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Ballast Water Treatment Systems on Board of Merchant Vessels and Crew Training

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Abstract. Since the 1960s, the Black Sea has undergone dramatic environmental changes. These changes are considered as result from a complex interaction of different pressures, the most important being eutrophication, overfishing and introduction of alien species. As of September 2019, standard D-2 of the International Convention for the Control and Management of Ships' Ballast Water and Sediments shall enter into force. It demands the ballast water, taken into ballast tanks, to be treated with special systems in order to prevent the spreading of invasive species in different parts of the world during deballasting operations. The aim of this article is to draw the attention of interested institutions to the problem resulting from the need for crews to be prepared to work with these systems and to deal with the expected problems related to their execution, maintenance and certification. There is also a clear need to train marine personnel - from cadets to officers, including the ship's management level. Nikola Vaptsarov Naval Academy, together with partner universities from Romania, the Netherlands and Cyprus, participates in the preparation of a concept within the DivSea project - Diversification of the professional development of seafarers by jointly developed programs for higher competency and certification under the Erasmus program.

Key words: ship's ballast, sea environment, alien marine species.

Introduction

People have been using ships as a means of transporting goods and people, performing various underwater operations for centuries. When the ship is in ballast condition or partially loaded, especially with cargo on the upper decks, it is necessary to take extra weight to improve her stability and seaworthiness, and to reduce the effect of the waves on her hull. Practice has shown that taking an additional "load" would result in an even weight on the keel and a better seaworthiness of the ship. This extra load is called ballast, and over the years, its appearance has changed. Stones, sand and iron have been placed at the bottom of the ship and have been used as hard ballast.

In the nineteenth century began the use of liquid ballast - seawater, initially in cargo spaces and tanks, and later in specially designed cisterns or tanks. The use of this new type of weight has become necessary and has spread very rapidly. The reason for this is the fact that seawater is cheap and it can be taken onboard in a very easy manner. The ship loading and unloading procedure is also associated with receiving or discharging overboard of ballast water - processes known as ballasting and deballasting.

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Loading and unloading operations are the main activity of ships and are carried out in ports, coastal areas or sea terminals, which are sometimes heavily polluted. Even though they appear to be clean at first glance, these areas contain micro-organisms. With take-in of seawater, huge quantities of these microorganisms also flow into the ballast tanks during unloading of the cargo. In most cases, the areas in which the ballast is received and in which it is pumped out are considerably remote from each other, with widely differing native species of micro- and macro-organisms. If transported organisms survive, they adapt, turn into invasive species, and can adversely affect the economic interests of the coastal state, the native marine ecosystem and even human health. The amount of ballast that is transported within the World Ocean by ships every year is enormous and can reach up to 10 million tons. More than 6,000 marine organisms are carried daily to various locations around the world (HEILEMAN *et al.*, 2015; EL-DAHHAR *et al.*, 2017).

Invasive alien species (IAS) are considered as one of the key causes of biodiversity changes worldwide. The impacts of IAS are immense, sometimes disastrous and usually irreversible. Some invaders are re-forming the structures, dynamics or functions of aquatic communities. They impose significant economic costs. In monetary terms, it was recently calculated that the lost output due to all aquatic IAS, health impacts and expenditure to repair IAS damage costs European Union stakeholders more than 100 million EUR per year (DAVID & GOLLASCH, 2015). The global rate of new aquatic invasions increased in recent years, which amplifies the concerns. The United Nations noted this also and IAS are categorized as one of the top four anthropogenic threats of the world´s oceans (KETTUNEN *et al.*, 2009).

There is hardly to find any area in the ocean which ecosystem is not affected by such invasive species. About 15% only are unaffected. In the remaining 85%, invasive species reproduce, settle and displace some native species, thus altering or destroying the food chain and ecosystem balance (MOLNAR *et al.*, 2008). Shipping is the dominant vector of unintentional species introduction in estuarine and coastal marine systems worldwide, and connects distant regions using ports as stepping stones (BAX *et al.*, 2001; KELLER *et al.*, 2011). More than 1,000 alien marine and coastal species have been recorded in Europe (Table 1) (GOLLASCH, 2006). Most have established self-sustaining populations of long duration, whereas some have been known from ephemeral populations of short duration.

