Design of special ships equipped with non-conventional de-oiling equipment for cleaning oily ship’s waters and removal of oily spills

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Abstract

During the last 30 years pollution of the world’s oceans has become a matter of increasing international concern. Most of it originates from land-based sources. Nevertheless, a significant amount of pollution is caused by shipping and maritime activities generally. In tonnage terms the most important pollutant resulting from shipping operations is oil. In the introductory part of the paper an assessment of the amount of oil damped into the seas from ships is made. Shortcomings of the de-oiling systems installed on ships today are discussed.

To reduce further the oil pollution threat more effective methods of oil separation from ship’s bilge and ballast waters are proposed. A better solution to avoid oil pollution seems to be disposal of oily waters to reception facilities in ports. Therefore to realize such an idea, special ships with proper systems designed as reception stations of all kinds of oily waters from various ships are proposed and described. These special ships shall be equipped with non-conventional separation units, like hydrocyclones and filters operating on an adsorption principle. Finally various solutions of complex reception systems consisting of special ships or barges are proposed.

It is concluded that disposal of oily ship’s waters to special reception facilities is a safer way of minimizing the risks of oil pollution.
1 Introduction

A very intense increase of world population, dynamic development of industry, transport including waterborne during the last quarter of the XX th century entails considerable escalation of environment pollution both on land and at sea. However, particularly acutely occurred the problem of oceans and seas contamination due to the fact that all pollutants finally appear in rivers and further in coastal waters of seas and oceans.

If in the thirties of the XX th century the waters of rivers, lakes and coastal waters contained in their chemical composition only traces of human activity so in present days in many water intakes the concentration of hydrocarbon compounds exceeds by hundreds or even thousands the allowed maximum limits.

For many years the oceans have been considered as an ideal place for dumping any kind of waste generated during the production activity of man. Taking into consideration the magnitude of oceans it was difficult to notice that such views could be wrong and create any problems. Therefore if we are so much concerned about the cleanliness of the marine environment this is because the waste products created in connection with the production activity of our civilization are very uneven distributed in the oceans volume. For that reason among others, high local concentrations of hydrocarbon products should be considered as very harmful for the marine environment.

Following main sources of marine environment pollution can be distinguished:

- natural crude oil seeps from the sea bottom,
- processes of crude oil extraction from the sea bottom and its further processing,
- oil spills as a result of floating objects disasters,
- discharge overboard of fuels and lubricating oils by ships,
- hydrocarbon wastes from industrial installations on land,
- rain waters and municipal sewage containing crude oil products,
- leaks from crude oil pipelines transporting oil on long distances (losses may reach 10%).

The amount of hydrocarbons discharged today into the seas is quite difficult to estimate, therefore quoted by various sources figures should be considered as very subjective. It is estimated that within the period from 1969 to 1990 about 3 mil. tons of crude oil has reached the seas due to tankers catastrophes. The most known and reliable estimations of discharged into the marine environment amount of hydrocarbon products are the reports of the American National Academy of Sciences (N. A. S.). Published in 1973 report assesses that in the beginning of the 70’s every year over 6 million of hydrocarbon products have been discharged into the seas and oceans. In November 1981 the N. A. S. has completed another estimation of hydrocarbon amounts dumped into the marine environment, stating that the amount of discharged hydrocarbons has been reduced to about 3.5 mil. tons, the share of sea transport in marine pollution was estimated to be about 1.5 mil. tons i. e. about 40% of all hydrocarbon products discharged into the oceans. Within this amount 0.5 millions tons has been
pumped out into the sea during operations on board ship either by cleaning ballast tanks or pumped from the bilges.

The last available data from 1990 quoted by N. A. S. (1) shows further reduction in oil pollution caused by ships by about 60% compared with figure from 1981. Namely in 1990 about 568 000 tons of oil came into the seas due to the transport activities of ships. From that amount 114000 tons of oil contaminated the marine environment due to catastrophes of tankers, and 158 000 tons was discharged into the seas as a result of ballasting and tanks cleaning of tankers.

It was also estimated that 1800 tons of oil landed in the seas during cleaning of the engine bilges on tankers and 64 000 from ships of another type. Besides that 186 000 tons of oil sludges was dumped into the seas from other ships than tankers.

The main reason behind the quite significant reduction of hydrocarbon products amounts dumped into the seas is the more and more stringent compliance with the rules of the Marpol 73/78 Convention. This Convention being in force since 1983 is now respected by 85% of the world fleet influencing substantially the improvement of seas and ocean cleanliness.

