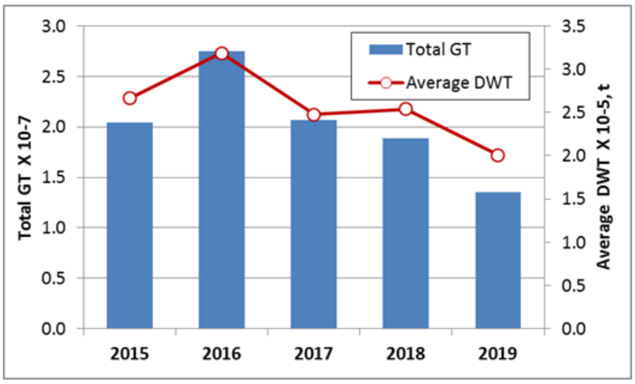

Fig 8 Total GT and average DWT for the last 5 years (based on [2])

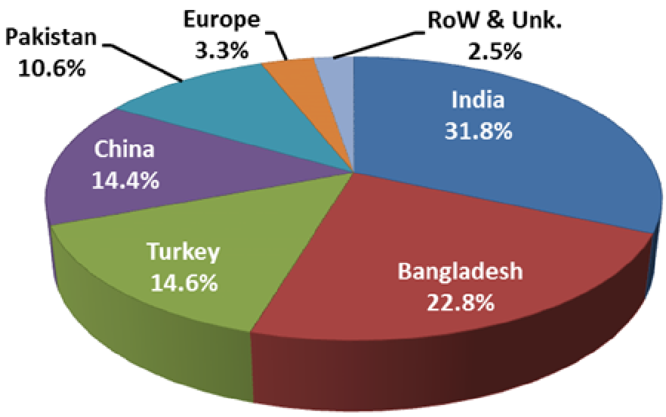

Fig. 9. Percentage of ship scrapped volume between the first 6 countries (based on [2])

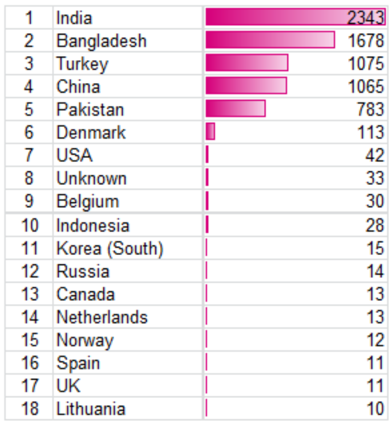

Fig. 10. No of scrapped ship for the last seven years (based on [2])

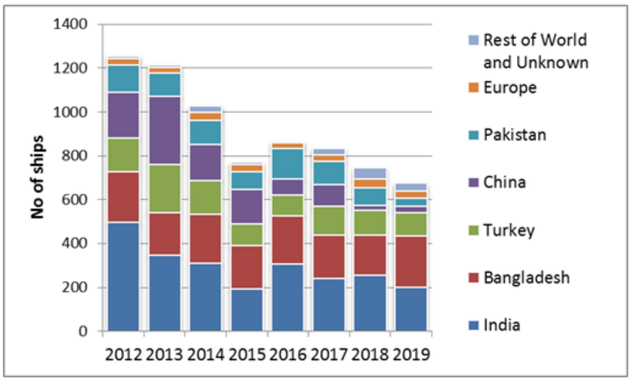

Fig. 11. Numbers of scrapped ships per country for 2012-2019 (based on [2])

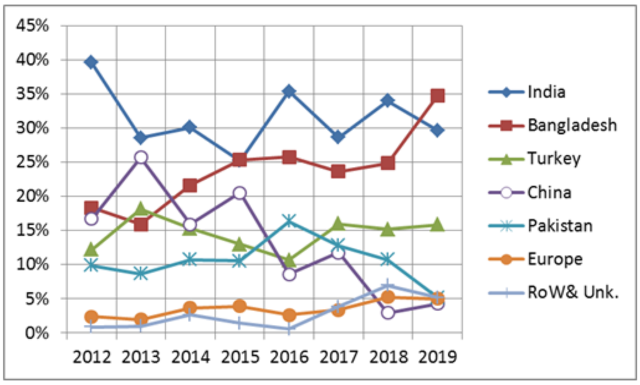

Fig. 12. Percentage from the total amount per country for 2012-2019 (based on [2])

The NGO shipbreaking platform [2] provides data for the amount of scrapped ships from the last seven years. The data were extracted and elaborated. Figure 7 and Figure 8 present the total amount of recycled ships. Figure 9 represents in percentage the volume of recycled ships. After the peak in 2012 there was a decline in 2015, with a low average age of ships during 2016. More than 30% of all ships are scrapped in India (Figure 9). In Europe this figure is about 3%. In India more than 2300 ships are recycled during the last seven years this period (Figure 10). Figure 11presents the number of scrapped ships per country and the percentage per country is shown in Figure 12. India holds about 30% of the total volume for the whole period considered. For Bangladesh there is a steady increase in the percentage and for Pakistan a decline over the last 3 years.

Legislative framework

Ship recycling legislation dates back to the 1990s. Over the years, it has become much stricter as one can see from Table 1. Regulation (EU) No 1257/2013, which entered into force on 20 November 2013, gives the main rules applicable for ship recycling [9]. The Annexes of the regulation include "Control of hazardous materials" and "List of items for the inventory of hazardous materials". Article 6(2) of [9] requires ship owners to ensure that ships to be recycled only in specialized facilities included in the European List published and updated permanently. The last update of the European list of ship recycling facilities is from 22 January 2020 [10]. The list includes facilities located in the member states, and in third countries like Turkey and USA. A map of the facilities in Europe is presented in Figure 13.

Regulatory landscape [11]

Table 1

Hong Kong Convention	• Adopted 2009, conditions for entering into force not yet met • Applicable for all new and existing ships >500 GT, and to ship recycling facilities
EU Ship Recycling Regulation (EU SRR)	• Entered into force December 2013, fully implemented December 31st 2020. • IHM part 1 required for EU/EEA-flagged vessels and other vessels entering EU/EEA waters by year end.
EU Waste Shipment Regulation (EU WSR)	• Entered into force July 2007 • Basel Ban Amendment transposed into EU law
Basel Convention	• Control of trans boundary Movements of Hazardous Wastes and their disposal • Adopted 1989, entered into force 1992
Basel Ban Amendment	• Adopted 1995, entered into force December 5th 2019

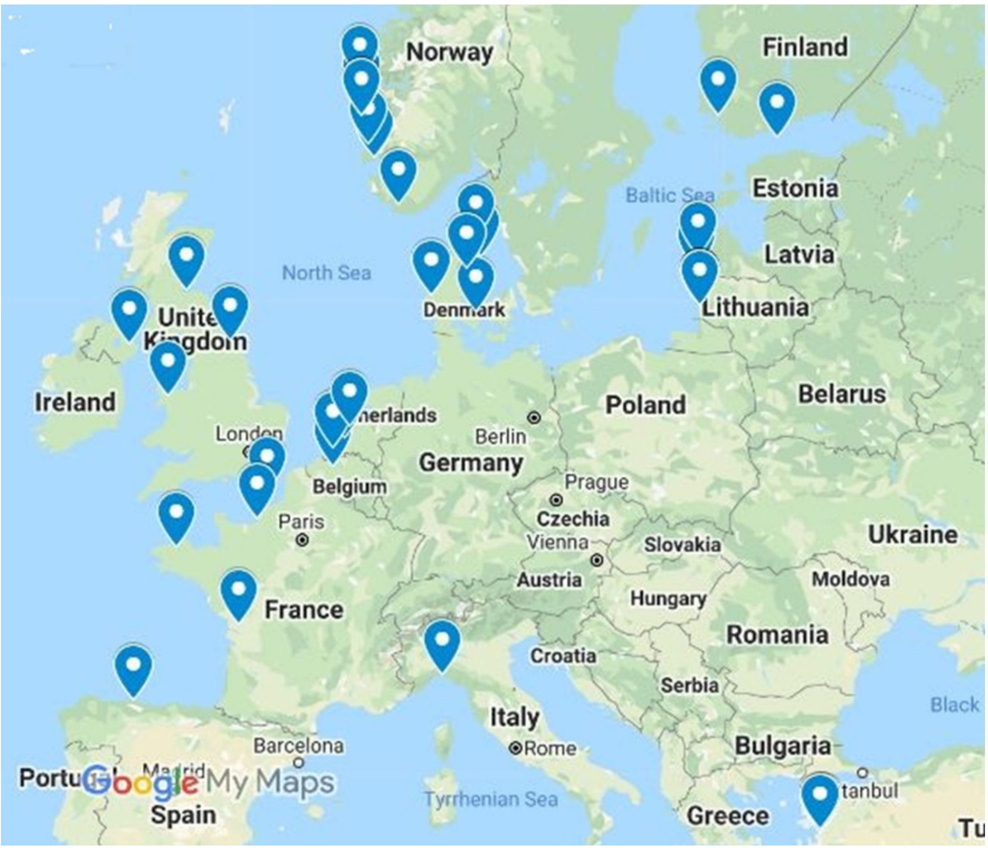

Fig. 13. Map of recycling facilities in Europe (developed by authors)

EXPERIENCE IN SHIP RECYCLING IN BULGARIA

Licensed ship recycling companies

The recycling of ships in Bulgaria started under Measure 1.1 “Public aid for permanent cessation of fishing activities” within Priority Axis 1 “Measures on adapting the Bulgarian fishing fleet of the Operational Program for the Development of Fisheries Sector / 2007-2013 / [12]. This measure supported projects for the cessation of fishing activities by (a) the scrapping of a fishing vessel (b) reassignment for activities outside fishing and (c) exhibition as a museum piece. Under this measure, more than 15 fishing vessels have been decommissioned since 2011.

“Ship and Industrial Service” Ltd. is a leader in the operations of utilizing decommissioned vessels. The company reports annual processing capacity for ships of light weight exceeding 20,000 tons [13]. The company is fully licensed for its operation on ship breaking by the Ministry of Environment and Water of the Republic of Bulgaria and it has applied for inclusion in the European list which is currently being considered.

Fig. 14. Rail slipway and the adjacent quay [13]

Fig. 15. View from the recycling site

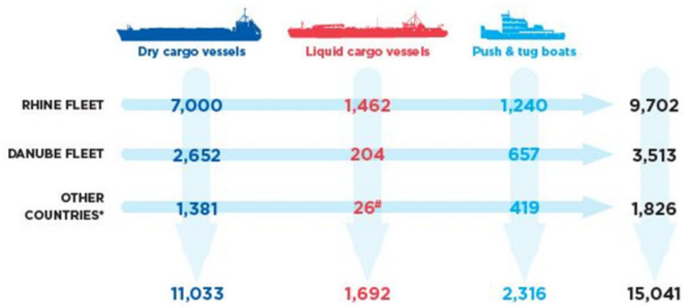

Fig. 16. Distribution of inland waterway vessels by types and regions by 2019 [14]

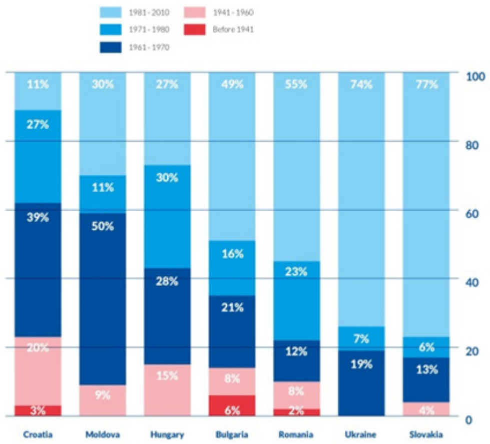

Fig. 17. Danube fleet by year of construction (% based on number of ships) [15]

The company operates with a floating dock and rail slipway for ships with length (L) up to 145 m, breadth (B) - up to 16 m and light weight up to 1,800 tons, and also a 150 m quay and power crane equipment (Figure 14). Figure 15 shows part of the work site.

Possibilities for recycling ships on the Danube River

In 2018, more than 15,000 cargo ships for inland navigation were registered in Europe; 65% of the fleet is in the Rhine countries, 23% in the Danube countries and the remaining 12% in other European inland waterway countries (Poland, Czech Republic, Italy, Great Britain, and Lithuania) [14]. Figure 16 schematically shows the distribution of ships by types and regions of navigation.

The annual report of the Central Commission for Navigation on the Rhine estimated that only 15% of dry cargo ships and 37% of tankers are under the age of 20 [15]. The year of construction and respectively the age of the ships for the Danube countries, are presented in Figure 17. In Croatia and Moldova, the structure of the fleet by year of construction is quite similar. Most of the vessels (59% - 62%) were built in the period between 1941 and 1970. In Hungary, half of the fleet is over 45 years old. In Bulgaria and Romania, about half of the fleet was built in the last three decades. In these countries, most of the companies work to transport goods and their ships are relatively newer than the dry bulk fleet in the Rhine. Ukraine and Slovakia have the newest fleets, with most of the ships under 30 years old.

The company "Kemsteel" (http://www.kemsteel.com) has submitted for consideration an investment proposal for „Separation of a site for recycling of ships". The site is in Ruse on the Danube River and will use existing infrastructure (Figure 18, Figure 19). The proposal is currently open for public discussion.

Fig. 18. Plot provided for the organization of ship recycling

Fig. 19. Satellite image of the plot for the site for ship recycling (Google maps)

CONCLUSIONS

Decommissioning of a ship is the last stage of its life cycle. Nowadays use of unskilled labor and primitive practices, such as beaches in developing countries, are factors for the negative impact of the ship recycling industry on the environment and on human health. In response to this, the International Maritime Organization is developing new standards and strategy in order to achieve cost-effective, safe and environmentally friendly ship recycling. As a result, the Hong Kong Convention, which aims to regulate this industry, has been submitted for ratification. This convention is expected to enter into force soon.

The paper summarizes facts and information from various sources in order to accumulate the most important information to be used for future research. This information can be useful for companies that decide to invest in the ship recycling industry, especially along the Danube.

From a long-term perspective, it is imperative to establish a strong link between the two ends of the ship's life cycle, i.e. the recycling and the design phase. The "Design for recycling" approach, although highly developed in other industries such as the automotive industry, is still in its infancy in shipbuilding. A detailed study of the ship recycling process can be used to improve ship design, taking into account the needs of ship recycling companies to achieve "green" ship recycling at reduced costs.

ACKNOWLEDGMENTS

The presented results were obtained from studies carried out within the project NP8/2020 from the scientific program of TU - Varna, funded by the state budget. Some of the results are included in the bachelor thesis of the second author.

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Black Sea 2020

MACHINERY AND PROPULSION SYSTEM

INFLUENCE OF THE ENERGY EFFICIENCY DESIGN INDEX ON THE PROPULSION SYSTEM TYPE OF LNG CARRIER

Viktor NIKIFOROV*, Irina KOSTOVA*

Abstract. *Introduced by the MEPC (Marine Environment Protection Committee) to the IMO (International Maritime Organization) compulsory for all new built ships - EEDI (Energy Efficiency Design Index) leads to new requirements about the ship propulsion system type. In this article will be analyzed various alternative propulsion systems for LNG Carrier in order to achieve maximum Energy Efficiency of the ship. The final choice of the relevant system will be justified after a technical and economical evaluation of each propulsion system included in this study.*

Key words: *EEDI (Energy Efficiency Design Index), Ship Propulsion System, LNG Carrier.*

I. INTRODUCTION

The major objective of the today's worldwide shipping industry is to reduce the harmful impact of the greenhouse gases (GHG) on the environment. With purpose to perform that and to improve the state of the environment, the International Maritime Organization (IMO) and Marine Environment Protection Committee (MEPC) introduced several requirements in connection with reducing the GHG generated by the shipping industry. IMO and MEPC in 2011 have adopted a packet of technical measures which have been included in a new Chapter 4 to Annex VI of MARPOL Convention under the name "Energy Efficiency Regulations for Ships". The packet includes Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP) which are in force from 1st January 2013 and are applied to all new built ships with 400 gross tonnage and above [1].

The EEDI represents a non-prescriptive, performance based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy efficiency level is attained, ship designers and builders would be free to use the most cost-efficient solutions for the ship to comply with the regulations. EEDI is requiring a minimum energy efficiency level for new ships by stimulating continued technical development of all the components influencing the fuel efficiency of a ship and by separating the technical and design-based measures from the operational and commercial ones [2].

The energy efficiency of a ship represents a function of its main and auxiliary engines power, its deadweight and service speed. The service speed of the ship or the required engines power can be achieved by various types of propulsion systems. In order to comply with the IMO requirements regarding the GHG, most of the ship engine manufacturers developed much more efficient engines which are able to work with fuels different from the conventional ones used widely in the shipping for many years. Increasingly wider application are finding the so-called Dual Fuel Engines, which are able to operate with gaseous fuels and a small portion of diesel fuel.

The energy efficiency of the ship could be improved and therefore the GHG emitting reduced by applying some of the various ways listed below:

- Proper engine selection;
- Fuels with lower carbon content;
- Design methods with purpose to lighter the ship or increasing its capacity;
- Speed reduction in order to lower the Specific Fuel Oil Consumption (SFOC);
- Innovative and renewable technologies reducing the CO2 emissions.

If we consider the deadweight and the ship service speed as constant value, we have to pay serious attention to choosing the proper propulsion system in order to improve the EEDI of the ship and reduce her GHG emissions.

The objective set in this article is to describe a methodology for choosing the proper propulsion system

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type of LNG Carrier based on calculations of various systems, comparing their energy efficiency and choosing the most efficient one with purpose to comply with IMO requirement about GHG Emissions.

II. CALCULATION METHODOLOGY OF ATTAINED EEDI AND REFERENCE EEDI (REEDI), SHIP PROPULSION SYSTEM TYPES.

The worldwide shipping is the most effective type of transport that could be used, but the harmful emissions generated by the fuels burned in the internal combustion engines serving for ship's propulsion represents a serious problem. The ship's efficiency could be measured by the amount of emissions radiated in the atmosphere and this could be accounted by calculating the ship's Attained EEDI and compare it to the Required EEDI which depends on the ship's specific type and its capacity.

Attained EEDI

The EEDI of a ship is a measure of the ship's energy efficiency and her GHG emission level, expressed in grams CO2 per tonne mile [3].

The methodology and requirements for calculating the Attained EEDI for new ships are published by MEPC in [4].