It is expected that the EU Strategy on Invasive Alien Species (GENOVESI & SHINE, 2004) will significantly help to reduce the future IAS impacts. Considering the IAS related costs, the implementation of this EU strategy will outweigh the associated costs. Other instruments to minimize the risk of species introductions include the IMO Ballast Water Management Convention, IMO biofouling guidelines for recreational and commercial vessels and quarantine procedures in aquaculture. In consequence, rules and regulations exist to reduce the IAS problem; they simply need to be followed.

No habitat is immune to invasions. All coastal waters of Europe are inhabited by at least one alien species. Some habitats, such as lagoons and ports serve as "hot spots" and "nodes" of invasion and some regions are more invaded than others are.

The world shipping process on the other hand also affects Black Sea region. Invasive species threaten local sea life and littoral countries economic.

Materials and Methods

The International Maritime Organization (IMO) has drawn attention for a long time on the negative impact of organisms discharged alongside the ballast water of ships into a new environment beyond their control. As early as the 1970s, the topic is under the International Convention for the Prevention of Pollution from Ships (MARPOL), which requires of the Administrations to take measures to prevent uncontrolled deballasting. Later, the IMO considered it is reasonable to decide that ballast water should not be the subject of the MARPOL Convention.

In 1993, the IMO Assembly adopted International rules for the prevention of the occurrence of undesirable aquatic organisms and pathogens through shipping ballast water and sediments, which was set out in Resolution A.774. This resolution urges ships to avoid the reception of ballast in shallow waters and areas heavily polluted by human activity. The ship's officers are required to record in an official logbook each ballast reception and discharge with detailed information about the date and time of the operation, geographical coordinates, salinity and quantity of the received or discharged water. It also requires a change of ballast in deep-sea waters with a depth of 2000 meters or more (IMO, 1993).

It turns out that the migration of pathogens with the ballast water of ships is not sufficiently limited. This led to the adoption of IMO Resolution A.868 - Rules for the control and management of shipping ballast water to limit the transfer of harmful aquatic organisms and pathogens in 1997. Resolution A.868 raises the requirements for teaching and training of ship crew as well as the mandatory implementation of shipboard ballast operations management plans. A "safe" ballast water is considered that water, which has been in ballast tanks for 100 days or more (IMO, 1997). The implementation of this Resolution led to significant decrease in the number of "attacks" of harmful hydrobionts around the world. Nevertheless, in some areas, such as the Great Lakes of North America and Australia, the damage caused by microorganisms and pathogens still increases and reaches significant proportions (Ricciandi, 2006).

These and some other problems led to a conference in London in February 2004, which finalized and adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM), 2004.

The Convention introduces two standards for ballast water treatment by crew:

Standard D-1 - Ballast Water Exchange

The rule requires every ship to ensure that at least 95% of the volume of the ballast is replaced. This can be achieved by the "flow-through" method, with the tank receiving water equal to 3 times the tank volume and the same amount being thrown overboard. It has been found that the one-off volume of a tank exchanged under this method provides the replacement of 63% of the water in it; twice - 86%; three times - 95% and four times - 98%. The International Maritime Organization has judged that triple shift is sufficient. If a ship has replaced its water by this method less than three times, then it has to prove that the 95% shift requirements are met (IMO, 2004).

The other existing empty-refill method gives better results, but the risk of damage to the ship's stability is greater and may lead to undesirable consequences, especially if ballast replacement is done under bad weather conditions.

