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Box coolers as an alternative to existing cooling systems

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Abstract

The marine Diesel engines cooling systems and its elements were changing similarly to engines construction. Evolution of the cooling systems tends to reduce sea water pipelines inside engine room. Application of a central cooling system with box coolers completely eliminates sea water pipelines from engine room. Now that solution is rarely used on ships. It can be met on smaller ships, whose power output usually does not exceed 5000 kW, for example: tugs, dredgers, barges, supply vessels, fishing vessels, ferries, cargo freighters, reefers, ice breakers, carriers, etc. – operating inland, as well as in open sea navigation.

The article presents an example of practical application of the central cooling system with box coolers on the tug running in Gdynia harbour. In author's opinion, central cooling system with box coolers has a chance to spread out on bigger ships in the future. It will mainly depend on efficiency and reliability of box coolers secure systems. These systems ought to ensure correct operation of a cooling system between ship class dry-dockings. The box coolers used on the presented harbour tug are secured by ICAF system. The article presents also a proposition of solution to the cooling system with box coolers for merchant ship with power output higher up 5000 kW and advantages (disadvantages) of that solution.

Introduction

Permanent development of marine engines tends towards increasing unit power and simultaneously its reliability. It causes the quality of construction elements and installations to be more and more high. One of these installations is cooling system, which should be characterized by high operating efficiency – it means reliability, low operating costs and simple maintenance.

The marine Diesel engines cooling systems and its elements were changing similarly to engines construction [1, 2, 3, 4]. Evolution of the cooling systems tends to reduce sea water pipelines inside engine room. Direct cooling system in which plants were cooled by sea water was quickly replaced by indirect systems. The sea water is not good cooling medium due to its contamination and corrosion aggressiveness. Now indirect cooling system is commonly used in ships engine rooms. Firstly, all plants were cooled by fresh water and cooling heat was transferred to sea water in appropriate cooler. Evolution of the indirect system caused that all sea water coolers were replaced by one central cooler. In that system sea water pipelines inside engine room were reduced to minimum and as a result the problems connected with corrosion of the sea water pipelines practically not exist. Simultaneously, the jacket-pipe type coolers are replaced by plate coolers, which are characterized by better cooling efficiency and easier cleaning. The next step towards complete eliminating sea water pipelines from engine rooms is the use of central cooling system with box coolers. According to box coolers producers, its use is possible on ships with power output to 30,000 kW [5]. But now that solution is rarely used on ships. It can be met on smaller ships, whose power output usually does not exceed 5000 kW, for example: tug boats, dredgers, barges, supply vessels, fishing vessels, ferries, cargo freighters, reefers, ice breakers, carriers, etc. – operating inland, as well as in open sea navigation. That fact results from usually conservative approach of the ship owners. But, in author's opinion, central cooling system with box coolers will gradually spread out on new built ships.

The examples of central cooling systems with box coolers

The tug boat running in Gdynia harbour which cooling system is presented below is driven by two high speed engines CATERPILLAR 3512B which total power output is 2850 kW and two SCHOTTEL rudderpropellers. Every engine with rudderpropeller is an independent propulsion unit which can ensure emergency run of the ship in case of another one failure (in normal operating conditions both propulsion units are needed). Electric power is get from two alternating current generators driven by CATERPILLAR 3056 engines with total power output 168 kW. Every propulsion unit, it means main engine-rudderpropeller, is provided with independent systems of control, cooling and lubricating, which ensure normal movement even during black out.

The view of the sea chest with box coolers is presented in figure 1. There are three box coolers inside the sea chest: low temperature (LT) main engine cooler, high temperature (HT) main engine cooler and auxiliary engine cooler.

