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THE PROTECTION OF THE ENVIRONMENT DURING THE OPERATION OF INLAND AND COASTAL SHIPS

Key words

European inland shipping, burning gas in marine diesel engines, non-conventional method of purifying ship's oily waters and exhaust gases.

Summary

This paper considers problems related to environment protection that occur during the operation of inland and coastal ships and proposes a means of changing the used fuel to gas fuel and applying a complex cleaning of both exhaust gases and oily ship's waters in a contact heat exchanger.

Introduction

The inland shipping industry in Europe will have to play a more prominent role in the carriage of all kind of goods (especially containers) as well as passengers travelling for sightseeing.

Inland shipping has finally been established as an important carrier of goods and people. It is worth while to notice that Germany plays an important role for European inland shipping, and its network of waterways of 7,476 km is the largest in Europe. The most important river by far is the Rhine, on which two thirds of inland traffic is concentrated [1].

Total cargo turnover in the Rhine area in 2005 was 173 m tonnes. Cargo transport within Germany only plays a minor role with 56.7 m tonnes, compared with cross-border traffic 180.2 m tonnes.

According to figures from the German Federal Office of Statistics, nearly 1200 companies were engaged in domestic shipping at mid 2004. The biggest share consists of small companies with a turnover of less than €500,000 and which own 42% of the 2,795 inland vessels. However, their share of the total sales figure reached only 16%.

In 2005, cargo volumes transported on German rivers and canals rose by 0.3% to 236.8 m tonnes reaching the third highest figure since 1989. One growth driver is container transport, where total inland box traffic reached 2.1 m teu in 2005 up by 8.5%. However, the share of container transport on German rivers is still less than 10%. The German inland fleet includes 937 dry cargo vessels and 369 tankers, the number of which is constantly growing. According to the Union of German Inland Shipping, nearly 60 new double-hulled tankers are put into service each year, while only a few are scrapped. This is to meet the new requirements of oil companies, which want shipping firms to use double-hulled tankers that meet higher security standards on European inland waterways.

Transport ministries expect total volumes to rise by two thirds by 2015, especially in Germany. To prevent a collapse of the land-based traffic infrastructure, inland shipping will have to play a more important role in the future. The European Commission also wants to shift traffic from roads to waterways. With an action program called Naiades, it plans to enhance maintenance and expansion of European waterways. The program is much appreciated, and there is hope that the bottleneck of the Rhine-Main-Donau Canal will be removed, in particular.

Higher cargo rates also means new challenges for Germany's and other countries inland ports. The port of Duisburg, which is the largest inland port in Europe, expects the volume of container transport to grow by 50-60% until 2010; therefore, it plans to double its container handling capacity.

The most capitals and cultural centres of the world (Warsaw, Moscow, Paris, London, St. Petersburg, Venice, Szczecin and others) are located along rivers or on the sea-coast. Therefore, sightseeing is often done from the decks of small passenger ships. Demand for cruises has reached an all-time high. These ships constitute the other group of ships in the inland shipping structure, although their share is relatively smaller compared with the number of cargo carrying inland ships.

Engines are installed on these ships of relatively small power and high revolutions, which are characterised by a higher fuel consumption and an increased content of toxic components in the exhaust gases.

The increase of the economy of operation of these ships by changing from diesel oil to a cheaper alternative fuel oil generally augments the problems of environment protection. At the same time, it is known that the discovered resources of natural gas are continuously increasing and the developing infrastructure of transport pipes secures its supply relatively cheaply, for example, from Russia to Poland and to other European countries. Today, natural gas at bunkering stations has a price which is 1.5–2 times lower than diesel oil, based on value of a heat unit and taking into account the costs of transport, its protection and distribution; and, in the foreseeable future, this price difference will continue to increase. Therefore, these days the interest in burning gases for usage on small passenger ships increases.

The economy of burning gaseous fuels is not any worse than the economy of engines running on liquid fuel. Consequently, operation costs are practically lower proportionately, as related to price levels of these two kinds of fuel.

As operational experience indicates, the wear of engines burning gas is lower than using diesel oil, which not only reduces the expenses of maintenance but also minimises the adverse effect on the environment during increase in the operating hours of the engine.

Today, several regulations have already been introduced in European countries, including Russia, concerning the limitation of exhaust gas toxicity. In the beginning of 60's, regulations already existed. For example, in Russia for ships steaming on lakes, the NO_x emission was limited to 15 g/kWh for engines above 100 kW power. In 1974, this limitation was further lowered to 10 g/kWh.