The simplified formulae for calculating the Attained EEDI is listed below:

(1) $$Attained\ EEDI = \frac{(P_{ME(i)} \times C_{FME(i)} \times SFC_{ME(i)}) + (P_{AE} \times C_{FAE} \times SFC_{AE})}{f_i \times f_c \times f_l \times Capacity \times f_w \times V_{ref}} = \frac{CO_2\ Emissions}{Transport\ work}$$

if Power Take In / Power Take Off devices (PTI/PTO) and/or renewable energy efficiency technologies are used into the ship propulsion system, the following have to be included into the numerator of (1) to account their effect:

(2) $$\left(\left(f_j \times P_{PTI(i)} - f_{eff(i)} \times P_{AEeff(i)}\right) C_{FAE} \times SFC_{AE}\right) - \left(f_{eff(i)} \times P_{eff(i)} \times C_{FME} \times SFC_{ME}\right)$$

Where

P_{ME} - 75% of the MCR of the main engine, if shaft generator is installed its effect could be take into account as follows:

(3) $$P_{ME(i)} = 75\% \ (MCR_{(i)} - P_{PTO})$$

with P_{PTO} = 75% (Output Shaft Generator)

C_F - non-dimensional conversion factor between fuel consumption measured in grams and CO_2 emissions also measured in grams based on carbon content in the fuel. The values for C_F could be found in [4].

SFC_{ME} - specific fuel oil consumption in grams per kWh of the main engine(s) at 75% MCR.

P_{AE} - the required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodations.

For ships with a total propulsion power of 10000 kW or above, P_{AE} have to be defined as follows:

(4) $$P_{AE} = \left(0.025 \times \left(MCR_{ME(i)} + \frac{P_{PTI(i)}}{0.75}\right)\right) + 250$$

For ships with a total propulsion power below 10000 kW, P_{AE} have to be defined as follows:

(5) $$P_{AE} = \left(0.05 \times \left(MCR_{(i)} + \frac{P_{PTI}}{0.75}\right)\right)$$

SFC_{AE} - specific fuel oil consumption in g per kWh of the auxiliary engine(s) at 50% MCR.

Note: For LNG driven engines of which the SFC is measured in kJ/kWh should be corrected to the SFC value of g/kWh using the standard lower calorific value (LCV) of the LNG equal to 48000 kJ/kg as per 2006 IPCC Guidelines.

P_{PTI} - 75% of the rated mechanical power of the shaft motor(s) divided by the weighted efficiency of the generators:

(6) $$P_{PTI(i)} = 0.75 \left(\frac{rated\ power\ shaft\ motor\ (i)}{\eta_{Gen}}\right)$$

$P_{eff(i)}$ - is the output of the innovative mechanical energy efficient technology for propulsion at 75% main engine power;

$P_{AEeff(i)}$ - is the auxiliary power reduction due to innovative electrical energy efficient technology;

$f_{eff(i)}$ - availability factor for each innovative energy efficiency technology;

f_j - correction factor to account ship specific design elements;

f_i - capacity factor for any technical/regulatory limitation of capacity, should be assumed to be 1.0;

f_c - cubic capacity correction factor, should be assumed to be 1.0;

f_l - factor for General Cargo ships equipped with cranes and other cargo-related equipment;

f_w - non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed. For Attained EEDI calculated under regulations 20 and 21 of MARPOL Annex VI, f_w have to be assumed as 1.0;

Capacity - depending on the type of the ship its DWT or gross tonnage have to be used as capacity;

V_{ref} - is the ship speed, measured in nautical miles per hour (knot).

Required EEDI

Each new built ship have to meet the requirements for REEDI based on the ship's type and size and the calculations have to be performed in compliance with [5][6][7].

The formulae for calculating the REEDI is listed below:

$$REEDI = a \times b^{-c} \tag{7}$$

Where

"a" and "c" are parameters determined from the regression curve fit and they are specified in [5] and [7], the parameter "b" represents the deadweight of the ship.

The REEDI is going to be reduced step by step and the reduction will be performed in three phases as the last one have to be introduced in force from 1st January 2025 and aims for a reduction of REEDI by 30%.

The Attained EEDI of the ship should be lower or equal to the calculated REEDI:

$$Attained\ EEDI \leq Required\ EEDI = \left(1 - \frac{X}{100}\right) \times Reference\ Value \tag{8}$$

Where "X" is the reduction factor depending on the ship type specified in tables in [5] and [7].

Propulsion System Types

There are a various ways to configure a propulsion system of the ship. The most used systems are arranged with one or two main engines (ME) and up to three diesel electric generators (DG), also PTI/PTO devices could be included with purpose to boost the ship's speed or to produce additional electrical energy (Fig.1).

The engines could be distinguished by their working cycle - 2 or 4 stroke, speed - low, medium or high, fuel used - diesel or dual fuel (DF), and design features.

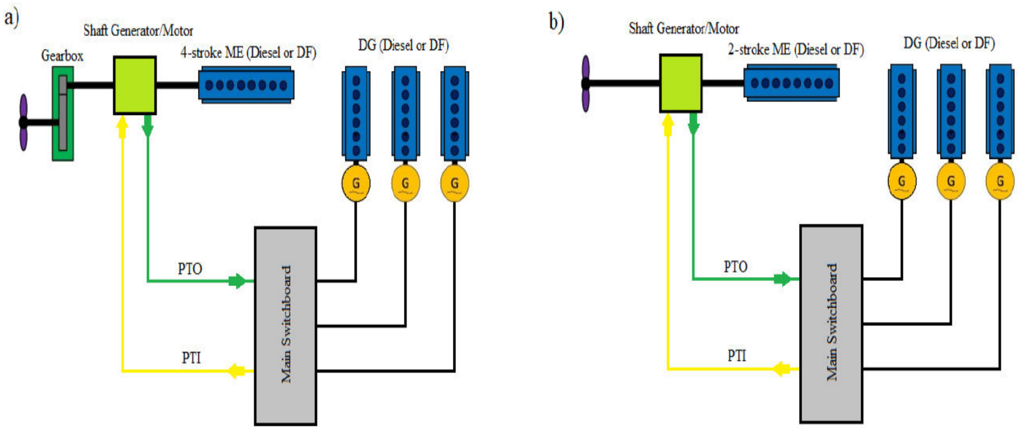

Fig. 1. Typical arrangements of Ship Propulsion Plant

In this paper will be considered different options for propulsion system arrangements of LNG Carrier including ME and DG working with diesel or dual fuel, 4-stroke medium speed and 2-stroke low speed ME, 4-stroke medium speed DG and also an option for PTI/PTO. The comparison of the propulsion systems will be performed based on the achieved EEDI value, also an operational costs comparison will be done depending on the fuel type used.
To achieve the goals set in this article and to perform the calculations for the propulsion systems which we want to observe, first we have to step on a ship project. For the purpose of this paper we have chosen project for 30,000 m^3 LNG Carrier with Deadweight of 15 000t and Design Speed of 16 knots performed by WÄRTSILÄ Ship Design. The data necessary for the purpose of the calculations and for the size of the ship are presented in Tab. 1 and 2, more detailed project information could be found in [8].

Main dimensions of the ship

Table 1

30,000 m3 LNG Carrier WSD50 30	
Length over all	170.00 m
Length between perpendiculars	164.00 m
Breadth moulded	29.50 m
Depth moulded, to upper deck	15.40 m
Draught, design	7.70 m
Draught, max	8.00 m

Project Propulsion Data

Table 2

Initial Propulsion/Machinery Data	
Main Engine	4-stroke 7L46DF, 1x8,015 kW
Diesel Generators	4-stroke, 6L20DF, 2x1,065 kW
Shaft Generator (PTO)	1,000 kWe
Shaft Motor (PTI) *	1,000 kW

*Initially the ship is equipped only with PTO, but with regard to the calculations in this article PTI effect will be also considered.

In this article will be analyzed four options for propulsion plant types presented in Tab. 3 and 4:
1. 4-stroke Medium Speed Diesel ME + 4-stroke High Speed Diesel Generators + PTI/PTO;
2. 2-stroke Low Speed Diesel ME + 4-stroke High Speed Diesel Generators + PTI/PTO;
3. 4-stroke Medium Speed DF ME + 4-stroke High Speed DF Generators + PTI/PTO;
4. 2-stroke Low Speed DF ME + 4-stroke High Speed DF Generators + PTI/PTO.

Parameters of the Main Engines

Table 3

#	ME Type	Maker	ME Power at 100%	ME Power at 75%	BSFC at 75% (HFO)	BSPC at 75% (MGO)	BSGC at 75% (LNG)
Option 1	7L46F	Wärtsilä	8015 kW	6011 kW	-	181.1 g/kWh	-
Option 2	7X52	WinGD	8015 kW	6011 kW	154.5 g/kWh	-	-
Option 3	7L46DF	Wärtsilä	8015 kW	6011 kW	-	1.3 g/kWh	154.6 g/kWh
Option 4	7X52DF	WinGD	8015 kW	6011 kW	-	2.2 g/kWh	137.9 g/kWh

Parameters of the Auxiliary Engines

Table 4

#	ME Type	Maker	AE Power at 100%	AE Power at 50%	BSFC at 50% (HFO)	BSPC at 50% (MGO)	BSGC at 50% (LNG)
Option 1 and 2	6L20F	Wärtsilä	1110 kW	555 kW	-	204.6 g/kWh	-
Option 3 and 4	6L20DF	Wärtsilä	1110 kW	555 kW	-	7.0 g/kWh	192.0 g/kWh

All the data regarding the power and fuel consumption for Wärtsilä engines listed in the Tab. 3 and 4 have been extracted from the product guides of the specific engines and with the help of Wärtsilä Online Engine Configurator. For WinGD engines General Technical Data Application (GTD) have been used.

REEDI for 15 000t DWT LNG Carrier

Table 5

Required EEDI	
Base REEDI	23.63
Phase 1 (10% reduction)	21.27
Phase 2 (20% reduction)	18.90
Phase 3 (30% reduction)	16.54

Attained EEDI for observed propulsion plants

Table 6

Attained EEDI	
Option 1	16.62
Option 2	14.35
Option 3	12.60
Option 4	11.61

The calculations for Attained and Required EEDI have been performed by the methodology exposed in this article and the values are given in Tab.5 and 6, ME power is considered as 75% of the nominal engine power and PTO effect have been also accounted. Required AE power is calculated based on a total propulsion plant with power less than 10 000 kW. The fuel consumption of the ME is considered at 75%, while the AE consumption have been considered at 50%. PTI effect have been also included in the calculations.

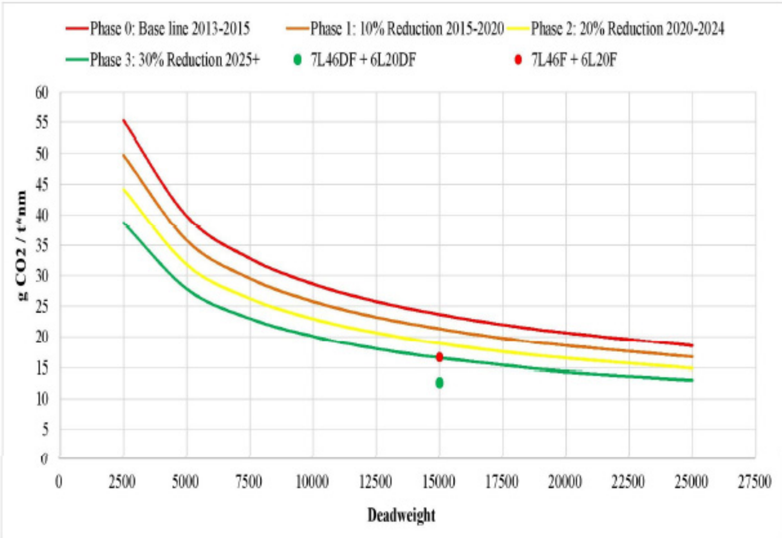

Fig. 2. EEDI of 4-stroke engines (Option 1 and 3)

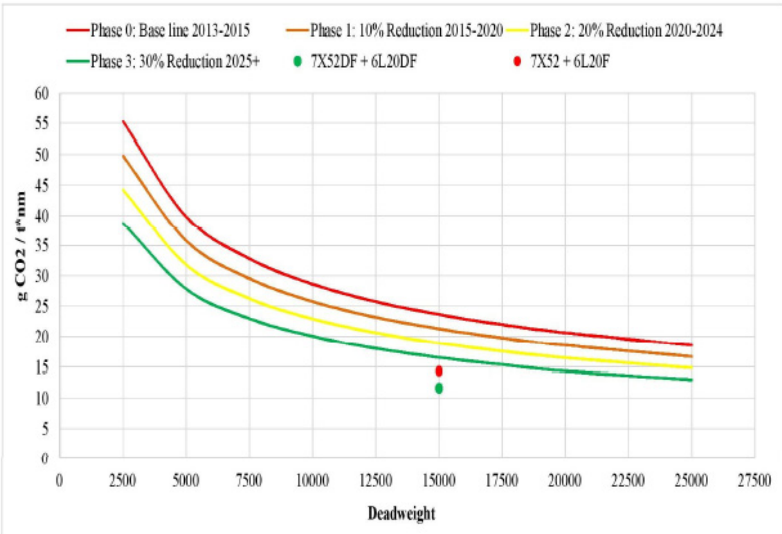

Fig. 3. EEDI of 2-stroke engines (Option 2 and 4)

Financial aspect regarding the fuel costs for operating the ship for a period of 1 year

In the calculations will be considered the 4 options for propulsion plants in this article. The calculations for fuel costs are performed based on the ME Power and SFC at 75% + PTO effect calculated with formula (3), AE Power and SFC will be accepted as 50%. The fuel prices used for calculations (Tab. 8) are the average for HFO and MGO in Rotterdam port and the average of LNG for the European market based on [9] and [10].

The values given in Tab.7 and 9 are achieved with the assumption that the ship sails 300 days per year.

(9) *RC = SFC (ME, AE) × Power (ME, AE) × 24 (hours) × 300 (days) ×Fuel Price (USD per tonne)*

Fuel consumption for a period of 1 year

Table 7

#	ME Fuel Cons. / 300 days	AE Fuel Cons. / 300 days	Total Fuel Cons. / 300 days
Option 1	8604t, MGO	816t, MGO	9420t, MGO
Option 2	6060t, HFO	816t, MGO	6060t, HFO
			816t, MGO
Option 3	6066t, LNG	768t, LNG	6834t, LNG
	51t, MGO	27.9t, MGO	78.9t, MGO
Option 4	5481t, LNG	768t, LNG	6249t, LNG
	87t, MGO	27.9t, MGO	114.9t, MGO

Average fuel prices

Table 8

Average Fuel Prices	
0.1%S MGO	366.50 $/tonne
HFO	239.50 $/tonne
LNG	232.00 $/tonne

Total fuel costs for operating the ship for a period of 1 year

Table 9

#	HFO Costs	MGO Costs	LNG Costs	Total for 1 year
Option 1	-	3 452 430 $	-	3 452 430 $
Option 2	1 451 370 $	299 064 $	-	1 750 434 $
Option 3	-	28 916 $	1 585 488 $	1 614 404 $
Option 4	-	42 110 $	1 449 768 $	1 491 878 $

CONCLUSIONS

In this article have been studied 4 options for ship propulsion systems which include the most modern 2 and 4-stroke engines manufactured by Wartsila and WinGD operating with diesel or dual fuel. For the considered options EEDI and REEDI for each reduction phase and also the fuel costs necessary for operating the ship with each propulsion system for a period of 1 year have been calculated. Based on the performed calculations and analysis of the EEDI and Fuel Costs, we can conclude that Option 4 is the most energy efficient and economical propulsion system.

“This paper has been prepared within the project NP8/2020 “Conceptual design of the ship minimizing the risk of environmental pollution”, funded by the State Budget under contract No 108/22.05.2020”

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INFLUENCE OF THE WASTE HEAT RECOVERY SYSTEM OF CONTAINER VESSEL ON ENERGY EFFICIENCY OF THE SHIP

Viktor NIKIFOROV*, Irina KOSTOVA*

Abstract. *The energy containing in the exhaust gases of the powerful 2-stroke engines installed on the large vessels represents a good option for producing energy with lower cost on the board of the ship. Obtaining an additional mechanical or electrical power by utilizing the exhaust gases in various types of Waste Heat Recovery Systems (WHRS) contributes in improvement of the Energy Efficiency Design Index (EEDI) of the ship. In this article will be considered various WHRS on Container vessel in combination with either Dual Fuel or Diesel 2-stroke engines from the one of the leading manufacturers in the ship industry. The results will be analyzed with purpose to select the best option for propulsion in order to improve the EEDI of the ship.*

Key words: *Container vessel, EEDI (Energy Efficiency Design Index), Marine Diesel Engine, WHRS (Waste Heat Recovery System).*

I. INTRODUCTION

The international shipping is the most widely used and cost-effective way to transport large amount of goods. As the most preferably common method of transportation, shipping also has its disadvantages. Annually the worldwide shipping emits significant volume of Greenhouse Gases (GHG) and harmful emissions which cause a negative effect on the surrounding us environment.

The increasing interest in emission reduction, ship operating costs reduction and the adopted by IMO rules calls for measures that ensure optimal utilization of the fuel used for main engines on board ships [1]. The exhaust gases separated by the main engines (ME) during the fuel combustion represents a good opportunity for utilizing and producing energy with lower cost onboard of the ship. By utilizing the exhaust gases in Waste Heat Recovery Systems (WHRS) we could obtain an additional electrical or mechanical power leading to significant fuel savings and improved Specific Fuel Consumption (SFC).

For the modern new built ships, Energy Efficiency Design Index (EEDI) is the most important indicator for their ecological efficiency. Each new built ship has to meet the requirements set by IMO with regard to EEDI and Required EEDI. The lower the EEDI value the efficient the ship.

In its essence, the EEDI could be expressed as the CO_2 emissions radiated by the ME and auxiliary engines (AE) divided by the transport work done by the ship.

$$Attained\ EEDI = \frac{CO2\ Emmisions}{Transport\ work} \quad (1)$$

Combining the use of WHRS and Power Take-In devices (PTI) could improve the SFC or achieve additional fuel savings leading to lower EEDI values of the ship which will render a positive effect on the environment by radiating lower levels of GHG and harmful emissions in the atmosphere. Also using the WHRS is a good solution for the ship owners to save funds as the fuel costs of every ship represents a major part of its operational costs.

In this article will be considered various ship propulsion systems for Post-Panamax Container vessel, including Dual Fuel (DF) ME and AE, Diesel ME and AE and each of them will be considered independently or equipped with WHRS. Their efficiency, fuel savings, CO_2 emissions and payback period will be accounted with purpose to choose the best option for ship propulsion.

II. WASTE HEAT RECOVERY SYSTEM TYPES

Today several different WHRSs are readily available. Depending on the level of complexity acceptable to the owner and shipyard and the actual electrical power consumption on-board, it is possible to choose between

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the following systems [1]:

● **Power Turbine and Generator (PTG) -** PTG is the simplest and cheapest available system. It consists of a gas turbine also called a power turbine, which is driven by the amount of bypassed exhaust gases before the ME turbochargers. The exhaust gas bypass is available only when the ME is operating with power more than 40% of Specified Maximum Continuous Rating (SMCR). Such a system offers a recovery rate of about 3 to 5%;

● **Steam Turbine and Generator (STG) -** STG consist of a steam turbine driven by the steam produced in the exhaust gas boiler (EGB). The steam turbine itself drives a generator, producing an electricity. STG is impossible to be used, if the ME load is below 30-35% SMCR. This kind of system ensures a recovery rate between 5 and 8%;

● **Steam Turbine - Power Turbine and Generator (ST-PT) -** ST-PT is the most complex system of those listed. It consists of Power Turbine and Steam Turbine each equipped with reduction gearboxes and connected to a common generator (See Fig.1). This system combines the advantages of PTG and STG systems. Such a kind of system provides to users approximately a recovery rate of 8-11%.