As can be seen from the quoted figures the amount of oil dumped today into the seas is significantly smaller, however the problem of marine pollution can not be depreciated, because these relatively small amounts of oil dumped usually into coastal areas create always a serious ecological threat for the local biosphere, not mentioning the purely aesthetical aspects like soiled beaches.

Offered today by various manufactures ship's oil separators, unfortunately not always guarantee the required by Convention level of cleanliness of pumped overboard water at any stage of ship's operation. On board ships in common use are two stage units consisting of a gravity stage and a coalescence or filtration section. It is envisaged that such type of oil separators will be used in the future, however it's efficiency changes during operation, what causes problems for the ship's crew trying to maintain the required level of water purity pumped overboard.

The main problem which today we face during operation of oil separators is the short period of oil separators efficient filter or coalescence elements performance due to being clogged by solid particles which are present in the oily waters. Hence efficient and effective operation of the filtering or coalescing beds depends primary on removing the solid particles from the oil – water mixture, before it flows into the oil separator. Settling of solid particles in the bed (filtering or coalescing) not only changes its porosity index and local flow velocity values, but what is more important it changes also the surface properties of the bed. The final result of solids particles settling will be a total clogging of the filter pores what is equal to disruption of its function. In the light of mentioned problems, connected with the presence of solid particles in water, a fully reliable in operation oil separator must be equipped with a preliminary separator, installed before the filter or coalescing elements. Mentioned conventional two-stage gravity-coalescence oil separators have also this drawback that they are having a low treatment capacity (up to few tons per hour) therefore they are not suitable
for de-oiling of larger amounts of water what may be needed during washing and ballasting of tanks on a tanker ship or on offshore oil rigs.

At the base of interest of the possibility to apply hydrocyclones for de-oiling ship's waters were lying the above mentioned shortcomings of conventional oil separators. Therefore undertaking research on hydrocyclones for cleaning of oily sea waters a goal was set to work out a construction of a hydrocyclone for an effective separation of two immiscible liquids. Such a hydrocyclone of different geometry from a conventional one according to initial assumption should play a function of a preliminary stage for cleaning oily water in a three stage ship's oil separator, separating firstly oil droplets of larger diameter ($d_k > 40 \mu m$) and secondly not less important catching various solid particles in order to secure proper efficiency of various coalescing elements in contemporary ship's oil separators. It should be however, emphasized that the research work was mainly concentrated on achieving possibly the highest separation efficiency of two immiscible liquids, whereas the possibility of simultaneous separation of solid particles was given attention during later research work. The contemporary international and national requirements in the scope of marine environment protection are very restrictive as far as discharging of hydrocarbon products overboard ship is concerned. Bilge or ballast water pumped out from a ship wherever a ship may navigate can not contain more oil then 5-15 ml/litr of water and in special cases required water cleanliness is in the range not more then 0.05-0.1 mg oil/litr water.

Currently there are many methods of sea pollution prevention by hydrocarbons products through installation of proper de-oiling equipment on board ships which should comply with the Marpol 73/78 Convention.

Another method is discharging the oily waters and sludge to shore reception facilities in the harbour. The harbour reception facilities can constitute special designed for this purpose ships or barges adopted for receiving oily waters from ships arriving at a particular harbour.

It can be stated that we are now at the beginning of a new trend, it is the disposal of oily waters on special ships or barges. This is dictated by the fact, that such a way of oily waste disposal is a more reliable one, securing a much better avoidance of marine pollution by oil. As ship operating practice shows oil separators installed on board not always safeguard the required oil removal efficiency, especially after few years of operation and not with a well trained engine crew. Thus transfer of oily waters to available port reception facilities is especially a very useful solution for passenger ships and ferries navigating in special areas like the Baltic Sea or North Sea.

2. Cleaning systems of oily waters on various special type ships.

As already mentioned the purification of oily waters can be accomplished in two ways:

1) directly on board ship by means of various types of oil separators,
through application of cleaning systems on specialized ships designed for reception and cleaning of oily ship waters. Technical means placed outside ship for cleaning waters contaminated by hydrocarbon products constitute a complex of appliances which may contain:

a) ships collecting waters contaminated by hydrocarbon products,
b) ships securing collection and cleaning of oily waters,
c) ships securing cleaning of ship’s oily waters,
d) collecting barges serving as reception and storage facilities of oily waters,
e) land based cleaning stations,
f) floating cleaning stations.