Standard D-2 - Ballast Water Treatment

Vessels handling ballast water operations under this standard must dispose water, which contains living organisms of specified sizes according to the parameters set out in Table 2. A requirement for microbial content and concentration is also required. The D-2 standard requires ships to be equipped with Ballast Water Treatment Systems. Shipowners have to allocate funds for the supply and installation of such systems, which proves to be a longer-than-expected process.

The final text of the Convention states that it enters into force one year after it is ratified by the 30 flagged countries of 35% of the world's gross tonnage (GT). With the enforcement of the Convention, Standard D-2 becomes mandatory for all ships. On this basis, the International Maritime Organization had set a deadline to cover these parameters in early 2015 in order to have fully implemented Standard D-2 from the beginning of 2016. It did not happen. The number of signatures exceeded 30, but the tonnage requirement for ships was not reached.

Table 1. Invasion status of introduced species according to the European Seas considered (including adjacent waters)

Region	Number of established species	Number of unestablished species	Number of cryptogenic species	Number of extinct species	Number of species with unknown invasion status	Total number	Total %
Mediterranean Sea	325	116	23	No data	198	662	46.8
North Sea	144	9	16	4	57	230	16.2
Atlantic Coast	112	19	5	2	39	177	12.5
Baltic Sea	99	1	15	5	50	170	12.0
Black Sea	61	9	3	No data	10	83	5.9
Azores	24	No data	No data	No data	1	25	1.8
Irish waters and NW UK	39	3	4	No data	5	51	3.6
Arctic waters	10	1	1	No data	6	18	1.3
Total	814	158	67	11	366	1416	100.0

Table 2. The IMO D-2 standard for discharged ballast water.

Organism category	Regulation
Plankton, >50 µm in minimum dimensions	<10 cells/m3
Plankton, 10-50 µm	<10 cells/ml
Toxicogenic *Vibrio cholera* (O1 and O139)	<1 colony forming unit (cfu)/100ml or less than 1cfu/g (wet weight)
Escherichia coli	<250 cfu/100ml
Intestinal Enterococci	<100cfu/100ml

Understand the obligations under the BWM Convention and other national and local regulations the ship owners and ship's Masters need to:

– ensure that all ballast discharges comply with Standard D-1 or D-2, i.e., that ballast is exchanged or treated: this obligation applies to ballast discharges both at sea and in port;

– ensure that procedures in the Ballast Water Management Plan are followed at all times;

– keep proper records in the Ballast Water Record Book;

– operate and maintain ballast water treatment systems in accordance with the manufacturer's instructions.

From 3-th to 7-th of July 2017, the Marine Environment Protection Committee held its 71-st meeting in London. The main topic of the meeting was the proposed "compromise" solution for the implementation of the D-2 standard submitted for consideration by Brazil, India, Liberia, Norway and the United Kingdom. The "compromise" solution was based on the fact that the deadline for the implementation of this standard was almost reached, and a large proportion of these countries' ships were not prepared for the D-2 standard. A document was proposed at the meeting to postpone the enforcement of the mandatory D-2 standard for 2 years and thus the deadline became September 8, 2019 (IMO MEPC, 2017).

With regard to the D-2 standard, the Convention applies to all types of ships, even those less than 400 gross tonnage. These ships must meet the D-2 standard no later than 8 September 2024.

The D-2 Convention and Decisions referring to, do not affect and are not accepted by United States legislation. Vessels visiting or planning to visit US ports should be convinced that they meet the United States' Ballast Water Management requirements.

With the approach of the deadline date in 2019, the production of systems intended for installation on board vessels for ballast water treatment has expanded considerably. More than 104 types of such systems have been developed in the world, some of which are also recognized as functional. In order to be recognized each of them must pass test and approval in accordance with the requirements of the International Maritime Organization.

The technologies currently used in the systems can be grouped into three main categories, based on the mechanism that they affect organisms: mechanical, physical and chemical (Fig. 1).

The processing itself can be divided into 3 stages:

- Pre-treatment - the stage where the main goal is to extract as much as possible solid deposits and larger organisms to make the next stage of processing more efficient.