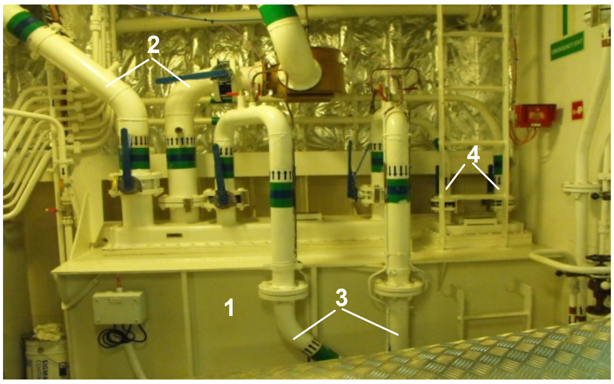

Fig. 1. The view of the sea chest with box coolers: 1 – sea chest, 2 – main engine HT pipes, 3 – main engine LT pipes, 4 – auxiliary engine pipes

Thus, main engine cooling system consists of two separate systems: high temperature (HT) and low temperature (LT). The scheme of the port side propulsion unit cooling system is presented in figure 2. HT system cools main engine cylinders and oil in lubricating oil cooler 5. The cooling medium (distilled water with the addition of the refine additive) circulation in HT system is executed by centrifugal pump 10. This pump is driven by main engine 1. The water temperature is controlled by thermostatic thee-way valve 8 which divides water stream into box cooler or main engine. The gravity tank 12 serves the following purposes: venting, cooling medium refilling and creating overpressure on circulating pump suction. LT system cools fuel and scavenging air in jacket type pipe coolers 6 and

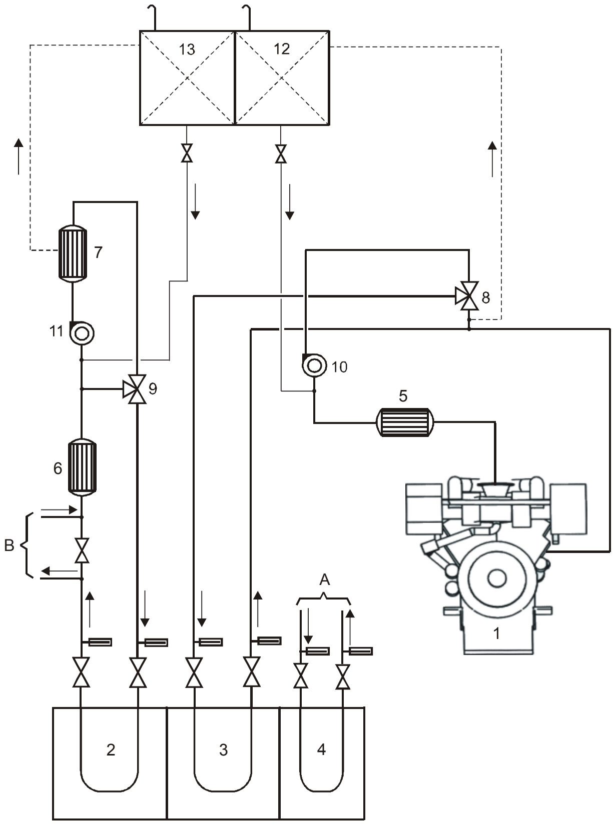

Fig. 2. Central cooling system with box coolers on the tug boat running in Gdynia harbour: 1 – main engine; 2 – LT box cooler; 3 – HT box cooler; 4 – auxiliary generator box cooler; 5 – lubricating oil cooler; 6 – fuel oil cooler; 7 – scavenging air cooler; 8, 9 – thermostatic thee-way valves, 10, 11 – centrifugal pumps; 12 – HT gravity tank; 13 – LT gravity tank; A – to auxiliary engine; B – to hydraulic oil coolers

7. The cooling medium (also distilled water with the addition of the refine additive) circulation in LT system is executed by centrifugal pump 11. This pump is also driven by main engine 1. The water temperature is controlled by thermostatic thee-way valve 9 which divides water stream into box cooler or scavenging air cooler 7. The gravity tank 13 serves in the same purpose as in HT system. The cooling medium from the box cooler 4 is fed to auxiliary generator (connections A). Additionally, from LT system the cooling medium is supplied to hydraulic oil coolers (connections B). The cooling of the starboard side propulsion unit is executed the same way.