Since 2000, the rate of NO_x emission for new main engines is 7 g/kWh. Engines operating on gas have emission levels of 2–3 g/kWh or even only 1 /kWh. In this way, the interest in engines operating on gas is stimulated, not only by economic factors, but also by the increasing demands on lowering exhaust gases toxicity.

1. Burning gas in marine diesel engines

Problems with converting marine diesel engines from burning diesel oil to burning gas fuel or gas-liquid fuels have been considered and designated engines for burning gas are available. For example, in the USA (Alabama State) a dual fuel engine was designed based on a Caterpillar 3406 – WDI – TA engine with a direct combustion chamber, its main data being S/D = 165/137, N_e = 240 kW and 1800 rpm. This engine works on either on diesel oil or gas. The gaseous fuel is fed into a carburettor, from where the air gas mixture is further delivered to the turbocharger compressor and finally passing through the air cooler into the engine inlet manifold. Diesel fuel is injected into the cylinders by means of an injector at the end of the compression stroke. Concentration levels of toxic media in the exhaust gases of this engine consist of CH – 0.2%, CO – 0.2%, NO_X – 0.075%, CO_2 – 8%.

For the Russian river fleet, "GAZPROM" has designated dual fuel engines of 50 to 200 kW with a complete set of gas bottles, low temperature system and feeding system of condensed natural gas and a control system of gas distribution for use in the ship's accommodations for various functions. For example, the Northwest Shipping CO together with the St. Petersburg University of Water Communications have modified a ZD6 diesel engine with a direct combustion chamber a stroke to bore ratio S/D = 180/150 and 110 kW power at 1500 r.p.m. for burning liquefied gas.

During the conversation, the following technical solutions have been realised:

- The ignition of gas – air mixture from a self-igniting set dose of diesel fuel;
- The delivery of gas into the combustion chamber by means of external mixture creation through the inlet collector;
- The control of engine revolutions is carried out by means of a mixture feeder shutter, i.e. a qualitative control of mixture composition is realised;
- The designed system of gas feeding is, to a large degree, similar to the system of KamAZ cars.

Data concerning exhaust gas toxicity is analogous to achieved results by American researchers [3, 4]. For example, the smoke index of exhaust gases at nominal load was lowered by a factor of nearly 10. It is quite obvious that gas for feeding the ship's machinery should follow these research trends.

It is necessary to notice that classification societies have a very cautious approach to storage systems; therefore, it is important for inland ships of rather small capacity is to secure fire and explosion safety during gas storage and distribution into the engine.

At present, three methods of gas storage can be used:

- compressed gas stored in tanks under pressure,
- liquefied gas under pressure, and
- liquefied gas under atmospheric pressure and low temperature.

The second method can be applied only for relatively heavy gases like propane and butane.

Usage of tanks with liquefied propane or butane onboard ships is not possible at present; because even a small of these gases in the air (in the range of 2–2.5%) represents an explosive mixture, and the higher density of these gases (1.5–2 times larger than air) and the small coefficient of diffusion will cause high concentration zones of these gases if there is a leak, and removal through ventilation is difficult.

For these reasons, methane is most often used onboard ships, because it has a density 0.67 of air density (molecular mass 16, air 29) and a lower range of explosive concentration, 5.28% by volume.

Russian scientific research firefighting institutions recommend the following to prevent fire or explosion when using methane on water transport vessels:

- Working out procedures and the means of desensitisation and the spreading of methane-air zones;

– The calculation of accommodation ventilation multiplicity in which methane circulates;
– The calculating and planning of the means of securing fire-safety of methane drainage;
– Planning the means of explosion safety by the controlled burning of damped methane vapours;
– Planning procedures and the means securing the ship's fire-safety defence considering methane circulation;
– Defining the procedures and means of extinguishing methane fires;
– Planning the procedures and means of liquid methane velocity evaporation after overflow;
– Planning the procedures and means of defence against heat created by men or machinery during fires onboard ships on which methane circulates;
– Planning for the establishment of firefighting brigades and proceedures for extinguishing fires involving methane;
– Planning and design of safety techniques for extinguishing fires involving methane onboard ships. Whereas, for the ship's engine room, the following conditions should be observed:

$$\frac{V_g}{\mathrm{VER}} \cdot 100 < 5$$

where:

V_g – volume of gas in free state which during an accident can enter into the engine room, m^3,
VER – volume of engine room minus the volume of machinery, m^3.