- Basic treatment - according to the mechanism by which microorganisms are affected. If the treatment is physical - with UV light, the efficiency is significantly reduced in the presence of solid particles, as the microorganisms fall into their shadow and survive.

- Neutralization - in order to eliminate the consequences of the treatment during the second stage, so that no poisonous and other substances that can damage the marine environment can be found in the discharged waters.

Some systems use water treatment when receive ballast only, others – when receive ballast and during ships' voyage, and third – when receive ballast and during discharging. The combinations of methods are also different - for example, filtration and hydrocyclone separation.

The most used combined systems are those that filter the water upon its receipt. It then passes through an UV-system or chemical disinfection and finally through cavitation treatment.

It is clear from the above that a good knowledge of the functionalities of the systems, their positioning on the ship and the proper handling of them is essential for the crew.

Results and Discussion

Unfortunately, ballast water management systems study has not been included in university curricula for student education, as well as in the training courses for officers and crew. The shipping companies allocate money and resources for the early implementation of the systems and their certification, so that they can meet the requirements of the Convention in time by September 2019, relying on the fact that Management level officers will deal with the operation following the manufacturer's instructions. Probably, they also rely on Operational level officers to be acquainted with the technical parameters and the proper work of the system during their free time and under the supervision of a senior officer. For the knowledge of the ratings is not even thought out, although their obligations to maintain the systems are inevitable. The practice, based on already installed and operating systems, shows that they are extremely sensitive in terms of correct handling and any deviations from the rules when operating or maintaining can result in frequent stoppages and need for repairs made by coastal specialists. It is worth to be mentioned that there are ports where the loading process is so fast that de-ballasting must be on time and continuous (for example Novorossiysk tanker terminal). Otherwise, the loading operation might be completed, while the Chief Officer has not completed the de-ballasting yet. The draft of the ship would exceed the permissible draft for the port. This leads to delay of the ships departure.

Here are some other problems that may arise when working with ballast water systems, related to the method of impact on microorganisms and to the navigation areas:

- Some systems do not have ballast pre-treatment. This may result in non-compliance with the D-2 standard for the number of remaining microorganisms and respectively lead to sanctions for the ship or to a refusal of the port administration to approve the de-ballasting in the port.

- Most systems use active substances for filtration. For them, the requirements of the International Maritime Organization, regarding certification, maintenance and inspections, are increased.

- A key point for the good operation of the UV system is the good selection of the lamp concerning lamp power-to-water flow ratio. The purity of the received ballast water is also essential. Many European ports, Rotterdam, Hamburg, Bremerhaven, Tilbury, are built in rivers and the water in them is with high level of sediments.

- Some systems using vacuum oxygen abstraction and bio-impact are very expensive. The latter uses microorganisms that affect and destroy organisms in the ballast water, which requires regular supplies from coastal services with such microorganisms.

- An important feature of systems that use active substances is that, if the concentration of the active substance is greater than required for purification, surpluses cannot be thrown overboard. Therefore, collecting tanks are used, where the neutralization process results in a reduction in the level of active substances to acceptable levels. For example, chlorine dioxide decomposes for 12 hours, but it can only be safely thrown overboard in 24 hours. These systems definitely require spaces from the ship's deadweight and high precision in operation requiring pre-training of the crew.

- Chlorination water systems use approximately 10 mg/l during the treatment, while the acceptable amount of chlorine in the water that is discharged overboard is 0.2 mg / l, to which level the chlorine must be reduced before de-ballasting.

- Deoxygenation is also quite effective, as ballast water is stored in closed tanks. But to be as effective as possible, the ballast should last for at least 4 days. The method is not applicable to vessels performing short voyages. The system requires water to be enriched with oxygen when it is thrown overboard to prevent affecting natural seawater. The method is also inappropriate for destroying organisms that do not use oxygen for their development or have changed their metabolism.