Figure 3 presents a proposition of solution to the cooling system with box coolers for merchant ship with power output higher up 5000 kW. Cooling system is divided into two separate systems: high temperature (HT) and low temperature (LT). Every system is equipped with separate box cooler. HT cooling medium is cooled in box cooler 3 and LT cooling medium is cooled in box cooler 4. HT system cools main engine 1 and auxiliary engines 2 cylinders. Circulation in HT system is executed by

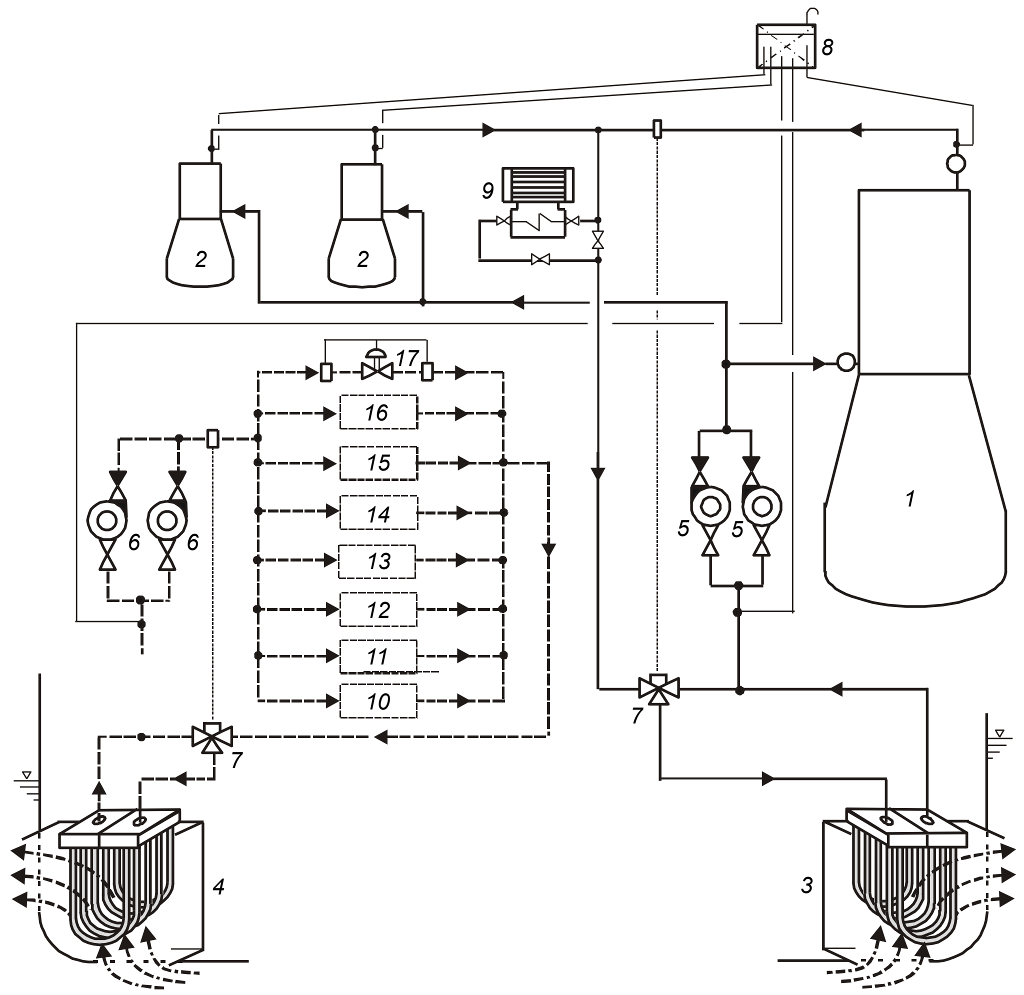

Fig. 3. Proposition of solution to the cooling system with box coolers for merchant ship with power output higher up 5000 kW [2]: 1 – main engine; 2 – auxiliary engine; 3 – HT box cooler; 4 – LT box cooler; 5 – HT fresh water pump; 6 – LT fresh water pump; 7 – thermostatic valve; 8 – gravity tank; 9 – evaporator; 10 – main engine lube oil cooler; 11 – main engine scavenge air cooler; 12 – auxiliary engine lube oil cooler; 13 – compressors; 14 – main engine shafting bearings; 15 – auxiliary condenser; 16 – air conditioning condenser; 17 – automatic regulating valve

centrifugal pumps 5 driven by electric motors. LT system cools: main engine lube oil cooler 10, main engine scavenge air cooler 11, auxiliary engine lube oil cooler 12, air compressors 13, main engine shafting bearings 14, auxiliary condenser 15 and air conditioning condenser 16. LT fresh water circulation is executed by centrifugal pumps 6 driven by electric motors. The cooling effect is reached by natural circulation of the outboard water in the sea chest or by a circulation due to the speed of the vessel. The outboard water is warmed up and raises by its lower density, thus causing a natural upward circulation (Fig. 3).