The above quoted complex of means secures the purification of water containing hydrocarbon products according to any of the schematic diagrams shown in Fig. 1. The presented diagrams guarantee a very flexible organization of water cleaning outside trading ships at minimum costs. Usually diagrams a) and d) could be recommended for ports and other places of ship stay, c) is a proposition for repair ship yards. Scheme d) can be applied for regions and river basins with a small number of visiting ships. According to scheme e) we should plan a filtering station for jetties of crude oil products transshipment from ship to ship or also for other areas with high probabilities risk of oil spills. In each case of specified system the choice is based on concrete given situations. Having been given data about the amount of oily waters collected on board ships we can say that special ships-cleaning stations with a separation capacity of oil and fuel from water of 0.5–1.0m³/h ensure purification of oily waters taken from any floating units steaming on rivers, whereas stations with a capacity of 1.0; 2.5; 5; 10.0m³/h can serve as reception stations for sea going vessels. As far as 24 hours cleaning capacity of reception station is concerned they should have separation capacities 10; 25; 100 or 200m³/24h.

Depending on the type of work organization on water treatment plants placed on special ships, they may operate in an 8 hour or continuous working system having a cleaning capacity of 0.5 to even 40m³/h if on board ship calling a harbour a larger oil spill occurs. Such a wide range of cleaning capacity doesn’t pose any problem if on ships being a cleaning station are installed appliances for oil separation from water like hydrocyclones destined for separation of two immiscible liquids having a different geometry from widely used in various industries conventional hydrocyclones. Single hydrocyclones can be coupled in parallel batteries of any hydrocyclone numbers, hence achieving this way the possibility of flexible output adjustment through switching off or switching on relevant number of hydrocyclones. As a result of conducted study work few technological systems for oily water treatment originating from ship’s machinery oilgels were worked out. One of the proposed alternative designs is illustrated on Fig. 2. In the above system foreseen is: a) primary stage of cleaning oily bilge water, part of which exists in a form of less or more dispersed layers in a gravity field (sedimentation), b) stage of coarse oil dispersion separation in a centrifugal field, c) stage for fine separation (polishing stage) of fine dispersed oil droplets (1–10μm). The oily-water cleaning system illustrated on Fig. 2 consists of
a tank 1 for collecting the polluted bilge water, hydrocyclone 2 and a rotating adsorption filter 3 and pumps 4 and 5 securing the operation of the system. Tank 1 is at the same time a primary settling tank of cascade design. The tank has been devided by vertical partitions 6 in such a way that in each settling division for example 7, water will flow from top to bottom and the hydrocarbon products will ascend into the upper part of the tank. The surface of tank 1 partitions can be covered by a hydrophobic material, which will play a role of a coalescing material and this way increases the effectiveness of process sedimentation in tank 1. Tank 1 has been also equipped with cylindrical elements 8, functioning as oil carrying away guide vanes. Element 8 can work in an automated system if for example it will be a ball valve. The weight of the valve will be then so selected that it will lower down itself if flown around by oil to discharge the oil. When the space around the ball valve will be filled by water the valve will be lifted upwards closing the oil outlet. Similar function can perform a system consisting of an oil sensor 9 for example of a capacity type together with a controlled by a controller valve 11. Hydrocyclone 2 has a tangential inlet of contaminated water in its upper part and an outlet of cleaned water in the lower part (underflow). The separated from mixture oil or fuel will flow towards the hydrocyclone axis and further upwards leaving the hydrocyclone in the upper part through the overflow. The operation of the hydrocyclone in the necessary operational rigour ensures pump 5, differential manometer 12 and control valves 13 monitored by controller 11. In the centrifugal adsorption filter 3 the flow takes place in a radial direction (from the centre towards outside walls) the filtering element 14 is set in rotation, what creates in the cleaning volume an additional field of centrifugal forces. The cleaned water collects in the filter casing 15 and is carried away to clean water tank or overboard.