For the appraisal of the necessary ratio of engine room volume with respect to explosion and fire safety categories, it is necessary to divide the gas volume in the vessel (for normal conditions) being equal to the volume relevant to the lower zone of flammability and multiply it by 20. If the received figure is smaller than the machinery room volume, then the latter does not need any supplementary design conditions.

Modification of diesel engines in order to burn gaseous fuel lowers, in an essential manner, the negative effect of exhaust gases on passengers and crew. Unfortunately, we cannot completely solve all of the problem of the contamination of our surroundings.

The exhaust gases, even after the transformation of the diesel engine to burning liquefied gas, will still contain a significant amount of solid hydrocarbons and polymer particles, which essentially complicate the work of a catalyst during the oxidisation reactions of incomplete combustion products and especially in the neutralisation reactions of nitrogen oxides. Supplementary cleaning can be secured by catalytic or plasmatic after-burning, filtration, and fluid based scrubbers. Realisation of the first method is hindered by a lack of a four functional catalyst and ceramic manifold blocks and filters with high gas permeability. The existing systems, due to the low velocity of gas convection in the catalysts, have large dimensions and weight, reaching a weight and size equal to 50% of a diesel engine, which, together with a high price, essentially reduces the possibility of applying it onboard small ships. Due to limited space, these ships as a rule are not equipped with oily water separators for the cleaning of oily ship waters.

2. Complex alternative purifying method of ship's oily waters and exhaust gases

As mentioned in previous chapter due to limited space on small ships, installation of large and efficient appliances for cleaning oily ship waters and NO_x reduction in emitted exhaust gases is not possible; therefore, the authors propose a low-cost complex system by securing the following:

- The extinguishing of sparks and liquid cleaning of exhaust gases,
- The cleaning of oily ship waters, and
- The utilisation of exhaust gases waste heat.

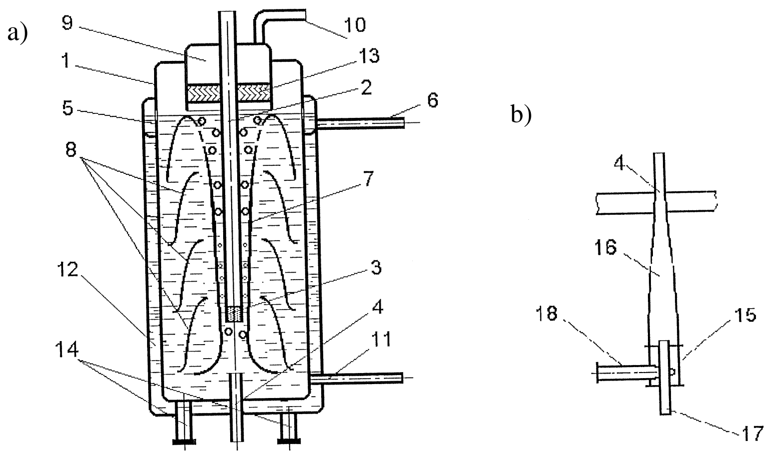

Fig. 1. a) Appliance for the simultaneous purification of oil waters and exhaust gases; b) Hydrocyclone connected to the inlet pipe (*4*) of appliance shown in Fig. 1a

The presented device (Fig. 1) consists of the following basic elements: *1* – casing, *2* — exhaust gases inlet pipe, *3* – porous cap, *4* – oily water inlet pipe, *5* – annular volume for collecting oil in the form of layers, *6* – outlet pipe for oily layers, *7* – barbotage column, *8* – guide plates, *9* – collecting volume of cleaned exhaust gases, *10* – outlet pipe for cleaned exhaust gases, *11* – outlet pipe for cleaned water, *12* – water mantle, *13* – shutter separator, *14* – drain for sludge removal, *15* – cylindrical part of the hydrocyclone, *16* – conical part of the hydrocyclone, *17* – outlet for separated oil, *18* – inlet pipe.

This task is solved by performing the three above indicated processes in one appliance – in a contact heat exchanger.

The appliance working principle is as follows:

The exhaust gases from the diesel engine, containing some soot particles, unburned droplets of fuel and oil, flow through the porous cap (*3*) into the internal half of the barbotage column (*7*). Towards the same space through the oily water inlet pipe (*4*) flows the water contaminated by hydrocarbon products.