Advantages and disadvantages of box cooling

The main advantage of central cooling system with box coolers using is the elimination of pumping raw water through the cooling system. The raw water causes many problems connected with corrosion of the cooling system elements (especially pipes). In addition, the flow of raw water may become restricted due to the ingress of animals, vegetations or solids, what decreases cooling efficiency. In this system there is no need for sea water pumps, filters, valves and pipelines etc. – parts that are sensitive for disturbances maintenance. Thus, the central cooling system with box coolers is simpler and cheaper. The cost of the central cooling system with box coolers for the ship which total power output is 5000 kW compared to traditional central cooling system is about 40% lower (Table 1). Values in table 1 are in US dollars.

In addition, operational costs are also lower because of sea water pumps, filters and pipelines absence. Thus, there is no need for cleaning, repairing or replacing that elements. The secondary pump absence gives additional energy saving.

Table 1. Comparison of the cooling systems costs [6]

	Central cooling system with box coolers	Traditional central cooling system
Sea water circuit		
Plants	3700	23,300
Valves	6000	33,100
Pipelines	15,100	101,700
Fresh water circuit		
Plants	63,000	32,200
Valves	4100	2400
Pipelines	33,700	19,300
SUM	**125,600**	**212,000**
DIFFERENCE	**86,400**	

Box cooling is very suitable for sailing under ice condition. In case of the other cooling systems the ice pieces can blockage a sea water filter. As a result the flow of raw water may become restricted or totally stopped. It makes impossible the normal ship movement, because of cooling lack. For central cooling system with box coolers that problem does not exist, since there is no filter.

There are two problems which can occur in this kind of cooling system: corrosion and biological fouling [5]. The corrosion of box coolers is not a problem. They are made of materials which are corrosion-proof (cooper alloys). But a sea chest, placed near a box cooler, is made of carbon steel and it imposes the risk of galvanic corrosion. The sea chest is protected against galvanic corrosion by a coating covering all noble surfaces. In this way a long lasting and reliable insulating effect is ensured because local damage to the coating results in a small galvanic drain only. Damage to larger surfaces can be taken care of by installing some sacrificial anodes. This solution is not sensitive to corrosion caused by stray currents. The ICCP (Impressed Current Cathodic Protecting) system can also be used. In case the coolers are uncoated, protection of the sea chest is obtained by insulating the numerous joints between the ship and the bundle. These joins should be checked each time after reassembling because any fault results in complete failure of the protection mechanism. Sacrificial anodes will be consumed fast. Stray currents may cause pitting attack of the bundle. Corrosion occurs also when vibrations induced by uncontrolled flows of the outboard water or by mechanical sources can cause the tubes to rattle in their supports. The protective oxide layer of the tubes will be scuffed away locally and as a result pitting corrosion will cause leakage.

Generally, the box cooler system is a maintenance free for most applications. However, depending on the area of sailing and on several operational conditions biological fouling can occur. Barnacles, mussels, algae and other types of shellfish grow in the cooling system and thus adversely affect its functioning. Vessels operating in coastal water are in the greatest risk. The type of organism most responsible for biological fouling on box coolers are mussels. When some bio-fouling has settled on the box cooler the negative effect on the thermal performance is hardly noticeable. Only when the box cooler is totally covered with bio fouling causing a blockage of the flow between the tubes, the thermal performance will be influenced. Biological fouling can appear on coated, as well as un-coated box coolers. To avoid this biological fouling an anti fouling system is recommended. Among used systems the ICAF system (Impressed Current Anti-Fouling) is up to now the most effective.