Method of adsorptive cleaning in a centrifugal field in an essential way improves the efficiency of separation due to reduced flow velocity of oil droplets in relation to the adsorptive insert. In normal conditions of adsorptive separation velocity \( V_p \) of dispersed oil droplets is assuming the velocity of the cleaned water stream \( V_p \) in this case it is presumed that the filter insert is at rest. It is known that the efficiency of adsorption depends especially upon the oil droplets velocity against the insert, which in normal conditions is equal the velocity of the undergoing cleaning water stream (see Fig.3a). In a centrifugal forces field an oil droplet will be subjected to a complex motion i.e. it will move together with the liquid stream and at the same time due to the action of the centrifugal force have a velocity component in the opposite direction to the stream flow. Therefore in this case the resultant velocity \( V_r \) (see Fig 3b) will be considerably lower than the stream velocity and can be expressed as follows:

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V_r = V_p - V_{c.f.}
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The expected complex flow of cleaned water in the centrifugal filter gives the following effects. Firstly due to the action of the centrifugal forces the throughput of the filter increases.
Secondly the velocity of the emulsified oil droplets in relation to the adsorption insert decreases. This last advantage as it was proofed exhibits an essential increase of adsorpted oil droplets number it is increases the separation efficiency. Another alternative de-oiling system could be a system shown on Fig.4a.4b. The technological design of this system distinguishes by an additional separation process of solid particles (sand, rust etc.) in a centrifugal field. This additional separation process of solid particles is realized in an additionally installed hydrocyclone. The parameters of this hydrocyclone are calculated this way in order to secure good separation of particles, which density is larger then density of water.

In the system illustrated on Fig. 4a, 4b the cleaning technology is carried out in a system which consists of a settling tank 1, hydrocyclone 2, Hydrocyclone 3, collector of solid particles 4, pumps 5 and 6 and adsorption filter 8. The system operates in a similar mode as the previously described. The additional separation process of solid particles is indispensable to ensure a better operating conditions of the adsorption filter. Oil separated from water in the hydrocyclone and in the adsorption filter is collected in tank 7. The presented separation systems of oily waters installed on special ships designed for this purpose can secure the required degree of purification i.e. to a level of 1 to 5 mg oil/litre water.

These described systems correspond with the basic technology of complex cleaning, which ensures the separation of oil from water even if oil exists in the most difficult condition to separate i.e. as an emulsion. The basic worked out alternatives of cleaning systems can be utilised for designing numerous modifications of similar systems, which will take into consideration specific requirements of an individual case.

Fig.7 illustrates general view of a floating de-oiling cleaning station equipped with traditional appliances and a de-oiling station on which a battery of hydrocyclone was installed. Both stations have the same treatment capacity ~200m³/24h and similar separation efficiency down to 5mg oil/litre water, but as can be seen from the drawing the station on which hydrocyclones were applied is a much more compact installation with a significant lower building costs (by a factor 3-5).

On the station (Fig. 7b) foreseen are tanks 1 for reception of oily water mixtures whose volume is equal the daily treatment capacity of the station, pump station 2, accommodation for filters of fine separation 3 and 4, forepeak 5, crew accommodation 6, laboratory 7, workshop 8, diesel-generator room 9, compartment of hydrocyclone batteries 10.

This floating station accepts oily water from ships and other objects into its collecting tanks, from which the station pumps feed the mixture to the hydrocyclone battery and further to the fine filters. If necessary the station can be moved (it may have its own propulsion) into areas of accidental oil spills to perform its function. The station can be further equipped with compact floating booms what enables to use the station for liquidation of hydrocarbon spills on water regions or in harbours.
3. Conclusions

If the marine industry and all other responsible people for a healthy marine environment think seriously of further reduction of the discharged hydrocarbon amounts into the seas and oceans, then it is a right time to reconsider the philosophy of oily ship waters purification.

In the light of the presented possibilities to transfer oily wastes generated on board ships to shore reception facilities which can be either specialized floating units or totally land based installations, it should be expected that shipowners start acting with proper diligence and prudence, to consider handover of the oily waters from ships whenever possible to shore facilities. When this trend of handing over the oily wastes from ships to shore facilities starts prevailing, we will certainly have still cleaner seas and oceans, as processing of oily waters ashore will guarantee their proper handling minimizing the risk of marine environment pollution close to nil.

Fig. 1 Schematic diagram of possible ship's oily waters treatment arrangements outside of trading ships
Fig. 2 Schematic diagram of ship's oily waters cleaning system

Fig. 3 Flow of a dispersed droplet in an adsorption filter (a) flow of the same aided by centrifugal forces (b).

Fig. 4 Alternative de-oiling system (a).
Fig. 4 Alternative de-oiling system (b).

a) Floating conventional cleaning station 200 m³/day

b) Floating cleaning station equipped with hydrocyclones

Fig. 5 General view (a) and location of basic elements of on a floating station for collection and cleaning of oily waters (b).