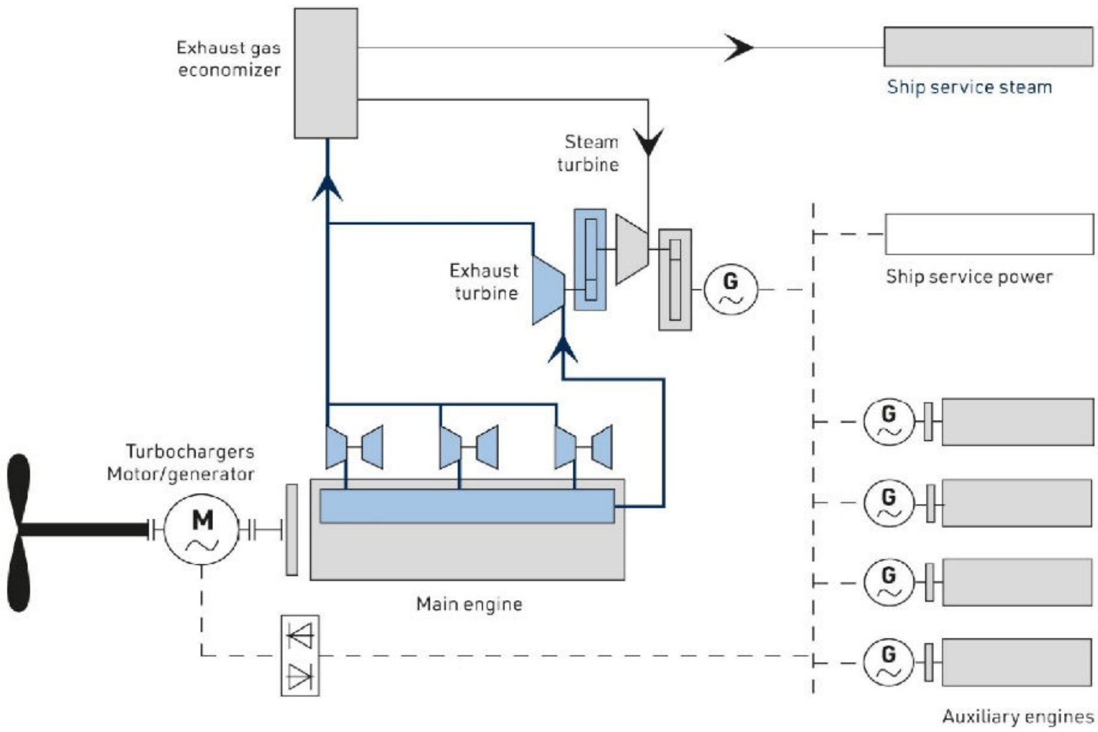

Fig. 1. Diagram of Typical High-Efficiency WHRS (ST-PT) for a large container vessel (Source: www.wingd.com)

The implementation of the listed above types of WHRSs mainly depends on the total output of the ME installed on the ship and her electricity demand. One of the leading engine manufacturer - MAN B&W recommends the following requirement with regard to choose the proper WHRS for our ship:

● ME Output up to 15 000 kW → PTG;

● ME Output up to 25 000 kW → STG;

● ME Output more than 25 000 kW → ST-PT.

III. CALCULATIONS

With purpose to perform the calculations and fulfill the objectives set in this article we have chosen as a prototype ship a container vessel operated by Danaos Shipping Co. Ltd. The size category of the ship is Post-Panamax with total nominal container capacity of 8428 TEU and Service Speed of 25.8 knots. The main parameters of the ship are shown in Tab.1 and 2. More information about the ship could be found in [2].

Main particulars of the ship

Table 1

Post-Panamax Container Vessel CMA CGM ATTILA	
Length over all	321.46 m
Beam	42.8 m
Depth moulded	20.23 m
Draught (summer)	14.65 m
Deadweight (summer)	101223.9 t

Required propulsion output of the ship

Table 2

Required Propulsion Output	
Main Engine	ME - 68520 kW
Auxiliary Engines	4AE x 2750 kW

In this article will be observed four options for propulsion systems listed below:

1. 2-stroke Diesel Main Engine + 4-stroke Diesel Auxiliary Engines;
2. 2-stroke Diesel Main Engines + 4-stroke Diesel Auxiliary Engines + ST-PT WHRS;
3. 2-stroke Dual Fuel Main Engines + 4-stroke Dual Fuel Auxiliary Engines;
4. 2-stroke Dual Fuel Main Engines + 4-stroke Dual Fuel Auxiliary Engines + ST-PT WHRS.

For the purpose of the calculations the recovery rate of the PT and ST will be accepted with their lower values, respectively PT - 3% and for ST - 5% at ME SMCR, therefore the total output of the WHRS at SMCR will be equal to 8% of the total power of the ME installed (see Tab.3). We will consider that the electricity demand of the ship during port stay is fulfilled by one AE working on 50%, during voyage by two AE working on 50% and during maneuverings by three AE working on 50%.

For the propulsion system we have choose ME from the portfolio of MAN B&W, respectively 12G95ME-C10.5 for options 1 and 2 and 12G95ME-C10.5-GI for options 3 and 4. For AE we have choose Generator Sets manufactured by Wärtsilä - 6L34DF with total output of 2770 kW. These type of generators will be applied for the 4 options in this paper as for option 1 and 2 they will operate in diesel mode while for option 3 and 4 - in gas mode. The information regarding the fuel consumption of the ME has been extracted by CEAS application of MAN B&W, while for AE - Engine Online Calculator of Wärtsilä has been used.

Output of the Waste Heat Recovery System depending on the ME Load

Table 3

ME Type	**12G95ME-C10.5, 12G95ME-C10.5-GI (SMCR: 65820 kW at 78 rpm)**									
ME Load (%)	100	90	80	75	70	60	50	40	30	20
PT Output (kW)	2055	1665	1315	1156	1007	740	514	-	-	-
ST Output (kW)	3426	2775	2192	1927	1678	1233	856	548	308	-
Gen. Output (kW)	5481	4440	3507	3083	2685	1973	1370	548	308	-

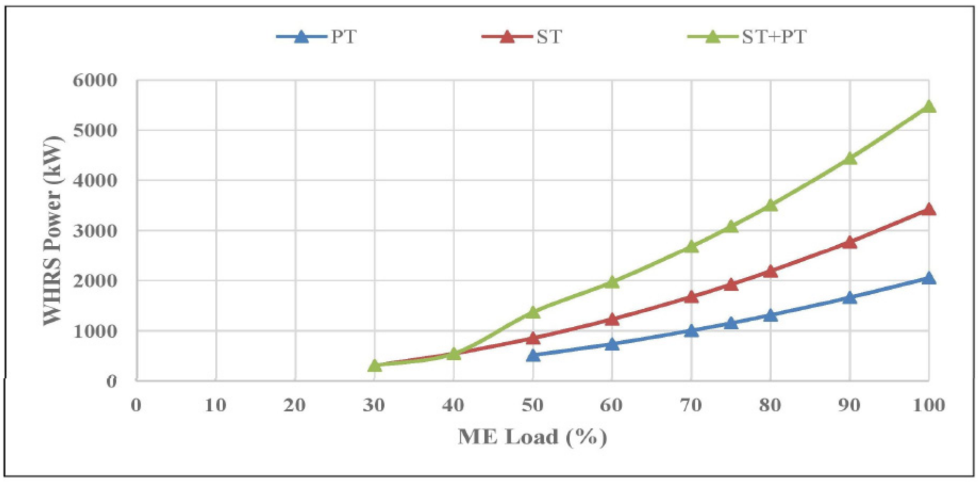

Fig. 2. Combined ST and PT Power depending on ME Load

Attained and Required EEDI

The EEDI for new ships is the most important technical measure and aims at promoting the use of more energy efficient (less polluting) equipment and engines. The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments [3].

Since 2011 each new built ship has to be in compliance with the requirements for EEDI and REEDI set by IMO. The Attained EEDI of the ship should be less or equal to REEDI calculated for the related vessel. REEDI is going to be tighten in three phases during the years and the objective set by IMO is reduction with 30% on phase 3 which have to be in force 2025 onwards.

The calculations for EEDI and REEDI in this article are performed in compliance with [4], [5], [6] and [7]. The total power of the ST-PT WHRS used into the calculations is considered as 5500 kW. The values of EEDI and REEDI for the chosen container vessel and the propulsion options mentioned earlier in this article are given in Tables 4 and 5. Graphical interpretation of the EEDI and REEDI is shown in Figures 3 and 4.

REEDI for 101 224t DWT Container vessel

Table 4

Required EEDI	
Base REEDI	17.18
Phase 1 (10% reduction)	15.42
Phase 2 (20% reduction)	13.74
Phase 3 (30% reduction)	12.03

Attained EEDI for observed propulsion systems

Table 5

Attained EEDI	
Option 1	13.94
Option 2	12.50
Option 3	10.22
Option 4	9.17

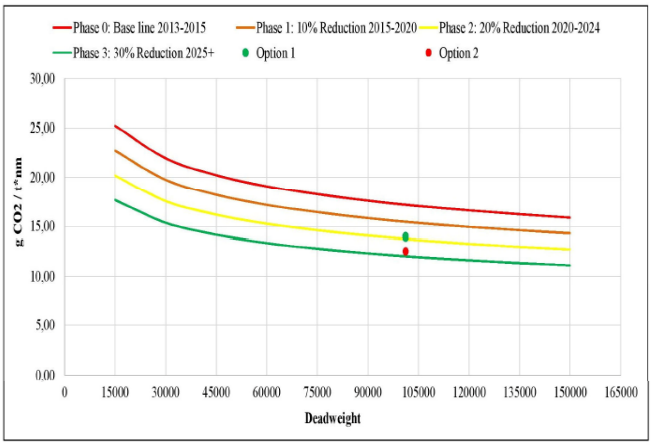

Fig. 3. EEDI for Options 1 and 2

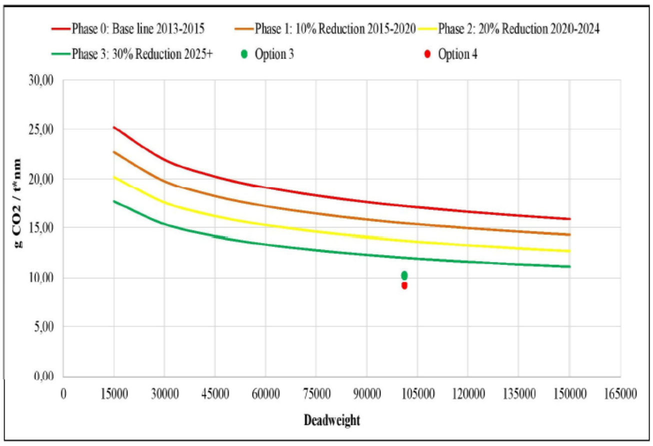

Fig. 4. EEDI for Options 3 and 4

Operational costs improving due to fuel savings

The expenditures for fuel represents a major part of each ship's operational costs. By lowering the fuel consumption of the ship we also better her operational costs, which will lead not only to reduction of the harmful gases emitted in the atmosphere, but also will offer a significant money savings for the ship owners.

Using the WHRS will allow the ship operators to stop the AEs during the voyage, as the system will ensure a full electrical redundancy in this operational conditions. WHRS will be unable to be used in ports as the ME are being stopped and during the maneuverings as the ME will work on low loading. Consequently the fuel savings could be calculated as the fuel saved during the voyage when the AEs could be stopped and the electrical demand is provided only by WHRS.

The values given in tables 6 and 7 are attained by the assumption that the ME load is 75% at voyage and 35% at maneuverings, AE load are 50% in each conditions, the ship is 80% at voyage, 15% at port and 5% during maneuverings i.e. 292 days at voyage, 55 days at port and 18 days spent in maneuverings.

(2) $RC = SFC\ (ME, AE) \times Power\ (ME, AE) \times 24\ (hours) \times (days) \times Fuel\ Price\ (USD\ per\ tonne)$

Total fuel consumption and fuel savings for a period of 1 year

Table 7

#	ME Fuel Cons. / Voyage	ME Fuel Cons. / Port stay	ME Fuel Cons. / Maneuvering	AE Fuel Cons. / Voyage	AE Fuel Cons. / Port stay	AE Fuel Cons. / Maneuvering
Option 1	55210t, HFO	0t, HFO	1654t, HFO	3758t MGO	354t MGO	347t MGO
Option 2	55210t, HFO	0t, HFO	1654t, HFO	0t MGO	354t MGO	347t MGO
Option 3	44189t, LNG	0t, LNG	1308t, LNG	3408t LNG	321t LNG	315t LNG
	1268t, MGO	0t, MGO	61t, MGO	76t MGO	7.3t MGO	7.2t MGO
Option 4	44189t, LNG	0t, LNG	1308t, LNG	0t MGO	321t LNG	315t LNG
	1268t, MGO	0t, MGO	61t, MGO	0t MGO	7.3t MGO	7.2t MGO

Fuel consumption of ME and AE

Table 6

#	Consumption	Total AE Fuel Consumpion	Total ME and AE Fuel Consumption	Total Fuel Savings (%)
Option 1	56864t, HFO	4459t, MGO	56864t, HFO	**6.5**
			4459t, MGO	
Option 2	56864t, HFO	701t, MGO	56864t, HFO	
			701t, MGO	
Option 3	45497t, LNG	4044t, LNG	49451t, LNG	**5.6**
	1329t, MGO	90.5t, MGO	1419.5t, MGO	
Option 4	45497t, LNG	636t, LNG	46133t, LNG	
	1329t, MGO	14.5t, MGO	1343.5t, MGO	

In Table 8 are given the values for operating the ship in a period of 1 year depending on the calculations for fuel consumption and the values placed in Table 7. The fuel prices for MGO and HFO are the global average for the period 01.01.2020 - 16.10.2020 and are extracted from [8], the price for LNG is based on the average for Henry Hub based on [9], the values for average fuel prices are given in Table 9.

Total fuel costs for operating the ship for a period of 1 year

Table 8

#	HFO Costs	MGO Costs	LNG Costs	Total for 1 year
Option 1	17 542 544 $	2 271 860 $	-	19 814 404 $
Option 2	17 542 544 $	357 159 $	-	17 899 703 $
Option 3	-	723 235 $	6 492 916 $	7 216 151 $
Option 4	-	684 513 $	6 057 262 $	6 741 755 $

Average fuel prices

Table 9

Average Fuel Prices	
0.1%S MGO	509.50 $/tonne
HFO	308.50 $/tonne
LNG	131.30 $/tonne

GHG and harmful emissions reduction

Along with improved EEDI and significant fuel savings, the positive effect on the environment by reducing the GHG and harmful emission radiated in the atmosphere should not be underestimated. In charts 4 and 5 are depicted the reductions of the CO_2 and SO_x Emission for each propulsion system observed in current article. For the calculation of the SO_x Emissions the following circumstances are took into consideration:

- HFO with sulphur content 3.0% for ME in Option 1 and 2;
- MGO with sulpur content 0.1% for AE for all options (For Option 1 and 2 - as Main Fuel, for Option 3 and 4 as Pilot Fuel);
- LNG is considered as sulphur free fuel.

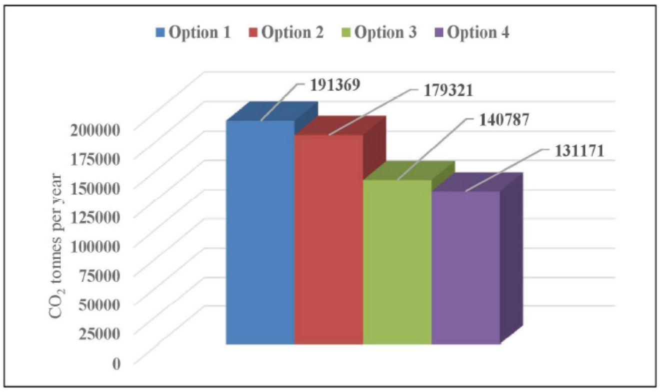

Fig. 5. Annual CO2 reduction due to WHRS use

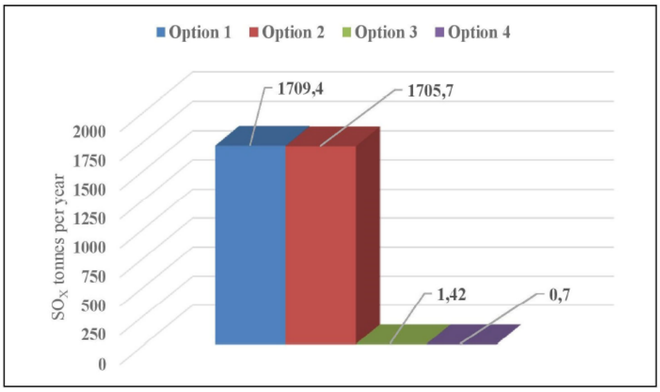

Fig. 6. Annual SOX reduction due to WHRS use

IV. CONCLUSIONS

In this paper four options for propulsion systems have been studied. In two of them WHRS have been included and the benefits for using such a kind of innovative technologies with purpose to improve the energy efficiency of the ship were accounted. For each of the systems have been calculated their EEDI and REEDI, fuel consumption and the fuel savings for operating the ship for a period of 1 year have been considered, also a comparison of the CO_2 and SO_X emissions radiated in the atmosphere by each system have been accounted. Taking into consideration the values achieved by the calculations performed we can conclude that Option 3 and 4 are the most efficient systems among the observed in this article.