- So far, no system has received approval from the Environmental Protection Agency and other competent authorities in the United States, so problems between the crew on the one hand and the US and federal authorities on the other are not excluded.

- Systems are complex, consisting of many components, and their dislocation of existing ships is a complicated process. Not all possible impacts on adjacent mechanisms may be taken into account, resulting in damages to system details, emergencies, and incidents during operation.

- In ships compartments, where flammable and explosive gases are likely to penetrate or to be generated, it is imperative to have instruments for their indication and measurement. This applies even more to ships carrying dangerous cargos and requires special instructions and crew training.

Standard D-3 of the Convention contains the order for the approval of a system: by the Flag Administration for a system operating with inactive substances; by the Flag Administration and by Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection – Ballast Water Working Group (GESAMP-BWWG) as an IMO working group for a system containing active substances. When an approval granted to a system, this does not mean that it can be used on all ships under all conditions. Even after fitting it on board after approval, the responsibility for the discharge of the ballast lays on shipmasters shoulders.

Once the type Approval Certificate has been issued, the Administration has to make sure that the operating parameters are in the norm and confirms this by issuing a Management of Ballast Waters Operations Certificate.

The task of the crew at management level is to monitor the validity of the certificates, the time limits for the various types of inspections, the regulations, together with testing and maintaining of all units in the system, as well as making emergency repairs to the crew's capabilities. For the performance of all these requirements and events, crew members must be duly educated and prepared. A major role in this process is assigned to the ships' officers and to the ship's engineers.

Unfortunately, we can conclude, that such training for work with ballast water treatment systems is not available. Since 2016 to 2018, the authors took part in an European Commission Grant Agreement – 2016-1-RO01- KA202-024663, ERASMUS+ Strategic Partnership project "Diversification of seafarers' employability paths through collaborative development of competences and certification". Main objective of the project was to improve the employability skills and work opportunities for marine workers and to reduce the existing gap between the educational world and labour market by diversification of career paths and skills recognition (Acomi, 2018). When participating in the DivSea project, representing Nikola Vaptsarov Naval Academy, the authors developed an online course for the initial training of students and ship's crew to work with Ballast Water Treatment Systems. The course is available on the project webpage (divsea.cmu-edu.eu) and enables the test to verify the acquired knowledge. E-Platform for blended learning is presented in Fig. 2.

Ballast Water Treatment Course is designed to gradually allow trainee and to view the learning materials. It means that the trainee has access to the first module, then to the associated test. Fig. 3 highlights the conditions set for the availability of learning materials.