The ICAF system principle of operation [7]

The ICAF functional principle is based on an artificially triggered voltage difference between the copper anodes and suitable cathodes. This causes a minor electric current to flow from these cooper anodes, so that they are dissolved in the sea water to a certain degree. The amount of dissolved cooper is proportional to used current. These CU^{+} ions create a continues toxic environment for biological growth preventing the attachment and growth of marine organisms. The environment remains toxic through the limited time only, because these CU^{+} are changing back to CU^{++}. Finally, the ICAF system does not influence the environment.

The ICAF system is reliable and effective under all circumstances and virtually maintenance free. Its structure and principle of operation was presented in figures 4–5. The anodes 3 are mounted on the angle steel profiles 9 with the help of U-clamp fixings 5 and insulation rings 4, directly under the box cooler 2 in the sea chest 1 (Fig. 4). The angle steel profiles (whose number depends on the anode length) are welded between the box cooler frames. Cathode plates 6 are made of mild flat steel strips and welded to the angle steel profiles. Each individual anode requires a cable feed through 7. The cables from the anodes 3 are connected via the cable feed through 7 to the terminals in the plug boxes 2 (Fig. 5). The plug boxes are connected to power unit DPU (Digital Processing Unit) 1 designed for controlling, monitoring and processing the ICAF system. The DPU is equipped with a transformer rectifier, anode control prints (ACP),

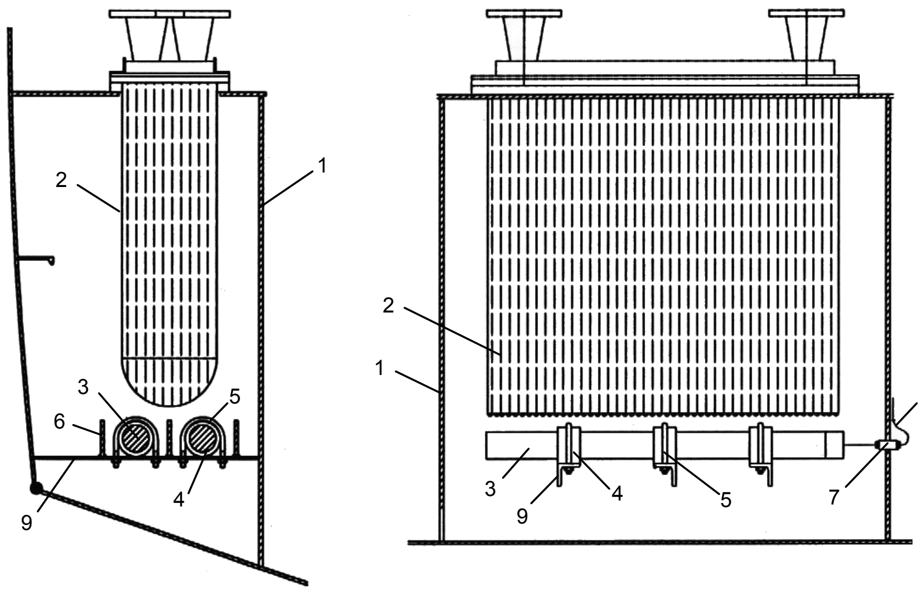

Fig. 4. The box cooler: 1 – sea chest, 2 – U-tube bundle, 3 – copper anode, 4 – insulation ring, 5 – U-clamp fixing, 6 – steel strip (cathode), 7 – cable feed through, 8 – cable to plug box, 9 – steel profile