The gas, having passed through the pores of cap (*3*), creates in the water contaminated by fuel or oil bubbles raising under the Archimedes force towards the upper surface.

Gas bubbles, moving in the barbotage column from a area of higher pressure to an area of lower pressure, will gradually increase in volume. Simultaneously, the volume enlargement increases the hydraulic resistance of the gas bubbles. Therefore, with the volume increase of individual bubbles, their ascending velocity considerably decreases, which in turn will allow the smaller bubbles to catch up with the bigger ones and coalesce with them, building up bubbles of a larger size and obviously with a larger potential energy. These larger bubbles again start to accelerate until consecutive braking occurs, and the process is repeated.

In this way, during the ascending process, smaller gas bubbles will grow to larger dimensions or form clusters of bubbles filling up a considerable part of the cross-section of the barbotage column. The high gas temperature boils the water, which also increases the interface surface.

The barbotage of gas and boiling promotes the lifting of hydrocarbon products and soot particles to the water surface on which foam is formed with a layer of hydrocarbons underneath. Both are collected in space (*5*), and move further through the outlet pipe for oily layer (*6*), and are directed to an oil-collecting tank. The cleaned gas is collected in space (*9*) and further released into the atmosphere through pipe (*10*).

To minimise the carry-over of water droplets into space (*9*), a water separator of a shutter type (*13*) is installed. In the inner space of the appliance, zones of reverse water flows are formed (circulation). Along the wall of the casing (*1*), water descends towards the bottom of the appliance and is flows back into the barbotage column (*7*), which allows many cycles to remove hydrocarbon products. To prevent secondary emulsification of hydrocarbon products, guide plates (*8*) have been fitted to secure a laminar flow of liquid outside the barbotage column (*7*).

To increase the growth of dispersed oil droplets (coalescence), the surface of the guide plates can be made of a lyophilic material. The oil ascends along the barbotage column, and it flows through holes in its upper part until it reaches the oily layer of hydrocarbons from where it finally arrives at the oil collecting annular volume (*5*).

During simultaneous cleaning of oily water and exhaust gases to avoid volumetric boiling of oily water, a cooling water mantle (*12*) can be connected with an outside cooling water system serving for cooling the diesel engines or with other heat using units.

To improve the efficiency of the described cleaning apparatus, the oily water inlet pipe (*4*) is connected to a hydrocyclone (Fig. 1b), which will separate part of the dispersed oil by the action of centrifugal force. The cylindrical part of the hydrocyclone (*15*) is equipped with a tangentially orientated inlet pipe (*18*). The overflow pipe for separated oil (*17*) is coaxial with the hydrocyclone axis. The undergoing cleaning liquid under pressure is delivered into the cylindrical part (*15*) of the hydrocyclone by a tangential inlet pipe (*18*). Thanks to this arrangement, a rotating motion occurs causing a separation effect of oil from water [2].

Conclusions

In the absence of a conventional cleaning system onboard small passenger ships, the proposed appliance of a dual function (i.e. de-oiling water and cleaning of exhaust gases) secures the following advantages:

1. Extinguishing of sparks, which increases the safety of ship's propulsion plant operation running on gas;
2. Increasing the quality of oily waters and exhaust gases, due to the intensification of the purification process (heating of water, turbulent mixing, bubble boiling, and circulation multiplicity);
3. The reduction of weight/overall dimension indexes, by connecting two processes – exhaust gas cleaning and ship's water de-oiling in one unit, as well as the simplification of the exhaust system of the ship's engines. For small passenger ships, the reduction of the overall dimensions of specific machinery units may allow increasing the ship's gas storage capacity while increasing her running distance without refuelling. The proposed system of complex purification can also be also on conventional ships with engines operating on liquid fuel.

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Ochrona środowiska podczas eksploatacji statków żeglugi śródlądowej i przybrzeżnej

Słowa kluczowe

Europejska żegluga śródlądowa, spalanie gazu w silnikach okrętowych, niekonwencjonalne metody oczyszczania zaolejonych wód okrętowych i spalin.

Streszczenie

Artykuł dotyczy zagadnienia ochrony środowiska podczas eksploatacji statków żeglugi śródlądowej i przybrzeżnej, gdy następuje zmiana dotychczas używanego paliwa na paliwo gazowe. Równocześnie opisana została metoda zastosowania złożonego procesu jednoczesnego oczyszczania spalin oraz zaolejonych wód statkowych w kontaktowym przenośniku ciepła.