"This paper has been prepared within the project NP8/2020 "Conceptual design of the ship minimizing the risk of environmental pollution", funded by the State Budget under contract No 108/22.05.2020"

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REDUCTION OF EXHAUST GASES AND HARMFUL EMISSIONS FROM OIL TANKERS

Vladimir YORDANOV*, Alexey DANILOVSKIY, Pyae Phyo AUNG ****

Abstract. *Annex VI of MARPOL entered into force on 19 may 2005, sets limits on emissions contained in the ship exhaust gases. The existing systems of marine engine's and boiler's does not meet the requirements of IMO for sulphur content in the fuel after 1 January 2020. The basic methods for reducing the exhaust gases and the harmful emissions from ships are presented in the paper: exhaust gas treatment, the use of alternative fuels and gases, the use of dual pressure exhaust gas boilers.*

Key words: *alternative fuels, exhaust gases, exhaust gas treatment and boilers, harmful emissions, tankers.*

INTRODUCTION

Air pollution depends to a certain extent on the exhaust gases of the engines of thermal power plants, all types of transport, including water transport. IMO standards for harmful emissions from ships are contained in the "International Convention for the Prevention of Pollution from Ships", known as MARPOL 73/78. In 1997, the MARPOL 73/78 Convention was amended - the "1997 Protocol", which includes Annex VI, entitled "Prevention of Air Pollution from Ships". Annex VI of MARPOL, which was first adopted in 1997 and entered into force on 19 may 2005, sets limits on NO_X and SO_X emissions contained in the ship exhaust gases and prohibits deliberate emissions of ozone-depleting substances., designated emission control areas set more stringent standards for SO_x, NO_x and particulate matter [1, 2]. In 2011, mandatory measures were introduced to Annex VI of MARPOL to reduce greenhouse gas emissions. Annex VI MARPOL defines two types of requirements for exhaust emissions and the quality of fuel used on ships: 1 - global requirements; 2 - more stringent requirements for vessels navigating in emission control areas (ECAs).

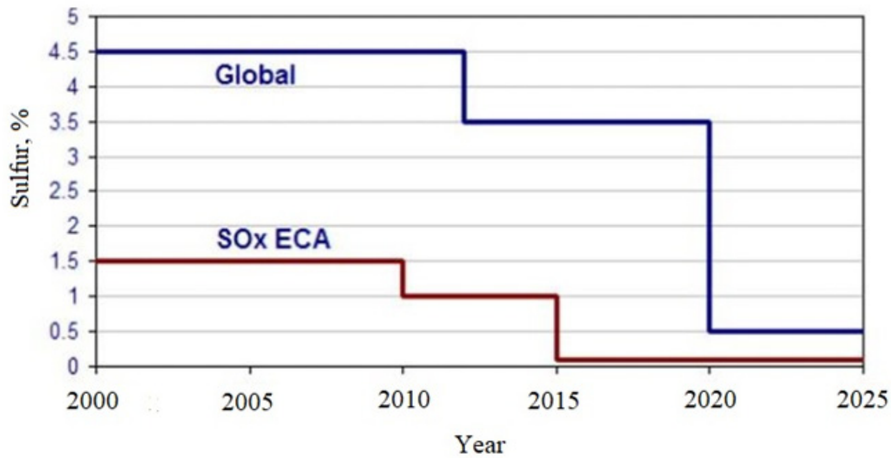

Fig. 1. MARPOL Annex VI requirements for sulphur content limits in the fuel for global sea and emission control areas (ECAs)

In fig. 1, requirements for sulphur content in the fuel are presented (as a measure to control SO_x emissions and indirectly particulate matter-PM emissions). As it can be seen from fig.1, the sulfur in marine engine fuel should not exceed 0,5% for the global sea after 1 January 2020 (and after 1 January 2015 this sulfur amount

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is 0,1% for ECAs - Baltic Sea area, North Sea area, North American area, United States Caribbean Sea area) [1, 2, 3].

It is obvious that the existing systems of marine engine's and boiler's does not meet the requirements of IMO for sulphur content in the fuel after 1 January 2020. This problem is particularly acute for tankers, because they use bigger amount of fuel for auxiliary boilers operation for heating of the transported cargo - heavy oil products and paraffin crude oil. In 2011, in accordance with Annex Vl MARPOL, it was planned to introduce two environmental standards, designed to ensure the efficiency of ships and indirectly to reduce greenhouse gas emissions: 1 - Energy Efficiency Design Index (EEDI) for new ships; 2 - Ship Energy Efficiency Management Plan (SEEMP) for all ships [4]. These measures are applied on ships with a deadweight of more than 400 tons and entered into force after 1 January 2013.

COMPARATIVE ANALYSIS OF MAIN METHODS FOR REDUCING EXHAUST GASES AND HARMFUL EMISSIONS FROM SHIPS

Use of traditional fuels and applying of additional equipment (scrubber) for neutralization and purification of exhaust gases and reducing harmful emissions

This is a basic method for reducing the sulphur content in the exhaust gas of the ship's energy plants wich is discussed in the technical literature. Purification technology for combustion products of highly sulphurous heavy fuel oil for reduction emissions of sulphur oxides emissions into the atmosphere is used. Scrubbers are developed for purifying of exhaust gases of sulphur, nitrogen dioxides and particulate matter (PM).

Scrubbers allow to reduce SO_x up to 90%, NO_x up to 10% and particulate matter up to 60-90% of the exhaust gases initial content [5, 6]. The use of wet scrubbers is common on ships for neutralization of exhaust gases, where as a cleaning medium seawater or fresh water with addition of an alkali solution (NaOH) is used. The efficiency of SO_X reduction with alkali injection corresponds to a reduction of fuel sulphur content from 3.5% to 0.1% [7].

Exhaust gas cleaning is performed in the scrubber housing. The housing usually consists of a number of basic elements: nozzles for spraying water in the scrubber housing; perforated plates for foaming on their surfaces; demister for separating liquids from exhaust gases at the scrubber outlet. Exhaust gases from the ship's energy plant enter through the inlet pipeline into the scrubber bottom. In the scrubber housing, the gases rise up and are washed with cleaning water. Water under pressure is fed into the scrubber housing. The nozzles, installed in the scrubber housing, provide the water spray. Waste water with sludge is collected at the scrubber bottom and discharged into the treatment unit. In the unit, sludge is separated from the wastewater. The sludge is stored in the tank and the treated water is reused.

Figure 2 shows a longitudinal and cross sections of the engine room single-shaft crude oil tanker with a lowspeed engine, a two-stage exhaust gas boiler, three diesel generators and two auxiliary boilers. In the housing of a funnel two scrubbers are located : 1) first scrubber with four entrances - from the main engine pipeline after exhaust gas boiler and from three diesel generator's pipelines; 2) second scrubber with two entrances - from two auxiliary boiler's pipelines.

Separate scrubbers - main engine scrubber (MES) and auxiliary boiler scrubber (ABS), are necessary due to the different pressure at the outlet from diesel engines and boilers. The process in the scrubber creates additional resistance, which requires the installation of smoke exhausters.

Use of alternative fuels meeting the IMO requirements

The next method for reducing the sulphur content in the exhaust gas of the ship's energy plants is the use of alternative fuels (ultra low sulphur fuel oil (ULSFO) of 0.1% maximum sulphur content - table 1 [8], methanol, dimethyl ether, water-fuel emulsion, marine gasoil (MGO), natural gas, petroleum gas, propane and butane).

Use of low-sulfur heavy fuel oil

The russian industry produces low-sulfur heavy fuel oil with a sulfur content of 0.1%. Such fuel can be used without additional purification of exhaust gases from SO_X. Its cost, according to the price lists, does not differ from the cost of sulfur heavy fuel oil. Probably, due to the increased need for low-sulfur heavy fuel oil after the entering into force of new MO requirements after 1 January 2020, its price will increase.

Sulphur content of marine fuels

Table 1

Fuel type	Sulphur content (%)
ULSFO	Max. 0.1
VLSFO	Max. 0.5
Heavy fuel oil (HFO)	>1.0
Marine diesel oil (MDO)	0.1-1.5
Marine gas oil (MGO)	0.1–1.0

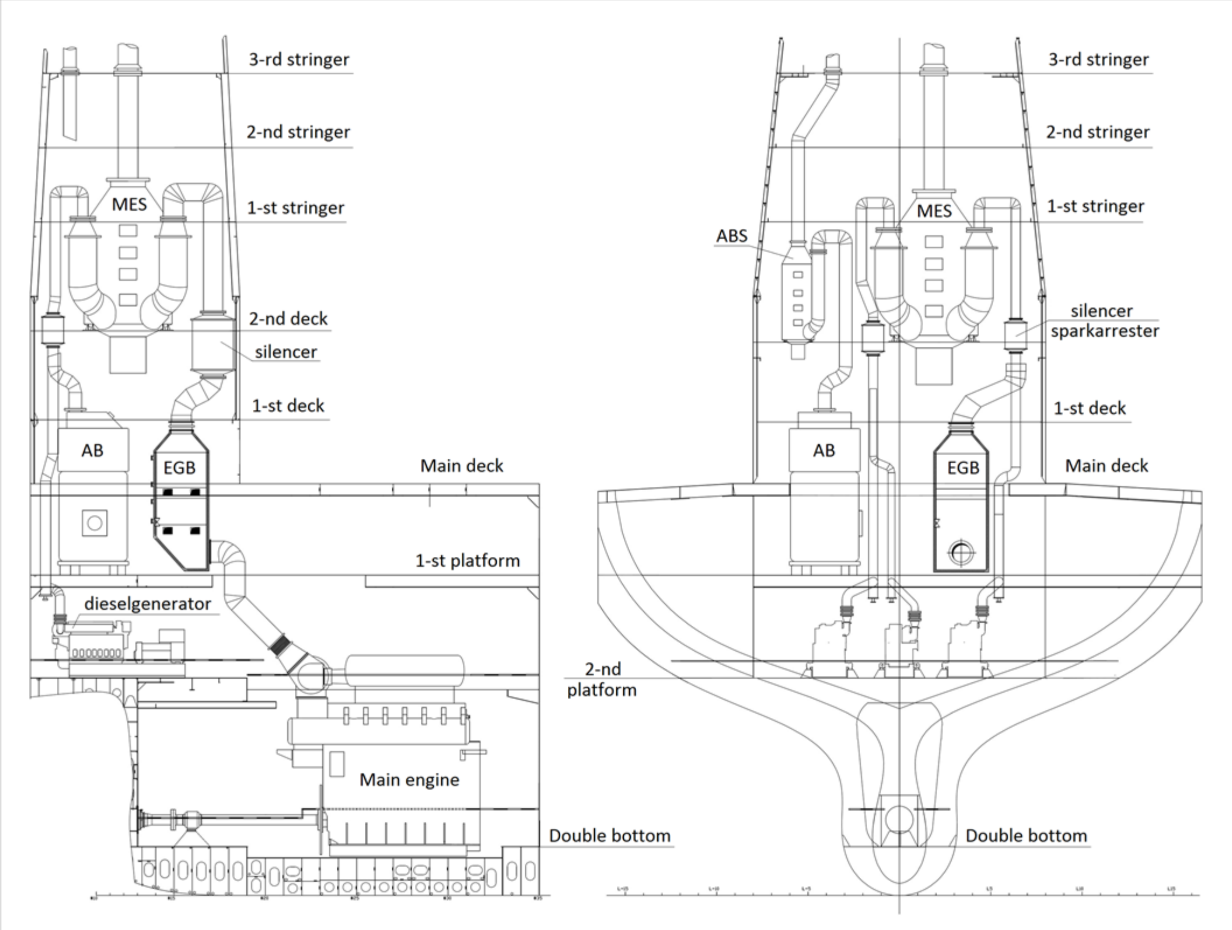

Fig. 2. Engine room of crude oil tanker with two scrubers

Use of liquefied natural gas (LNG)

The use of liquefied natural gas for the operation ship's power plant (SPP) is one of the perspective modes to reduce harmful emissions in accordance with the IMO requirements. The use of liquefied natural gas as a motor fuel for SPP makes it possible to eliminate completely sulphur emissions SO_X reduce nitrogen oxide emissions NO_X by 90 % and reduce carbon dioxide emissions CO_X by 30%, as well as to reduce the emission of particulate matter - PM. The main component of LNG is methane (CH_4). Engine manufacturers produce dual fuel marine engines, which are using of LNG (90÷99%) and diesel fuel (1÷10% - as ignition) [9]. An additional advantage of SPP using LNG is its lower cost compared to other alternative fuels. In addition, the use of LNG in Russia will insure even greater profits, as the gas price in Russia is 3.2 times less than its price for the European market.

However, at the same time there are also obvious disadvantages: the need to create a more complex infrastructure providing the supply of consumers, lack of a developed system of LNG ships bunkering, high requirements of the legislation of the Russian Federation to the locations of LNG storage tanks. It is necessary to modernize the storage and supply fuel systems when transferring the ship's energy plant for non-gas fuel. Special reserve tanks for storage of LNG are required on ships, providing powerful heat protection. In such reserve tanks, LNG is poured and stored as a liquid at a temperature of -162˚C. It should be noted here, that such tanks cannot protect fully LNG from the influence of the external environment, therefore, from 0.15% to 0.18% of the capacity of LNG tanks per day is converted into a gaseous phase [10]. Due to the 2.5 times lower density of liquefied gas, the size of the storage tanks for the fuel reserves on a cargo ship voyage is the same times bigger. Besides, they are cryogenic and insulated, made of special materials. All pipes must be double for safety. Due to the shapes, insulation and segregation required of cryogenic tanks, the fuel containment and supply systems often require three to four times more space on shipboard. As shown by the calculations, the evaporating gas is not enough for the ship's move and it is necessary to gasify a part of the liquid fuel.

Use of liquefied petroleum gas (LPG)

LPG is a mixture of hydrocarbons consisting mainly of propane and butane in liquid form. It is a by-product from oil and gas production or the oil refining process and can be derived from the production of biodiesel. The use of LPG as fuel is a relatively new concept in the commercial shipping industry and it is expected to be limited to LPG carriers. LPG is easier to handle and store than liquefied natural gas (LNG), which simplifies bunkering supply systems. LPG's calorific value is 12-15 percent higher than that of heavy fuel oil. In large quantities, LPG is stored or transported in pressure vessels at around 18 bar or semi-pressurized/refrigerated tanks at 5-8 bar and -10 to -20°C. Providing LPG bunkering infrastructure, including shipboard equipment, would be less costly than the operating systems and equipment required for LNG. Currently, there is only one marine dual fuel engine, MAN ME-LGI, designed specifically for LPG as an alternative. MAN also offers a generic engine variant capable of burning multiple fuels as gas, such as ethane or methane, in addition to LPG [11].

REDUCING EXHAUST GAS AMOUNT AND CORRESPONDING HARMFUL EMISSIONS GENERATED FROM SHIPS

Application of two-stage (dual pressure) exhaust gas boiler allowing to reduce fuel consumption and exhaust gas amount generated from ship

Application of two-stage boilers allowing to reduce fuel consumption in the case of heavy fuel oil use. Less burned fuels - less exhaust gas amount and less sulphur enters the environment. The using of single and dual pressure steam system have different variants because of different consumers of thermal energy [12, 13, 14, 15]. Consumers of thermal energy on transport ships have different requirements for the temperature potentials of the working fluid - steam for the auxiliary boiler plant [16]. Steam consumers can be divided into two groups:

1) high-potential consumers (heavy fuel heaters, steam drive auxiliary mechanisms) ;

2) low-potential consumers (heating of crude oil cargo, tanks, ballast, steam and water heating, air conditioning, household consumers).

First consumers require steam with temperature of 180 °C; for the second consumers it is enough 120 °C or less. Any heating system requires a temperature head - exceeding the temperature of the heating medium over the heated. In systems with saturated steam, when the temperature of the vapor during evaporation and condensation does not change, the temperature head is taken at the level of 25-30 °C, which allows to obtain a moderate surface area of heat exchange. Thus, the use of furnace fuel oil M-100 as a fuel for in the main engines, diesel generators and auxiliary boilers, requires heating of the fuel up to 150-155°C and temperature of the heating steam cannot be lower than 180°C.

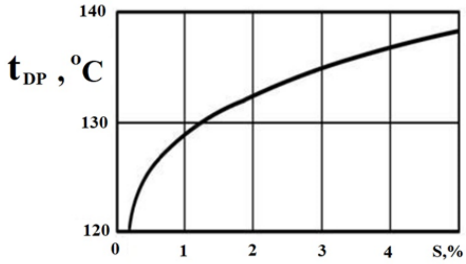

Fig. 3. The dependence of the dew point temperature of the sulphur content in the fuel

The maximum possible amount of steam in the exhaust gas heat recovery system is limited by the presence of sulphur compounds in the exhaust gases and the dew point temperature. The dependence of the dew point of the sulphur content in the fuel is shown in fig.3. At the maximum sulphur content up to 3,5%, the corresponding dew point is 136 ^{o}C and the decrease of the exhaust gases temperature is possible only to 145 ^{o}C (the reserve of the temperature is necessary to ensure the variable regimes). It should be recalled, that the dew point temperature should not be achieved by the gases, but by the working fluid that's taking the heat from the gases, because of the reason that water vapour condensation and acid formation occurs on the pipe surface, and the thermal resistance of its metal is low. If we use a single-stage exhaust gas boiler, then the exhaust gases can be cooled not lower than 205 °C (180 °C + 25 °C). In case of using of the two-stage exhaust gas boiler, proposed by us and shown in fig.4, the gases can be cooled to 170 °C [17]. At the same time, the scavenging air heat recovery system can be included, because of its high temperature of 170 - 180 °C at the compressor outlet. Separate utilization of exhaust gas heat in two-stage exhaust gas boiler and the use scavenging air heat, allows to reduce fuel consumption by 8-8.5 % on average per a cargo ship voyage and to reduce the carbon dioxide production by the same amount, and also to increase the ship's SEEMP.

The design of the two-stage boiler is similar to the exhaust gas boiler SKBK KUP 180 (russian production). In the boiler KUP 180, the steam-water mixture is transfered from the lower section to the upper section. In our design, the sections are separated and each operate for its own separator [18]. The composition of the two-stage exhaust gas boiler includes two evaporation surfaces, closed into two steam separators with different pressure levels - high pressure section (HPS) with high temperature (10 bar/180 ˚C) and low pressure section (LPS) with low temperature (4,3 bar/145 ˚C). The high-temperature section is needed to heat heavy fuel oil, that is burned in the main and auxiliary engines. The low-temperature section is used for as much as possible utilization of the exhaust gases heat. The latter is limited to the dew point.