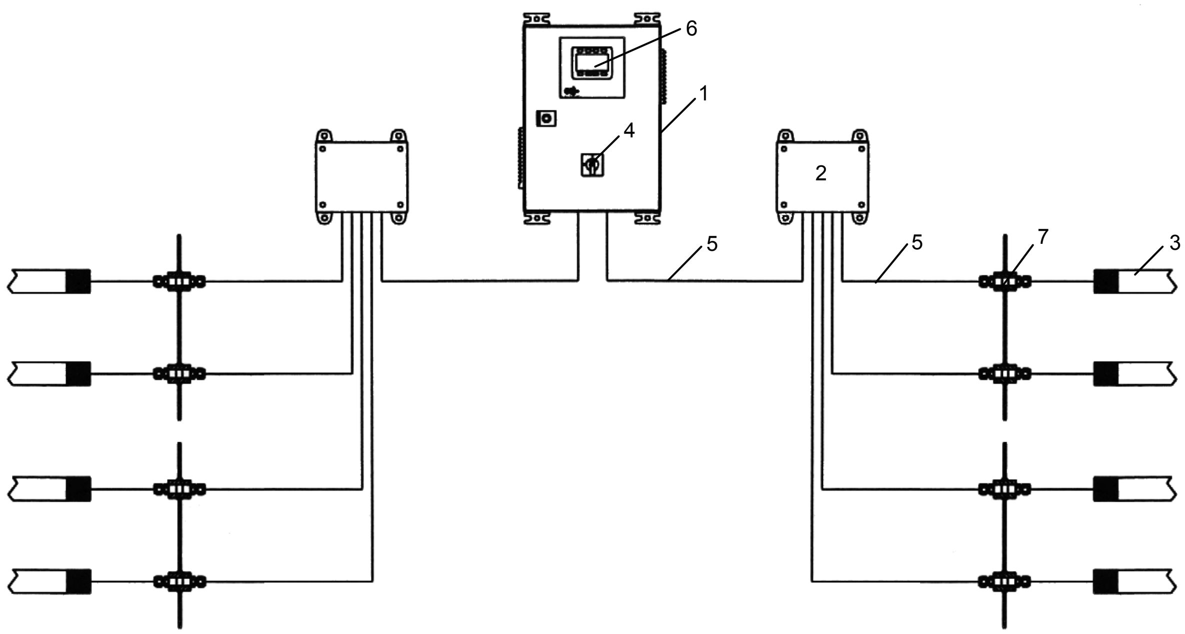

Fig. 5. Structure of the ICAF system: 1 – power unit (DPU), 2 – plug box, 3 – copper anode, 4 – main switch, 5 – cable, 6 – touch screen display, 7 – cable feed through

touch screen display, primary and secondary fuses and an on/off main switch. ACP is equipped with four constant current outputs. Each anode may be connected to one or more outputs, depending on the amount of current which is required for that specific anode. Each output can generate a maximum constant current of 1.1 A/12 VDC. The touch screen display 6, equipped with control buttons, ensures simple, fast and clear operation of the system.

In case the thermal performance of a box cooler has deteriorated due to marine growth, retrofitting an ICAF system is possible in most cases.

Conclusions

Box coolers compared with other cooling systems provide the following advantages: lower weight and price, easier maintenance, higher reliability – especially in contaminated water or under ice conditions.

Besides the above mentioned advantages, there are two problems which can occur in this kind of cooling system: corrosion and biological fouling. The box cooler producers use some solutions (coating covering, ICAF/ICCP systems) which successfully meet these problems. The largest defect of central cooling system with the box coolers is the lack of possibility to clean the box coolers during normal ship operation. They can be cleaned only during dry-docking. However, the ICAF system should ensure appropriate cleanness of the box coolers as long as the anodes are working. When the life time of the anodes has expired, they have to be replaced. So, as to do that operation, the ship must be docked. The problem is that the ICAF system must be able to ensure appropriate cleanness of the box coolers for five years, that is between the following class surveys which are always connected with dry-docking. It depends on the anodes size and velocity of their dissolving which is proportional to used current (the amount of bio-organisms in the area of sailing). On the other hand, a protection system which is based on cooper dissolution is not an environmentally friendly system, because CU^+ ions kill the bio-organisms. Another problem is the cleanness of the sea chest inlet and outlet openings (grids). If they are covered by bio-organisms the water circulation through a U-tube-bundle may be upset.

The above mentioned aspects cause that nowadays central cooling systems with a box coolers can be met at smaller ships only, although according to box coolers producers, their use is possible on ships with power output to 30000 kW. In authors opinion central cooling system with box coolers has a chance to spread out on bigger ships in the future. It will mainly depend on efficiency and reliability of box coolers secure systems. These systems ought to ensure correct operation of a cooling system between ship class dry-dockings.

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