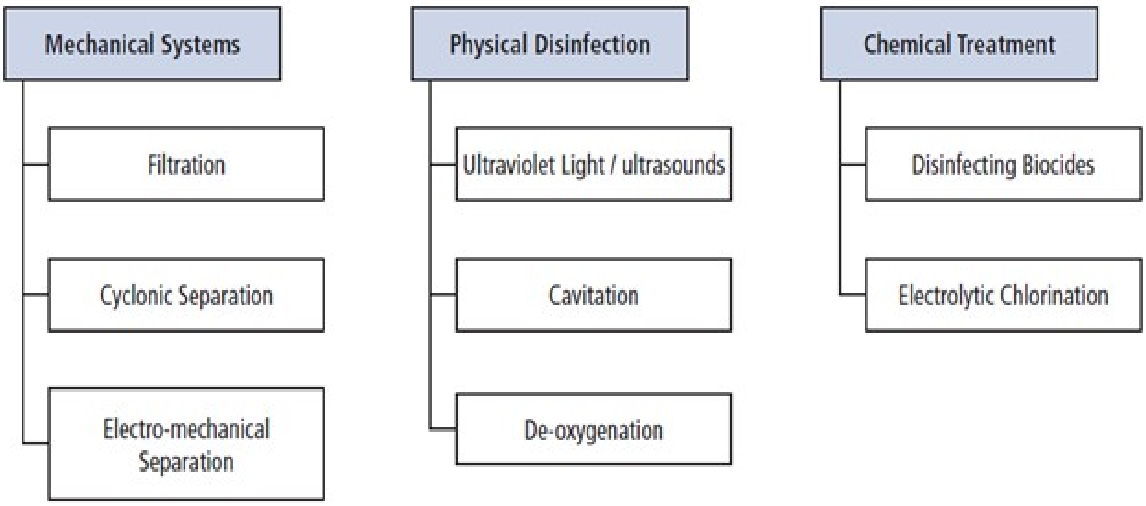

Fig 1. Technologies used in ballast water treatment systems.

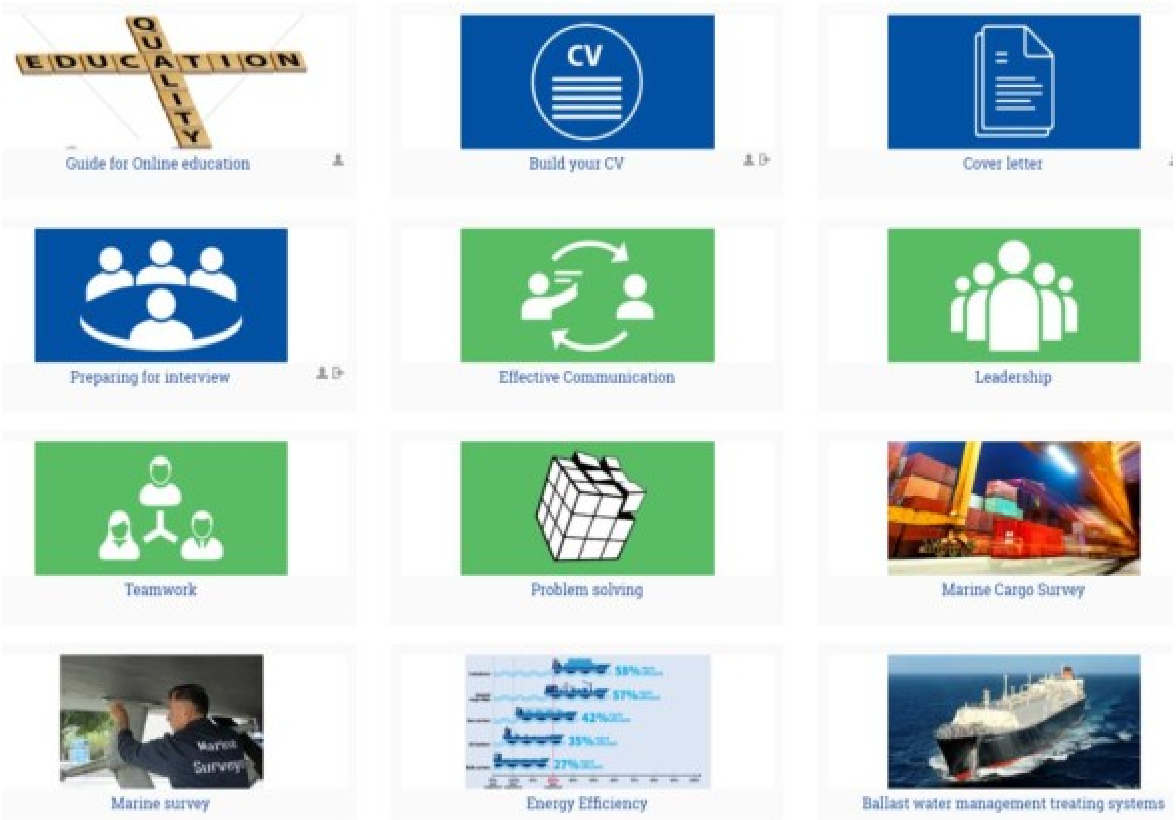

Fig. 2. Moodle E-Platform for Blended learning.