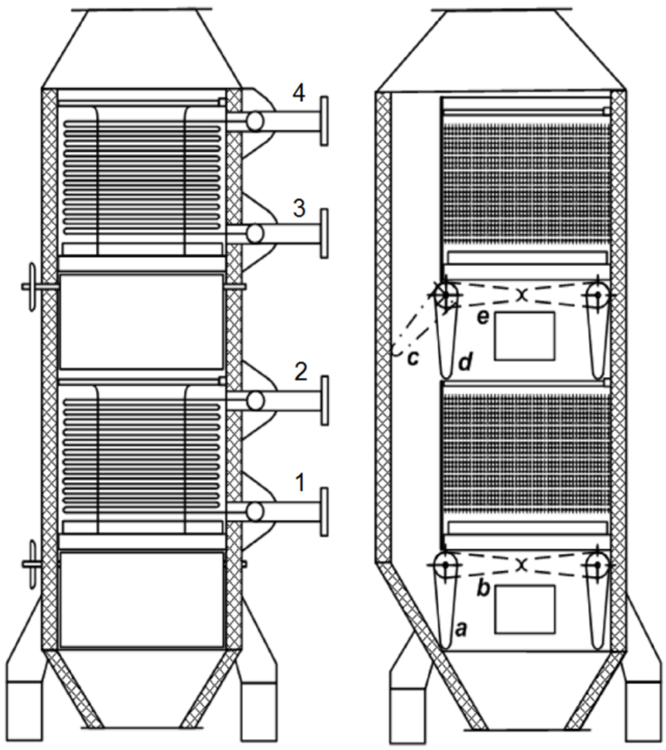

Fig. 4. Construction scheme of the two-stage (dual pressure) exhaust gas boiler

The supply of feed water to the HPS is realized with pipeline 1 from the HPS separator by means of the circulating pump to the water distribution mani-fold on the coils. Outflow of the steam-water col-lector goes to the HPS separator via pipeline 2. Feed water supply to the LPS is performed via pipeline 3 from the LPS separator by means of cir-culation pump. Outflow of the steam-water mixture is performed via pipeline 4 to the LPS separator. A two-stage (dual pressure) exhaust gas boiler operates as part of a separate steam supply system for consumers [19]. The scheme of this system is shown in fig.5. In the figure are designat-ed: 1 - two-stage (dual pressure) exhaust gas boiler (EGB); 2,23 - circulation pumps of EGB; 3 - steam separator of low pressure section (LPS) of the EGB; 4 - steam separator of cooling section 5; 5 - high temperature cooling section of the scavenging air; 6 - circulation pump of cooling section 5; 7 - auxilia-ry boiler (AB); 8 - air duct of AB; 9 - air flaps; 10 - boiler fan; 11 - heavy fuel oil service tank; 12, 15 - filters of cold and hot fuel; 13 – fuel pump; 14 - fuel heater; 16 - injector; 17 - feed pump of AB; 18 - feed pump of high pressure section (HPS); 19, 21 - feed pumps of EGB sections; 20 - hot well; 22 - separator of the HPS of the EGB; 23, 24 - steam for main engine fuel oil heating.

Reducing exhaust gas amount and corresponding harmful emissions by reducing ship's speed

Reducing ship's speed is an operational method with a significant effect on reducing exhaust gas amount from ships. It is estimated that 'slow steaming', as it is known, reduced shipping's overall carbon dioxide (CO_2) output in 2015 by dropping the carbon intensity of maritime transport by 30 percent compared with 2008 levels. Reducing ship speed impact on CO_2 emissions reduction is shown in Table 2 [11]. The reducing of speed can reduce fuel consumption by more than 15%, but considering that speed reduction is not unlimited because sailing in a low load can result in serious damage to the engine. Also using a slower sailing ship will require more time to cover a certain distance.

Reducing ship speed impact on CO_2 emissions reduction

Table 2

Ship type	CO_2 Emissions reduction	
	1-knot Speed reduction	2-knot Speed reduction
Dry Bulk	13%	25%
Oil tankers	15%	28%
Containerships	6%	11%

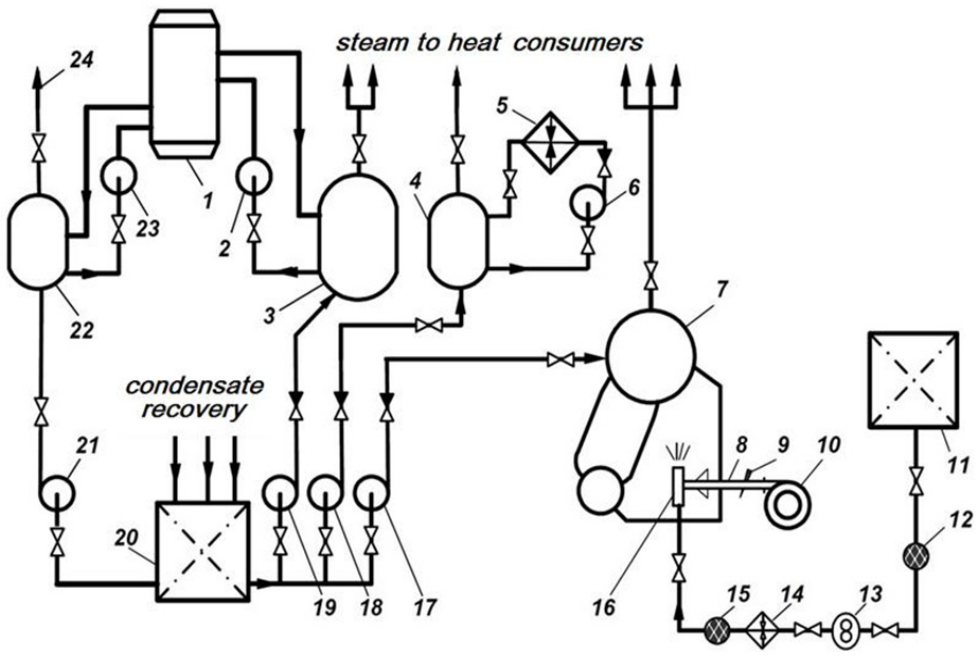

Fig. 5. Sheme of the separate steam supply system for steam consumers

Results of application of two-stage (dual pressure) exhaust gas boiler in the separate steam supply system

Due to the application of a two-stage exhaust gas boiler in the separate steam supply (SSS) system for consumers in crude oil tanker "Moskovsky prospect (type Aframax with deadweight-100150 t), about 143 tons of fuel (7.5% of the total demand) is saved on the period of ship navigation of 2*6000 nautical miles, in comparison with the use of a single-stage exhaust gas boiler. This tanker shown on fig.6 (overall length -250m, breadth - 44m, draught - 15m), transports heavy oil products from the port of Vysotsk (Baltic, Leningrad region of the Russian Federation). The most of the savings are realized during the first half of the cargo ship voyage, due to the heating of the cargo. There are also savings on the second half of the ship voyage, but in ballast tanker voyage, the need for steam decreases and economy on fuel decreases also. Auxiliary boilers are being switched on at one third of their capacity, for 30% of the first half of the two cargo ship winter voyages. On the remaining 7 cargo ship voyages (spring, summer and autumn) auxiliary boilers are not switched on at all.

Due to the fuel economy, it is possible to transport an additional amount of cargo corresponding to the amount of saved fuel and receive additional profit from the cargo transportation. The total benefit from the use of a separate steam supply scheme of consumers and a two-stage boiler is 973 000 USD/year. The reduction of carbon dioxide emissions due to fuel economy is 4054 tons CO_2 per year. Corresponding heat emission into the atmosphere is reduced by 59150 MJ/year.

Fig. 6. The crude oil tanker "Moskovsky prospect"

CONCLUSIONS

1. The all of the above considered methods for reducing exhaust gas amount and harmful emissions with exhaust gases into the environment, have their advantages and disadvantages. Each method requires development and implementation of innovative methods. On one hand, specialists are trying to develop more compact scrubbers for neutralization of exhaust gases and on the other, to solve the problem of bunkering and storage of LNG or LPG on the ship. It is necessary to carry out a comparative analysis of these methods and make the choice of the optimal variant for the modernization of the ship's energy plant, in accordance with the IMO requirements.

2. When liquefied natural gas (LNG) is used, additional investments are required for the transition of ship's power plant (SPP) to gas fuel. If the SPP continues to operate on traditional fuel using exhaust gas neutralization system, it is necessary to install scrubbers and the cost of the ship also increases. However, according to the analysis [20], the current number of ships using scrubbers is almost three times more than the number of vessels using fuel - liquefied natural gas. In addition, the majority of the vessels using LNG fuel are gas carrier ships transporting LNG.

3. Application of scrubbers in the exhaust gas systems of the main engines appears as an additional resistance, which can affect the engines power. However, it is possible that water injection promotes decrease in the hydraulic resistance and the installation of the scrubber will not have an impact on the characteristics of the engine. In addition, if it's necessary to avoid falling back pressure at the outlet of the engines, a fan is installed at the scrubber outlet.

4. A special feature of the tankers for transportation of heavy petroleum products is the need to install

auxiliary boilers for steam generation. A second scrubber must be built into their gas exhaust gas tract. The use of two-stage (dual pressure) exhaust-gas boilers allows to reduce the size of the scrubber of auxiliary boilers, which will facilitate its placement in the engine room smokestack.

5. On sea transport vessels, consumers of thermal energy - seam consumers are: high-temperature ones (the heaters of high-viscosity fuel and turbo-drive mechanisms) and low-temperature consumers (heating of crude oil cargo, tanks, ballast, steam and water heating, air conditioning, household consumers). As a result, the greatest fuel economy can be obtained in the dual-pressure (two-stage) waste heat recovery systems.

6. A separate scheme of heat recovery of exhaust gases and scavenging air is proposed, which allows not only to increase the amount of heat energy utilized, but also to abandon completely the operation of auxiliary boilers on long-term running regimes, not only on dry cargo ships, but also on tankers transporting high-viscosity crude oil products.

7. Improved waste heat recovery systems of marine engines are proposed, providing reduction in fuel consumption by 7,5% of the total demand, saving of operating costs, improving the energy and environmental efficiency of auxiliary boiler installations of transport vessels, reducing emissions of carbon dioxide and heat to the environment [21].

8. Two-stage exhaust gas boilers are not produced by either russian or foreign firms. We have set and partially solved the problem of developing the design and type-size range of such boilers [18].

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LAYOUT AND LOCATION OF THE POWER PLANT EQUIPMENT AND GENERAL SHIP'S SYSTEMS EQUIPMENT OF TRANSPORT SHIPS

Vladimir YORDANOV*, Alexey DANILOVSKIY, Htet Paing AUNG****

Abstract. *Annex VI of MARPOL entered into force on 19 may 2005, sets limits on emissions contained in the ship exhaust gases. The existing systems of marine engine's and boiler's does not meet the requirements of IMO for sulphur content in the fuel after 1 January 2020. The basic methods for reducing the exhaust gases and the harmful emissions from ships are presented in the paper: exhaust gas treatment, the use of alternative fuels and gases, the use of dual pressure exhaust gas boilers.*

Key words: *alternative fuels, exhaust gases, exhaust gas treatment and boilers, harmful emissions, tankers.*

INTRODUCTION

A system is a set of equipment, that performs a determinate complete function as a part of the vessel. There is a propulsive complex providing the ship's movement, an electric power system providing the vessel with electrical energy, an auxiliary boiler plant providing the vessel with thermal energy in the form of water steam energy, the ship's power plant systems and general ship's systems providing the ship with working fluids - liquids and gases.

Many of these working fluids are used for various purposes, for example, seawater is used for cooling of charge air, lubricating oil, compressed air in the compression process in the compressors, cooling of provisions store chambers, for operation of the refrigeration machines, for inclining, trimming and ballasting of the ship in the cargo receiving and delivery, washing and cooling of the decks in the hottest time of the year, works of desalination plants and fresh water generator, and etc. Systems include various mechanisms, their drive, pumps and heat exchangers, deck mechanisms, pipelines, instrumentation, automation elements. All this equipment should be located on the vessel as compactly as possible, without reducing the useful capacity of the vessel for transported cargo, providing access to mechanisms for maintenance and repair. In this paper we analyze the layout and location of ship's power plant equipment and general ship's systems equipment of transport ships.

AIMS AND PURPOSES

Transport vessels are designed to transport cargo with minimal costs and to obtain the most profit, during their construction and operation. Changing the layout and location of the various equipment does not have a significant impact on the change in ship's carrying capacity, therefore as a criterion for the effectiveness of decisions can be used ship's expenditures of the design object - ship's power plant equipment and general ship's systems equipment.

Depending on the nature of their cargo transport ships can be divided into different categories, classes and types (liquid cargoes ships: crude oil tanker, gas LPG/LNG tanker, product tanker, chemical tanker, Oil/Bulk/Ore carier; dry cargo ships: bulk carrier, general cargo ship, container ship (container carrier, roll on-roll off), multipurpose bulk container carriers, reefer, refrigerated cargo vessel; passenger ships: ferry, cruise vessel; and depending on navigation area (sea vessels, coasters and inland navigation vessels) [1, 2, 3].

In the majority (up to 95 % and more) sea vessels are single-shaft and equipped with low-speed main engines. Most coastal vessels are equipped with medium-speed engines, like all inland navigation vessels. For low-speed main engines, the power plant systems (PPS) are separate from the main engines and require layout, location and arrangement. The main system's elements of the PPS with medium-speed main engines are hung on the main engines and are supplied with them. Elements of compressed air systems and sometimes sea water cooling systems elements (in the case of two-stage cooling) are supplied separately. Therefore, we further consider the systems and equipment layouts of sea transport ships with low-speed main engines.

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METHODS OF LAYOUT AND LOCATION OF THE SHIP'S EQUIPMENT

The power plant equipment and general ship's systems equipment of transport ships is united into energy complexes - producing or consuming different types of energy to perform their functions. Such a union is designated by the technical term aggregation. The modularization of ship's systems and its equipment in several modules and units make the ship design process faster, and also the aggregation allows to reduce the ships construction time, improve the quality of installation [4, 5]. The installation of different aggregates (units) are performed in the shipbuilding workshop or on the preliminary assembly shop, which are equipped with special devices and stands for installation.

The aggregates are being worked out for disassembly in order to exclude related work during the dismantling of individual structural units during repair in the ship's conditions. However, the main one is the aggregate repair - with the removal of the unit from the ship's premises and replacing it with a similar, new or repaired in a repair and operational base. This aggregate repair reduces vessel demurrage during repair.

There are functional and zonal aggregation. The second does not exclude the first. A functional aggregate (FA) is a set of equipment, that performs a specific complete function in a ship or in a ship's power plant (SPP). FA includes corresponding SPP elements, internal pipelines and cables, automation elements and instrumentation united on a common supporting structure, Usually FA is assembled in the shipbuilding assembly workshop or in the assembly workshop of specialized enterprise. Zonal aggregates (ZA) or blocks are a set of equipment intended for installation in a certain area of the vessel, mounted on a preassembled hull structure. The ZA equipment can include separate SPP elements and functional aggregates united on a common hull structure part. Installation of zonal aggregates is carried out on preliminary assembly shop, as ready is supplied to the slipway for welding to the already installed hull structures or to other zonal aggregates (blocks).

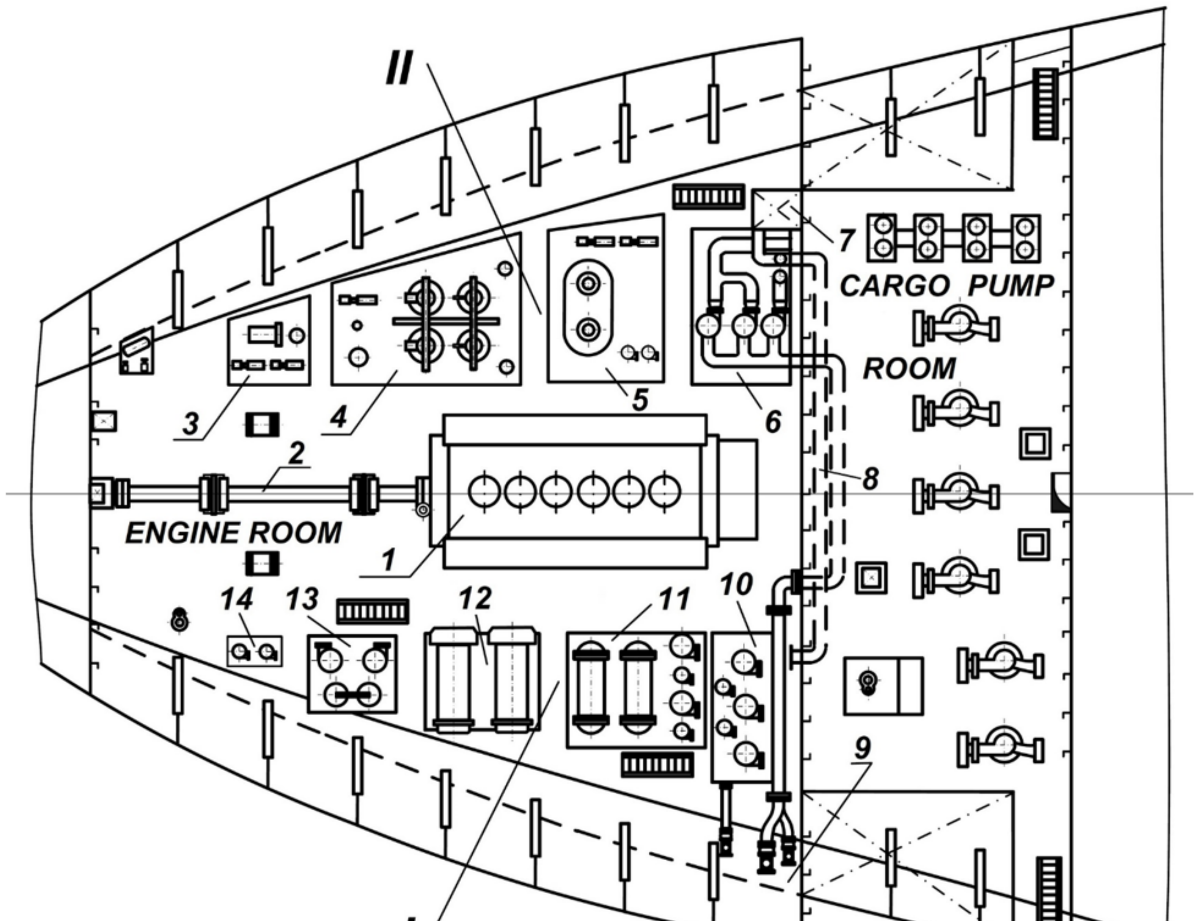


Fig. 1. Engine room and cargo pump room of crude oil tanker project 1596

There are aggregates of SPP and aggregates of general ship's system equipment. Figure 1 shows the plan of crude oil tanker project 1596, made on the principle of functional and zonal aggregation, fully implementing the development of the Krylov State Scientific Center of Shipbuilding of the Russian Federation [4, 6].

A zonal aggregate is located in the engine room center. This ZA includes the low-speed main engine (1) and located underneath the mortgage section of the double bottom with waste tank of main engine circulating oil. The zonal aggregate of shaft line (2) is located in the ship's aft. In the ship's bow, zonal aggregate of the cargo pump room (CPR) is located. A part of CPR is combined with the engine room regarding the room of cargo pumps drives.

On the left board of the engine room, the zonal aggregate (block) is located with designation II, including the following equipment, functional aggregates (FA) and components: 3 - FA of fuel transfer pumps; 4 - FA of fuel and oil separation; 5 - FA of bilge water separation; 6 - FA of general ship's pumps (ballast, cooling and fire); 7 - left side kingston sea chest; 8 - seawater ballast chanel. Function of block II is maintenance of the main engine and general ship's mechanisms. On the starboard side of the engine room, the zonal aggregate (block) is located with designation I, including the following auxiliary equipment of SPP systems: 9 - starboard side kingston sea chest; 10 - FA of sea water pumps and filters of SPP; 11 - FA of fresh water pumps and coolers; 12 - FA of oil coolers; 13 - FA of main engine lubricating oil pumps; 14 - FA of fuel supply pumps.

An additional feature of this equipment location is the placement of mechanisms interacting on the running mode with the main engine on the starboard side, which facilitates the detection of failures when they occur. On the basis of typical equipment locations, a computer-aided design system of the SPP location with low-speed main engine in the engine room of a sea ship has been developed by the Krylov State Scientific Center of Shipbuilding [7, 8].

In the work of Vasiliev A.L. [9] the general principles of modular shipbuilding are presented. The FA of the general ship's pumps has already been mentioned above. All of them (Fig.1) placed on a common foundation frame and take water from the ballast channel between the kingston sea chests. Supply of the fluids goes through separate pipelines of general ship's systems: water fire system, carbon dioxide smothering system, water supply system, sanitary water and sewage drain system, air-conditioning system, accommodation heating system, provision refrigerating system, fuel oil tank heating system, compressed air piping system, ventilation system, air sounding and filling pipe system, inert gas system. Each of the pump units includes a hydraulic machine and a driving electric motor on the foundation frame of this pumping aggregate. They can also be considered as functional aggregates, and their combination - a zonal aggregate.

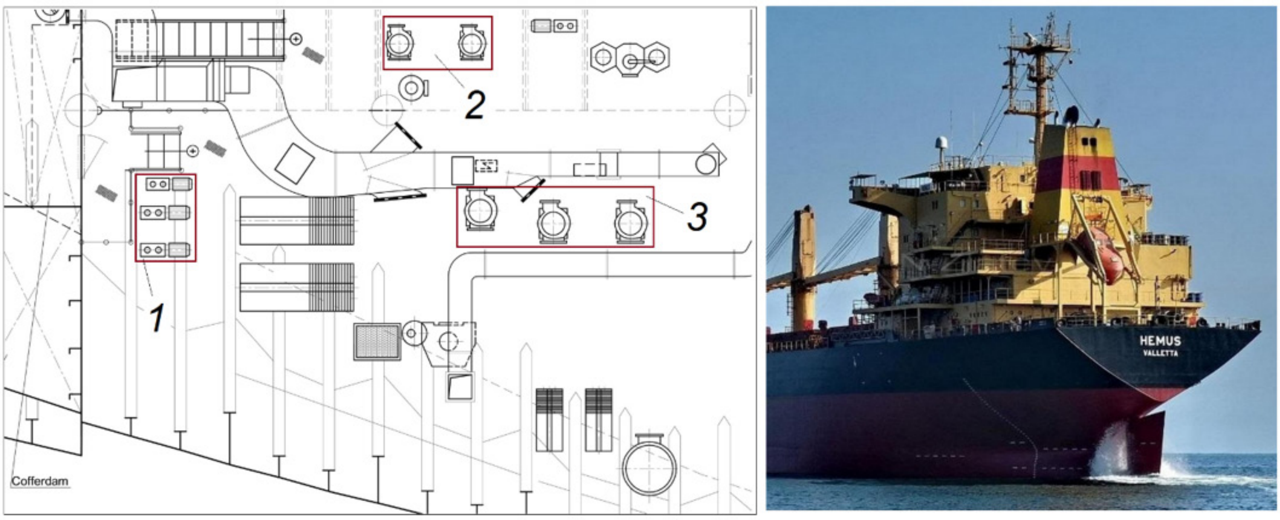


Fig. 2. Starboard side of engine room lower platform of bulk carrier "Hemus" (project 651) with deadweight 42600 t, built in "Bulyard Shipbuilding Industry AD" - Varna, Bulgaria

Figure 2 shows a part of the lower platform of bulk carrier "Hemus" with the following functional aggregates (FA): 1 - FA of two auxiliary boiler wa-ter feed pumps and one hot well feed pump; 2 - FA of main engine jackets fresh water cooling pumps; 3 - FA of two low temperature fresh water cooling pumps - sea service and one low temperature fresh water cooling pump - harbour service.

Figure 3 shows the same functional aggregates (FA) from fig.2, but in real engine room as following: fig.3.a - FA №1 (located near the boiler water tank), fig.3.b - FA №2 and fig.3.c - FA №3 (located near the main engine). Elements of functional aggregate №2 (for main engine jackets fresh water cooling pumps) are shown on fig.4: 1 - main engine jackets fresh water cooling pump type Azque CM-80/33; 2 - carcass; 3 - istallation plate with bolts and nuts; 4 - dowel; 5 - nut; 6 - butterfly valve ; 7 - non-return valve.

Similarly, other ship based aggregates - equipment of ship's devices (like anchor equipment, mooring equipment, steering equipment, auxiliary cargo equipment) are functional aggregates [10] and are used in the formation of zonal aggregates (blocks) of ship structures.

a b c

Fig. 3. Functional aggregates from fig.2 in the engine room: a) №1 б) №2 and c) №3)

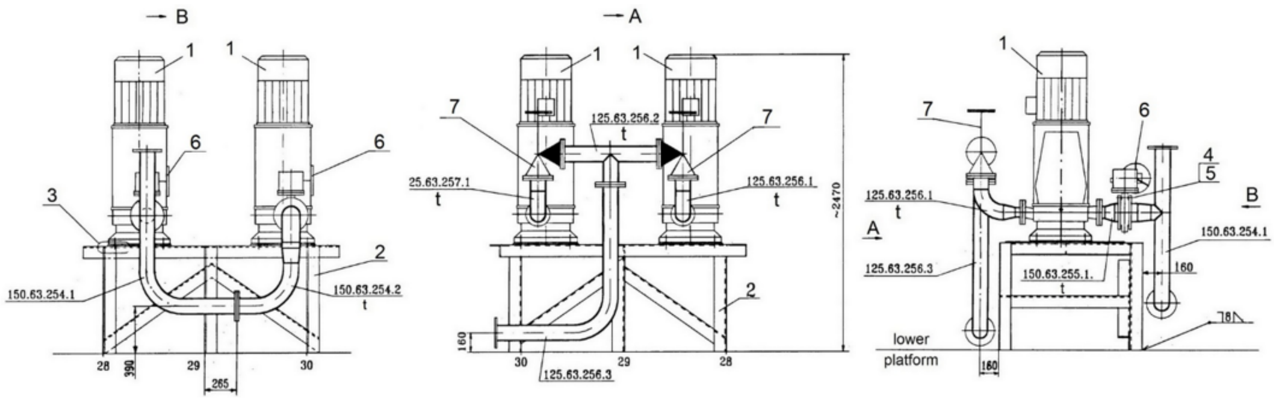


Fig. 4. Drawing of functional aggregate №2 (for main engine jackets fresh water cooling pumps)

Further development of the modular method is the use of large-block installation of the power plant. According to this principle, the Oil-Bulk-Ore (OBO) carrier of project 1593 (deadweight 100 000 tons) was built at the shipyard "Ocean" (fig.5). The ship is a single-deck, single-screw vessel, without forecastle. The superstructure for the accommodation spaces and the engine room are located in the stern. The OBO carrier have a low-speed type main engine with contract maximum continuous rating 15515 kW (engine revolutions at the according rating - 110 rpm) and according ship's speed about 15.2 knots upon draught moulded 14.5 m.

The ship's main electrical plant consists of three diesel generators with a output of 500 kW at 500 rpm and a single-stage turbo-generator with output of 800 kW. The ship's steam needs are ensured by automated auxiliary boiler with a steam generating capacity of 35 t/h (pressure 24 bar) and by exhaust gas boiler with a steam generating capacity of 9.2 t/h (pressure 7 bar).

All equipment of SPP and a part of general ship's systems equipment is combined into three zonal and fifteen functional aggregates (fig.5). These aggregates (blocks) are the folloing: A - zonal aggregate of the shaft line and diesel generators located above it; B - zonal aggregate of the cargo pump room; C - zonal aggregate of the engine room smokestack and shaft; 1 - functional aggregate of the main engine auxiliary equipment; 2 - functional aggregate of the turbogenerator auxiliary equipment; 3 - functional aggregate of the main engine circulating lubrication pumps; 4 - functional aggregate for lubrication of "simplex" type dead-wood pipe seals; 5 - functional aggregate of seawater pumps; 6 - functional aggregate for fuel and oil separation; 7 -

functional aggregate of general ship's systems equipment; 8 - functional aggregate of compressed air system; 9 - functional aggregate for diesel generators maintenance; 10 - functional aggregate of water treatment; 11 - functional aggregate of circulating pumps of exhaust gas boiler; 12 - functional aggregate of condensate-feeding system of auxiliary and exhaust gas boilers; 13 - functional aggregate of the boiler's fuel system; 14 - functional aggregate of the inert gas system. On the second platform on the starboard side of the main engine is the central control station.

The distinction of the presented layout from the previously discussed, consists in the application of smaller zonal aggregates (with previously reduced volume) in the ship construction, including several levels (a double bottom, the platforms and decks) and equipment mounted on them. The functional aggregates, which maintenance the main engines and the fuel and oil separation, include the equipment of several systems and by this they differ from the typical layouts of the tanker project 1596.

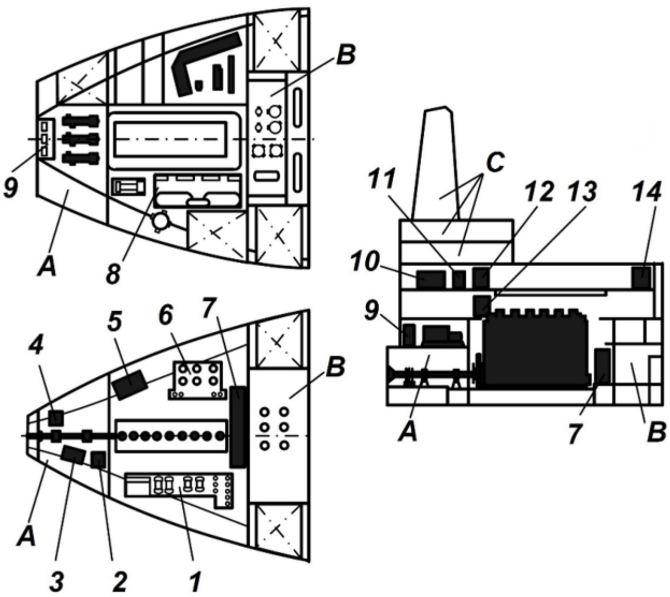


Fig. 5. Layout of engine room equipment of Oil-Bulk-Ore carrier - project 1593

The logical continuation of the considered direction of consolidation of the zonal aggregates and at the same time the limiting case will be the formation in the form of a single zonal and simultaneously functional aggregate of the entire engine room and its subsequent use in numbers projects. For this formation the corresponding engine room volume is necessary with engine room height (see fig.6a) which should not be less than the sum of the following components [11]:

D - distance from crankshaft cen-treline to base line of ship bottom;

F - height to crane hook (vertical lift of piston);

H_{CRANE} - distance from crane hook centreline to deck beam;

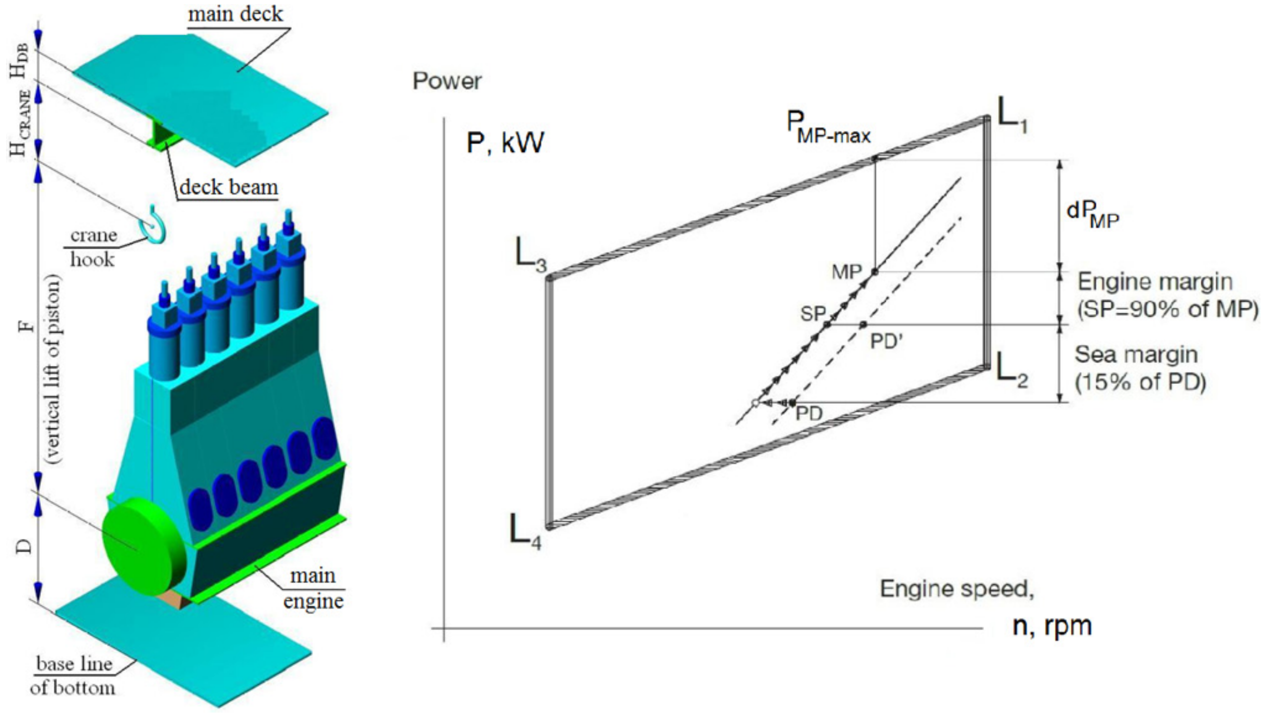
H_{DB} - deck beam dimension.

In addition, the main engine maximum power MCR (in point MP) should not be more than engine power $P_{MP\text{-}max}$ on line L1-L3 of main engine layout diagram and the difference dP_{MP} [11], between the powers $P_{MP\text{-}max}$ and P_{MP} must be positive (see fig.6b and next equations):

$$\frac{lg(n_{MP})-lg(n_{L3})}{lg(n_{L1})-lg(n_{L3})}=\frac{lg(P_{MP})-lg(P_{L3})}{lg(P_{L1})-lg(P_{L3})} \tag{1}$$

$$lgP_{MP}=\frac{[lg(n_{MP})-lg(n_{L3})].[lg(P_{L1})-lg(P_{L3})]}{lg(n_{L1})-lg(n_{L3})}+lgP_{L3} \tag{2}$$

$$P_{MP\text{-}max}=10^{lgP_{MP}} \tag{3}$$



a b

Figure 6. The limit Engine room height (a) and layout diagram of MAN Diesel engines (b)

CONCLUSIONS

1. A vessel is a complex technical system, a set of equipment designed to solve specific function (purpose) - transportation of cargoes and special equipment with the greatest efficiency. The vessel is characterized by a complex, subordinate hierarchical structure. Equipment and systems are installed on the ship for a reason, and to perform definite functions, hierarchically subordinated to the main function. Changes at any level of the hierarchy affect many elements of a complex system, including the upper level of the hierarchy. At each level, the equipment is divided into subsystems conditionally, generally referred to as systems or complexes of equipment. They are divided conditionally into the SPP systems and general ship's systems.

2. All ship complexes are energy complexes: they either produce or consume different types of energy used on the ship. The energy producing complexes are the following:

- propulsion complex, that provides the production of mechanical energy used for the vessel movement;
- ship electrical plant, that enshures the electric energy production;
- auxiliary boiler plant, that provides the production of thermal energy in the form of water steam energy or more rare in the form of thermal fluids.

3. All other ship's complexes refer to the energyconsuming complexes. Electrical energy is used by deck mechanisms (anchor mechanisms, mooring mechanisms, steering gear, thrusters, cargo gear for cargo holds, auxiliary cargo gears, cargo hatch covers with hydraulic drive, cranes and booms), by ship's and SPP systems for operation of pumps and fans, lighting systems. Electrical energy is used to operate compressors, that produce compressed air, applied in pneumatic systems, to start engines, blowing outboard openings, operation of pneumatic cistern. The electric drive is also used to obtain power liquids - oil or water. Power fluids drive hydraulic machines - most often plunger ones for translational or rotational motion of the actuators.

4. Thermal energy is used by premises heating system, ventilation system, air conditioning system, tanker cargo heating system, ballast heating system, heating of heavy fuel burned in the main and auxiliary engines and auxiliary boilers.

5. All elements of ship's systems (power complexes) have to be located on the ship, occupying as minimum space as possible, leaving more space for the location of the transported cargo. It is the capacity - the availability of space for the location of the transported cargo, that determines the carrying capacity of the ship and the income from the transportation of cargo.

6. The integration of power complexes into functional aggregates ensures a reduction in the construction

time of ships, improving the quality of equipment installation, facilitates operation through the introduction of aggregate repair. Presented in Fig. 1 aggregates have a relatively small weight (up to 10 - 15 t) due to the limited capacity of the workshop cranes during the installation of these aggregates. This disadvantage is compensated by application of zonal aggregation, implemented at the preliminary assembly shop. Further, the transition has been made on large-block aggregation - see fig.5.

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INFLUENCE OF PID CONTROLLER ON THE SHIP POWER PLANT OPERATION

Hristo MARINOV*, Irina KOSTOVA*

Abstract. *In control mode the Ship Power Plant realize PID laws. Very often when changing the parameters of the managed object, the control law (PID) is need to be adjusted in order to be specified and optimized. Thus, the PID regulation is applied to the different types of ship objects in the Ship Power Plant composition (thermal, mechanical and electrical). This requires research of the PID controller influence on the ship power plants operation and the energy efficiency of the ship.*

Key words: *PID controller, Ship Power Plant.*

INTRODUCTION

As a complex technical facility designed to transport cargo, a merchant ship is a complex system of individual elements connected to each other by kinematic and dynamic connections. These connections form SPC (Ship Propulsion Complex) whose main elements are ME (Engine) - Propeller - Hull. The engine converts the chemical energy of the fuel into mechanical work, which is transmitted in the form of torque through the propeller shaft to propeller. The propeller interacts with the water environment, transforming the torque into axial force - a thrust, which is transmitted again through the shaft line of the thrust bearing (connected to the hull).