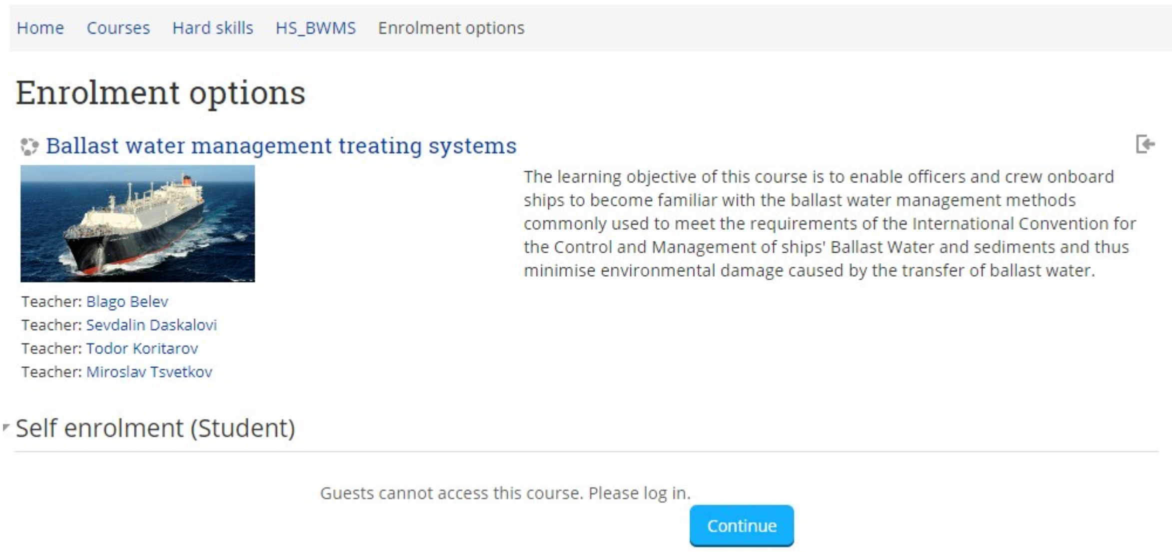

Fig. 3. Conditions set on E-platform.

Fifty percent passing score make available the next training module and associated test, then gradually to the next modules and tests. There is no time limit for reading. The trainees are invited to read at their own pace, even to close it and re-open when they are prepared for studying.

On completion of the modules and intermediate tests, there is a final test. The passing score for the final test is 60%. Achievement of this score would provide an understanding of the subject, the final test comprising 40 questions selected from various modules.

The platform has been set up to award the certificate in recognition of acquired skills and competencies and the trainee to be able download it. Moodle allowed designing the certificates and assigning individual codes for the issued certificates.

However, this is not enough for the crews of the ships and especially for the ship officers and engineers of management and operational level. It is appropriate, together with the Maritime Administration, to consider a qualification course of varying duration. The course should also include visit by the trainees to a vessel moored in the port of Varna and carrying out loading and unloading operations. This will enable them to become familiar with the organization and operation of the ballast water treatment system, its positioning on board and functionalities. At the same time, each trainer, depending on his position on board, will be able to familiarize himself with the instructions for operating a real system, as well as to share experience in solving problems with their colleagues on the particular ship. That way, at the next boarding, each trainer will be aware of the basic parameters and requirements of the systems and will only need to clarify the details in order for the ballast operations to proceed smoothly.

Conclusion

The dynamics of sea-going trade, the concise ship timetables and the complicated international situation call for new skills for the crews of the ships. Requirements for the protection of the marine environment increase by the growing number of potential pollutants. Nikola Vaptsarov Naval Academy maintains continuous connections with ship captains and chief engineers, and based on their experience and discussions, we conclude that the ship's knowledge and skills acquisition period should be shortened at the expense of the expanding one on the shore in specialized training centers. As an example, it is possible to bring the advanced system of ECDIS type specific courses for the deck officers, which help them to take over their duties on the bridge immediately upon joining the vessel.

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