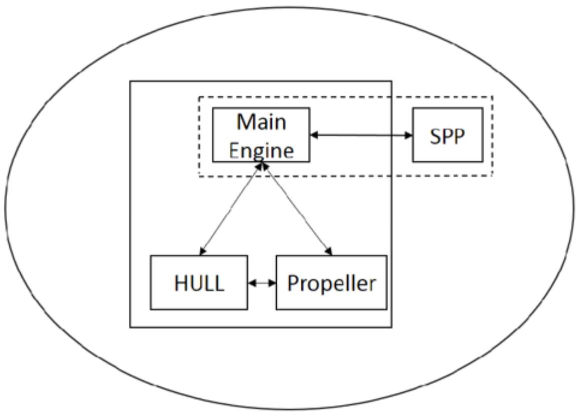

Fig. 1. Ship Propulsion Complex [1]

Since the ship's propeller and hull are the subject of research by ship theory and propeller theory, we will focus on a specific element of the SPC, ME (Main Ship Diesel Engine). In the Ship Power Plant composition the ME are subject to adjustment in terms of the required power and speed needed to ensure the speed of the shipThe control of ME revolution is done by adjusting the fuel supply. It can be seen that for this purpose it is necessary to refine the fuel quantity, which is also a subject to adjustment in terms of the qualities applied to the fuel itself (temperature and viscosity). There are similar requirements for the cooling water in the low and high temperature circuits of ME, the temperature of the lubrication oil intended for lubrication of the moving parts of DG and the Diesel Generators. There are also requirements for real-time adjustment of stored fuel, frequency adjustment of seawater pumps, etc.

In order to be able properly and precisely adjust all technical objects in the Ship Power Plant, it is necessary to use PID control that maintain correctly and as accurately as possible the required parameters of

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the considered objects.

PID controllers can solve a wide range of tasks related to the proper operation of Ship Power Plant (SPP), but for this purpose they must be optimized and set up for correct operation. Conversely, if an error is made in their adjustment, it is possible to achieve deterioration of the work process or its unsatisfactory operation in the operating conditions. This immediately affects directly the consumption and savings of fuel oil, fresh water, the total motor resource of ME. All this may lead to a deterioration in the overall energy efficiency of the ship and the Ship Power Plant in particular. Therefore, the correct and optimal setting of PID controllers is an extremely important for increasing the ship's energy efficiency.

For a clearer illustration of the place occupied by PID controller in SPP and particular in the ME composition we will consider the following two figures. An elementary model for the ME PID control is shown on fig. 1. SIMULINK model of the presented system is shown on a fig. 2.

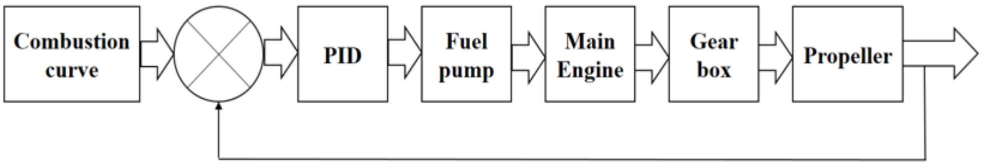

Fig. 2. Elementary model for the ME PID control

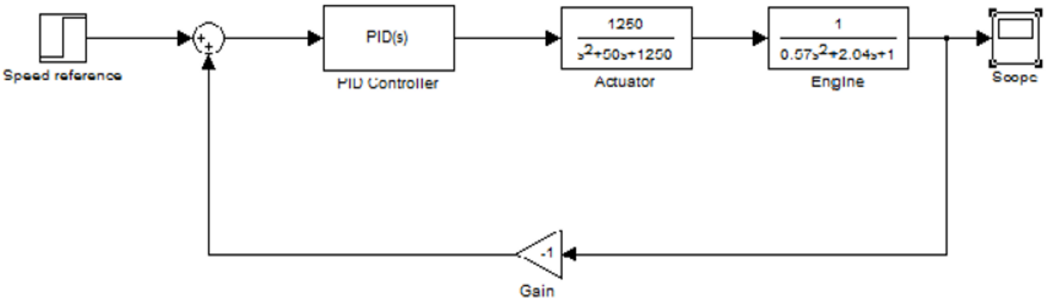

Fig. 3. SIMULINK model of ME PID control

1. PID Controller [2], [3]

PID law is one of the most common used control laws in the Ship Power Plants. It essentially „takes" the best of the three known laws of adjustments (Proportional, Integral and Derivative Law of control), trying to eliminate the shortcomings and problems related to the individual use of the laws mentioned above in the process. of functioning of the machines and mechanisms in the Ship Power Plants. In order to be able to describe more precisely the PID control law, we need to get acquainted with its main components which built him.

By regulator (governor) or control device is meant a device, forming control impact on the basis of the error. In SPP the following control laws have found main application in one form or another.

1. 1. Proportional law (P - law)

(1) $$U = k_p eu$$

The proportional law of regulation is implemented by regulators with solid feedback and is characterized by high speed, but also has statism, i.e. uneven regulation. The proportional control law is proportional to the current control error according to the expression:

(2) $$u(t)= K_p e(t) = K_p (r(t) - y(t))$$

Where

K_p is the proportional increase. The transfer function of a proportional controller can be represented as:

(3) $$C(s) = K_p$$

An important point is the gain, which represents the ratio of the manipulated variable to the deviation:

(4) $$K_p = y_0 / x_0$$

Where

Y_0 is the manipulated variable and X_0 is the deviation from the reference. Another important feature of the P-regulator is that as a result of the rough rigid connection between the deviation and the manipulated variable there always remains a non-zero error.

1. 2. Integral law (I-law)

The integral impact is proportional to the integral control error expressed by the expression:

(5) $$u(t) = Ki \int_0^t e(t)dt$$

Where

K_i is the integral magnification. The corresponding transmission function is:

(6) $$C(s) = K_i / s$$

The I-law integrates inside the system deviation. As a result, the level of change of the manipulated variable (rather than its absolute value) is proportional to the deviation. The larger the deviation, the steeper the characteristic of the manipulated variable. For this reason, the integrated controller is not suitable if full deviation compensation is required, it also causes oscillations or reacts too slowly to the setpoint deviation in systems with large transients.

1. 3. Derivative law (D-law)

While the proportional effect is based on the current value of the control error, the integral effect is based on the past value of the control error, the derivative effect is based on the predicted future value of the control error. The ideal derivative law can be written as:

(7) $$u(t) = Kd \frac{de(t)}{dt}$$

Where

K_d is the derivativel magnification. The corresponding transfer function is recorded as:

(8) $$C(s) = K_{ds}$$

The derivative controller calculates the rate of change of the deviation (differentiation of the deviation). If the deviation from the reference changes rapidly, the manipulated variable has a large value. A regulator only with D-Law is unusable, as the manipulated variable will exist only in case of changes in the deviation.

1. 4. Proportional - Integral law (PI-law)

(9) $$U = K_p e + Ki \int_0^t e(t).d(t)$$

The influence of the integral component is expressed in the absence of statism, under a certain regime. The influence of the proportional component is characterized by the speed of the regulator. The PI controller combines the behavior of P and I controllers, combining the advantages of both types - fast response and error compensation in set mode. In addition to the gain of (P component), the PI controller has another coefficient that characterizes the behavior of the integral component - the integration-time-constant T_i. This time constant (Ti) is a measure of how quickly the controller will change the manipulated variable (in addition to generating the manipulated variable from the P component to compensate the error in set mode.

The time-constant is a function of the coefficient $_{Kr}$, because the rate of change of the manipulated variable is faster for larger values of K_r. At large time constants, the effect of the integral component is small, as the summ of the deviation values will be slow. At small time-constants, the effect of the integral component is large.

The efficiency of the PI regulator increases with increasing the gain of the proportional component K_p, as well as increasing the integral component. But if these two coefficients are too large, the operation of the PI controller will be too rough and in the whole closed system there will be divergent fluctuations, i.e. the system becomes unstable.

1. 5. Proportion - Derivative law (PD-law)

(10) $$U = K_p e + K_d . \frac{de(t)}{d(t)}$$

The PD regulator is a combination of proportional and derivative regulators. The derivatives component describes the rate of change of the deviation of the reference. In addition to the standard P-regulator response, the PD controller responds to large deviation values with very short but large responses. PD - regulator is rarely used due to its two serious shortcomings. First, it cannot fully compensate for the residual error. Second, a very small increase in the differential component can cause instability of the closed system, which will cause fluctuations.

1. 6. Proportional - Integral - Derivative law (PID-law) [2], [3]

(11) $$U = k_p e + k_i \int_0^t e(\tau) d\tau + k_d \frac{de(t)}{dt}$$

Here

$\boldsymbol{k_p, k_i, k_d}$ are constants - transfer coefficients of the regulators.

If the deviation is large, the D-component provides a very large change in the value of the manipulated variable. While the influence of the D-component decreases immediately thereafter, under the influence of the I-component the value of the manipulated variable will slowly increase. If the deviation is small, the influence of the D-component is also negligible. This type of behavior has two advantages, faster response and faster compensation of the deviation in case the value of the setpoint or the value of the interfering signal changes. However, the disadvantage is that the control loop is prone to oscillations and therefore the setting is more difficult.

The main problems with conventional control systems using only proportional error signal (control variable) are:

- Impossibility to reach the desired value of the operating point (Setpoint - SP) of the controllable value;
- Slow reaction of the systems when the value of the operating point changes;
- As the proportional gain (K_p) increases, in order to reduce the above two problems, the system starts to oscillate and becomes unstable;

It is impossible to optimize the system with regard to these shortcomings only by adjusting the proportional gain.

In response to the need for greater precision in control systems, the so-called PID control is introduced. It is done by additional processing of the error signal using integral - K_I and differential - K_D functions.

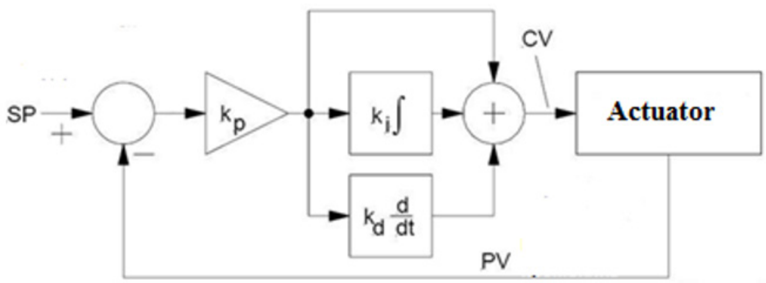

Fig. 4. PID control closed system

In the system shown in Fig. 4, the error signal is increased by K_P and then applied to the integral and differential functions. The Control Variable (CV) is obtained after summing the three components in the adder. The multipliers K_p, K_I and K_D are constants whose values are defined by the user in accordance with the desired implementation, and are almost always positive values or “0” - if this component is not needed.

The ideal PID controller scheme is the most commonly used in control systems. However, there are also systems with the so-called parallel PID controller, in which the three functional blocks (proportional, integral and derivative) are connected in parallel. When is fine-tuned, the parallel PID controller performs actions just like the ideal PID controller. The difference between the two schemes stems from the higher K_I and K_D values in the parallel PID due to the lack of pre-increasing level by the K_p, as in the ideal PID scheme.

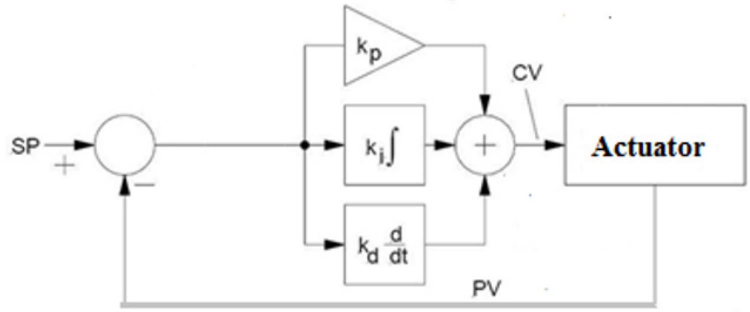

Fig. 5. Parallel PID control closed system

If the PID controller is set with a high degree of proportional effect, it follows that the control system generates only a high proportional gain of the error signal and it has the following output response:

Characteristic of the graph is the presence of large oscillations of the process variable, as well as a long time to establish the system in constant mode. At the same value of the proportional gain, if differential gain is applied to the error signal, the initial reaction would look like this:

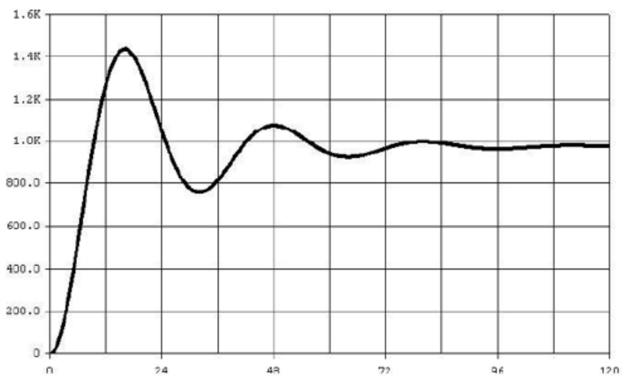

Fig. 6. PID control with high level of K_p

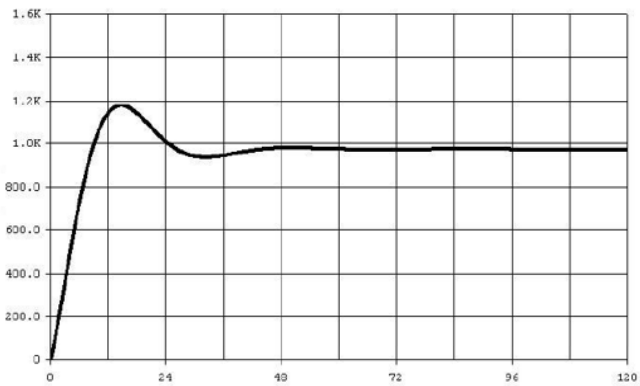

Fig. 7. PID control with high level of K_p and low level of K_d

At the output of the system there is a significantly faster reaching of the established mode and a lower level of oscillations. At the moment t = 0 the set operating point - SP changes from 0 to a value corresponding to the set in the condition of the task (revolutions, temperature, and in this case we require to reach a value of 1.0k). While the object is at rest, the output of the measured value is also 0, so the process variable - PV is 0. Therefore, the error signal in this case will be identical in shape and amplitude with SP. In t = 0 the shape of the error signal will have a strong increasing edge, which generates a very large positive signal as the output of the differential function. The sum of the proportional action and the differential action sets the initial form of the controlling influence - CV. Mathematically, this can be described by the expression:

$$CV(t = 0_+) = K_p SP + K_D m_{SP}, \qquad (12)$$

where

m_{sp} - derivative of SP (slope of the shape of SP). Since msp is extremely large at the moment t = 0, this will lead to very fast acceleration.

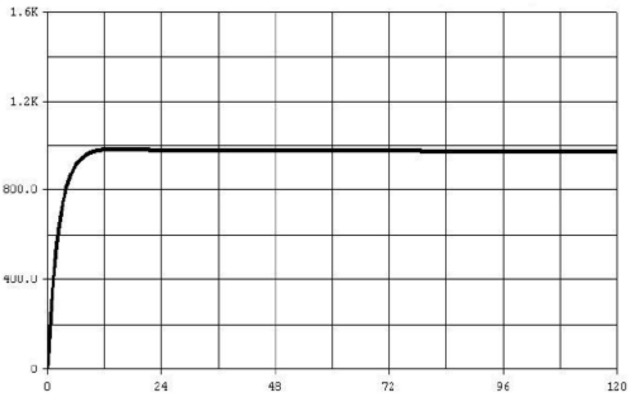

Fig. 8. PID control with high level of Kp and middle level of Kd

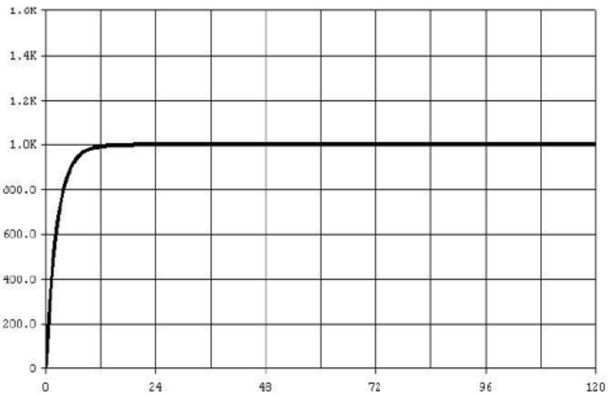

Fig. 9. PID control with high level of Kp, middle level of Kd and low level of Ki

As can be seen from Fig. 8 with the introduction of the differential function, the initial reaction of the system (PV) has the desired shape without exceeding the set value of SP (1.0k) and without oscillations, but the nominal value of SP (1.0k) is still has not been reached. This is because the error signal is different from 0, ie. SP and PV are not equal.

In order to achieve the desired value of SP in the closed control systems an additional unit is introduced - an integral function. The error signal entering the input of the integral function starts to accumulate. For large differences in the levels of SP and PV the accumulation will be faster and the output will increase accordingly, while for small differences in the levels the output of the integral function will be slower. As long as the error signal is different from 0, the action of the integral function will be directed in the appropriate direction, trying to reset it.

In order for the system with the included PID controller to function properly, it is necessary to adjust and refine it very precisely, because as we saw above, the change of each of the considered coefficients can lead to excessive deviations in the set parameters of the operating Ship Power Plant. This would have a great influence on the controlled parameters such as fuel temperature, cooling water temperature, Main engine speed, frequency regulation of seawater pumps, etc. In the practice of PID regulation various models and methodologies for adjustment have become necessary, as most of them are considered in the technical literature.

The considered qualities of the PID controllers show that the simple adjustment methods have a narrow range of application, and the methods with a wide range are too complex and require special qualification of the crew. Although at the present stage PID controllers can work with satisfactory accuracy, the requirement for refinement and more precise adjustment of the parameters shows the need to develop and study a methodology for optimizing PID controllers in the Ship Power Plants.

“This paper has been prepared within the project NP8/2020 „Conceptual design of the ship minimizing the risk of environmental pollution“, funded by the State Budget under contract No 108/22.05.2020”

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PHYSICAL MODEL REALIZATION OF SHIP POWER PLANT FUEL SYSTEM WITH PID CONTROL

Hristo MARINOV*, Irina KOSTOVA*

Abstract. *The Ship power plant is composed of a different separate systems. During the process of operation, they function together maintaining the set operating modes necessary for the proper operation of the technical object included in their composition. The technical characteristics of these objects and the need for permament and reliable operation of the systems sets special conditions for their operation within certain limits. The aim of the article is to present a physical model of Ship power plant fuel system with PID control and the parameters that must be adjusted in order to keep the system in optimal operating mode.*

Key words: *PID, Physical model, Ship power plant.*

INTRODUCTION

The physical modeling of a technical system requires knowledge and presentation of the individual design elements and declaration of their design values. The Ship Power Plants include systems related to the reception, storage and preparation of fuels and oils necessary to meet the technical needs of Main Engine and Diesel generators. Also with important participation are the Sea water and Fresh water system, Starting air system, Exhaust gas system, Steam system for fuel heating and etc.

An important point in these systems is their adjustment in order to maintain them in optimal mode allowing proper functioning of their users and long-term use of the physical objects (pumps, compressors, piping, valves, etc.) included in their composition. The correct and optimal functioning of the systems allows a savings of fuel oil, lubrication oil, spare parts, etc., as well as increases the energy efficiency of the ship.

The parameters that are subject to adjustment in the listed systems are temperature, viscosity and pressure of fuel oil, temperature and pressure of sea water, temperature and pressure of cooling fresh water, temperature and pressure of lubrication oil, air pressure, steam pressure and adjustment of water level in the boiler steam drum.

The precisely adjustment of the parameters are performed through PID controllers built into the Integrated monitoring, alarm and control system (IMACS). They also include PLC's (Programmable Logic Controllers), sensors and actuators (valves, pumps, etc.). In order to achieve the correct adjustment of the objects, the information received by the sensors and send to the PLC, compares the actual values of the parameters in real time with the set ones (setpoints) and, if necessary, proceeds to their correction by sending a signal to the actuators [1].

We will consider the physical model of the Ship Power Plant fuel system as an example of adjustment the parameters of the working environment (HFO) in order to achieve optimal values for the correct operation of fuel consumers. The maintenance of specific values of temperature and viscosity of the fuel oil are important for the quality of the fuel oil in the tanks (sedimentation in the Settling tk), fuel preparation (separation and purifying) and its influence on the fuel equipment and the proper operation of Main Engine and Diesel Generator. Poor fuel purifying can cause rapid wear of the High Pressure Fuel Pump and wear of the fuel valves (nozzle). On the other hand, incorrect temperature and viscosity can cause poor fuel injection by forming an incorrect fuel cycle. In order to properly separate and purifying the fuel, it is necessary to heat it before the HFO separator to a certain temperature at which the equipment manufacturer guarantees the best quality of the cleaning process (purifying).

The following mandatory functions of automatic adjustment and control systems are added to the regulation of fuel qualities [2].

- The unevenness in the adjustment of viscosity and temperature (before fuel valves) should not exceed

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4.10^{-3} [Pa.s];

- The transition process in the system should not be accompanied by dynamic errors, i.e. over-adjustment;

In order to avoid an excessive sudden increase on the fuel oil temperature, smooth heating of the fuel oil within the limits of 3 °C per minute is provided, while at the same time the viscosity of the fuel oil is kept within the necessary limits.

It should be noted that the temperature unambiguously determines the viscosity with unchanged fuel composition.

PHYSICAL MODEL OF FUEL SYSTEM WITH PID - CONTROL

Modern Ship Power Plant Fuel system widely used on the ship is shown on a fig. 1.

In order to simplify the scheme (model), the pipeline fittings, gauges, Sludge Tk, 3-way valve are not presented.

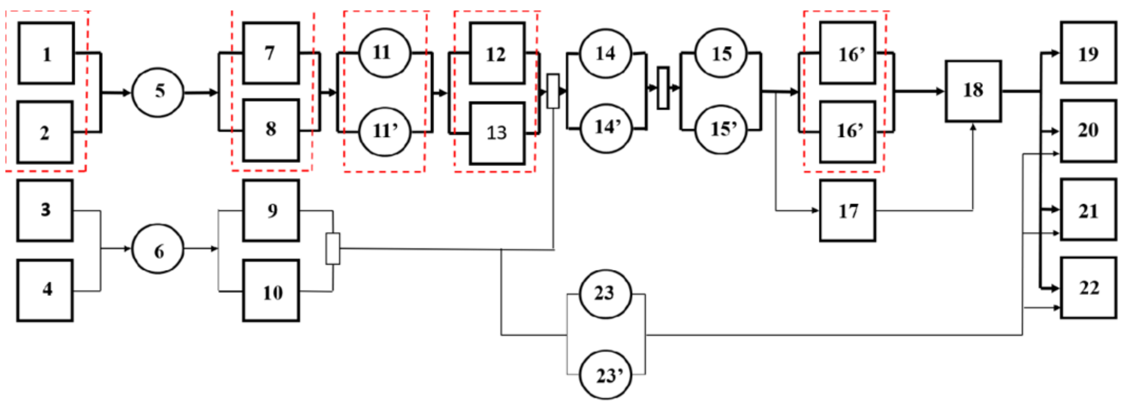

Fig. 1. Physical model of Ship Power Plant Fuel system

The main elements of the fuel system shown in the figure are:

1 - HFO Storage Tk
2 - HFO LS Storage Tk
3 - MDO Storage Tk
4 - MGO Storage Tk
5 - HFO Transfer pump
6 - MDO / MGO Transfer pump
7 - HFO Settling Tk
8 - HFO LS Settling Tk
9 - MDO Service
10 - MGO Service Tk
11 - 11' - HFO Purifier (Separator)
12 - HFO Service Tk
13 - HFO LS Service Tk
14 - 14' - FO Supply pump
15 - 15' - FO Circulation (Booster) pump
16 - 16' - FO Pre-Heater
17 - MGO Cooler
18 - Flushing filter
19 - MAIN ENGINE
20 - 21 - 22 - Diesel generators
23 - 23' - DO Flushing pumps

A dotted line shows the technical objects performing the functions of adjusting the parameters of the fuel oil related to its viscosity and temperature.

Pumps used in the fuel system are volumetric (non-adjustable) type - screw and gear pumps. Their main parameters are kinematic parameters (mass flow rate) and load parameters (pressure - i.e. the specific energy of the fluid). They have a constant flow of all operating modes, which means that there are no disturbances in the fuel oil consumption channel.

PRE - HTR are heat exchangers used to heat up the fuel oil to the determination values using the steam from the steam heating system of the vessel. Pre-heaters are stable and high-inertial technical objects.

As is shown on fig. 1 the temperature adjustment on the fiuel oil can be done in Storage Tk, Settling tk, HFO purifyer Pre-HTR, Service Tk and M/E G/E Pre HTR.

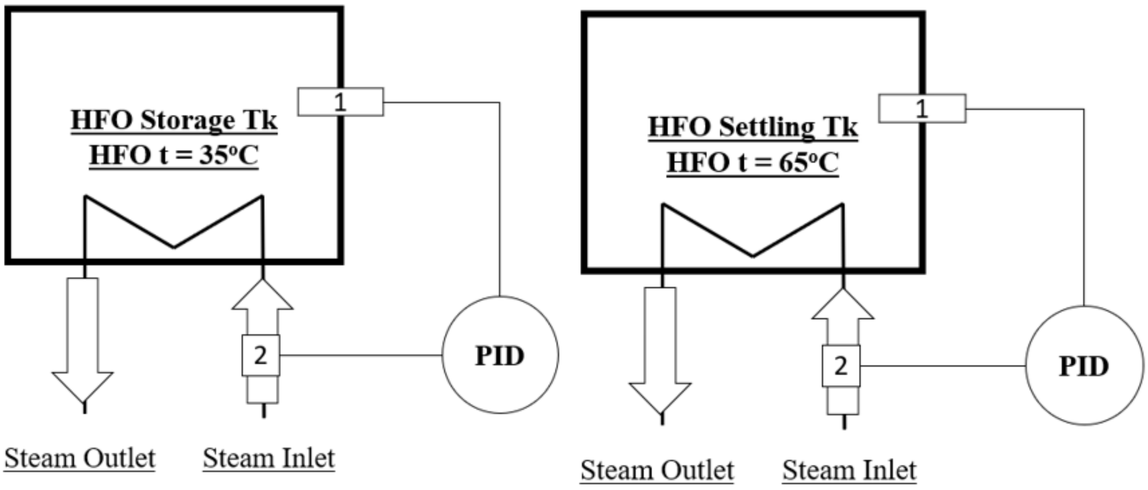

Fig. 2. Storage Tk and Settling Tk fuel oil PID-control temperature adjustment

An elementary simplified physical model of fuel temperature adjustment in ship tanks is shown on fig. 2. The PID controller shown on a figure receives a signal with the instantaneous value of the fuel temperature from a sensor 1 mounted in the housing of the fuel tank, forming a signal which is send to the actuator (automatic steam valve) adjusting the amount of steam flow passing through the fuel tank. With the correct optimal setting of the PID controller, the system will maintain a constant fuel temperature by adjusting the steam flow regardless of external disturbances (sea water and air temperature).

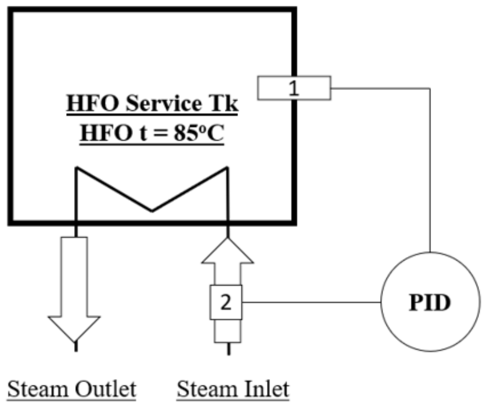

Fig. 3. Service Tk fuel oil PID-control temperature adjustment

Service Tk fuel oil temperature adjustment is analogically solved and shown on fig. 3.

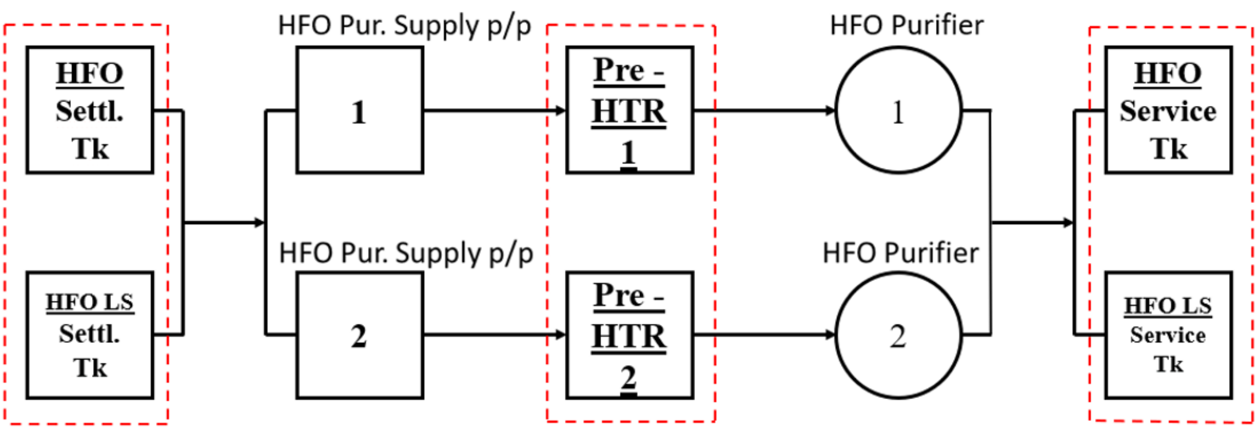

Fig. 4. HFO Purifyer Fuel oil temperature adjustment [3]

Very often manufacturers set conditions for the fuel temperature needed to achieve the best purification. Companies such as Alfa-Laval, Westfalia and others. require the fuel temperature to be 99 °C to ensure its best treatment. The pumps that supply the fuel to the heaters and separators are screw type as mentioned earlier.

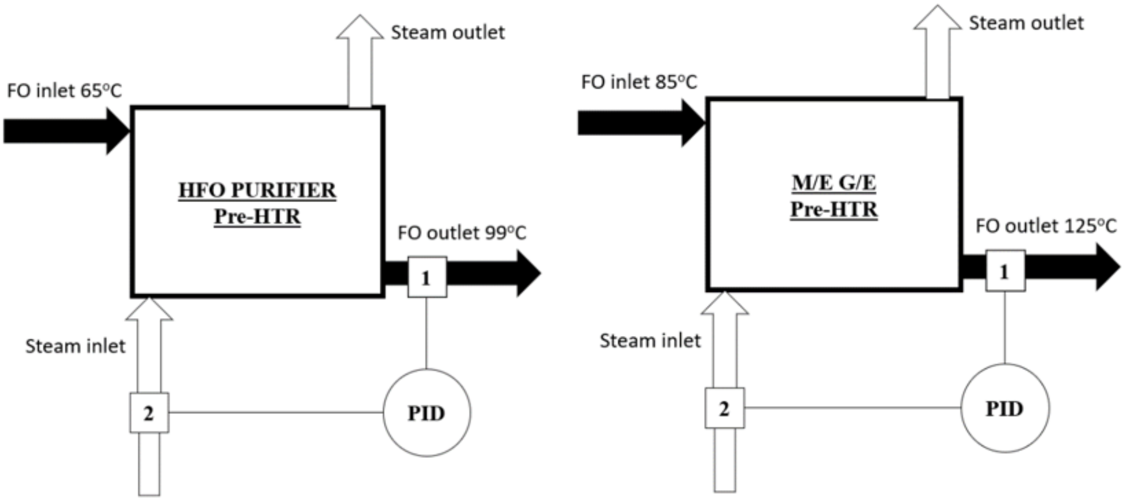

Fig. 5. PID-control Fuel oil system Pre-HTR temperature adjustment

Analogically to the previous solution, the scheme with PID controller which receives a signal from a sensor mounted in the pipeline supplying fuel to HFO Purifier or for the Main Engine or Diesel Generator is also used here. The PID controller generates a signal that is fed to the automatic steam valve performing steam flow correction. In contrast of the relatively static fuel oil located in the tanks, here the situation is more dynamic because we have a continuous flow of fuel oil that can change its flow depending on the fuel consumption of Main Engine or a change in the capacity of the fuel separator. If the PID controller is tunned incorrectly, a process of fluctuations or over-adjusting can occur which leading to frequent or continuous opening or closing of the automatic steam valve (and to its wear). The correct temperature of the fuel oil is important for its dispersion from the fuel valves and its atomization and complete combustion in the combustion chamber of Main engine. Conversely, poor heating causes poor dispersion, increased size of the fuel drops after the nozzles, prolonged evaporation time, external ignition of the drops and cracking of the fuel in the drops and coke formation. All this leads to scaling and wear of the nozzles. The large size of the drops shortens the range of the jet and creates local air insufficiency, creating worse combustion conditions.

Another part of the Ship Power Plant fuel oil system is the Boiler fuel oil system.

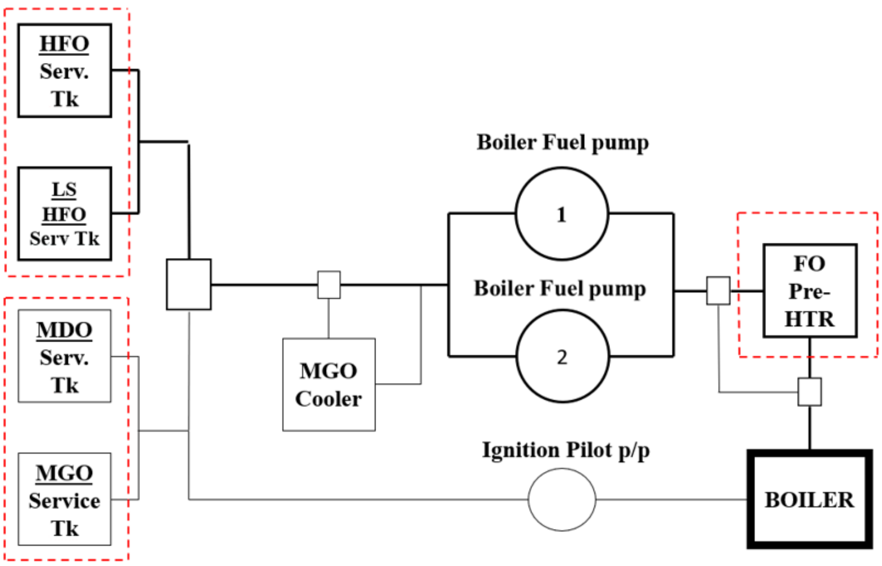

Fig. 6. Boiler fuel oil system [3]

The situation with the adjustment of the fuel temperature in the ship's Boiler is similar to those shown in the previous figures. The regulation of the fuel temperatures in the tanks is performed according to the schemes of fig. 2 and fig. 3. MGO Cooler shown on the figure participates when, using the light fuel (MGO or MDO) is required. The cooler maintains the temperature of the light fuel oil within the required viscosity by bypassing the fuel heater.

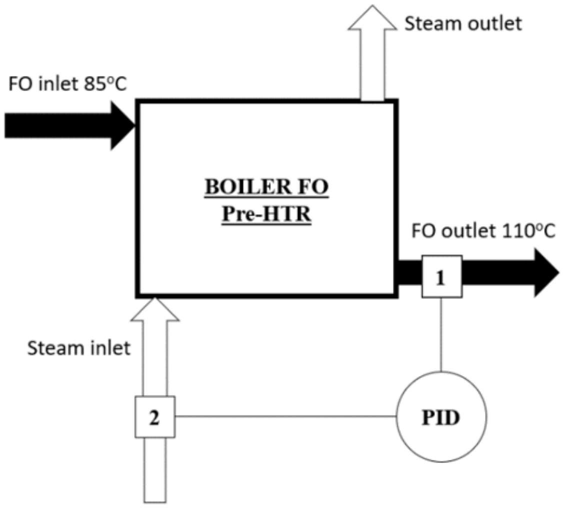

Fig. 7. Boiler Pre-HTR fuel oil temperature PID-control adjustment

The FO Pre-HTR shown in FIG. 6 and shown in FIG. 7 participates in the heating of HFO as the burners of the boilers have almost the same requirements to the fuel necessary for the good injection in the combustion chamber of the boiler. These requirements are related to the design features of the burners that can work by swirling the fuel, mechanical and steam burners, etc. The correct temperature of the fuel allows optimal adjustmen of its operating pressure and respectively atomization of the jet. Similar to the processes observed in the combustion chamber of Main Engine, moments of coke formation and scale can similarly occur here, which will worsen the combustion process in the boiler when we have poorly heated fuel.

The scheme of fig. 7 is analogous to the PID control schemes presented above in the article. Again, the PID controller receives a signal from the sensor located on the fuel line supplying fuel oil to the boiler burner. The regulator creates a signal that affects the automatic steam valve adjusting the steam flow. By adjusting the steam flow, the fuel temperature can be adjusted to the values required for the correct operation of the burner.

The considered physical models give an idea of the PID tuning in the fuel oil system in terms of fuel preparation. It should be noted, however, that a large role for the proper course of the adjustment process has the PID controller, and special attention should be paid to on its setting and optimization from which depends the perfection of the technical processes taking place in Ship Power Plants. This necessitates the development and research of a methodology for optimal adjustment of the PID controllers, which will meet the future challenges related to the maintenance of the required values of the parameters in the Ship Power Plants.

"This paper has been prepared within the project NP8/2020 "Conceptual design of the ship minimizing the risk of environmental pollution", funded by the State Budget under contract No 108/22.05.2020"

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Correction by PAUS LTD. - Varna
Computer layout by Donika Sarkoleva-Zlateva
Total print: 40, Format 60/84/8

PAUS LTD. - Varna
DESIGN, PRE-PRESS AND PRINTING

ISSN 1314 - 0957