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Computational investigations of the heating system installed on 50 SLS shuttle ferry

SUMMARY

In the paper the heating system design is presented applied to 50 SLS shuttle ferry intended for navigating in partly sheltered waters. On the basis of a simplified mathematical model dynamic characteristics of the accumulation tank provided in the system were determined.

For comparison investigations of the system based on heating oil (instead of water) were also performed. An oil-fired boiler was proposed as the alternative heat source to be used during long lying of the ferry at quay.

INTRODUCTION

50 SLS shuttle ferry was built for a Norwegian ship owner in 1999. This is a car-passenger ferry able to carry 50 cars, 7 lorries and 199 passengers in a single voyage. It is intended for making short voyages in partly sheltered waters such as e.g. fiords. The ship is equipped with two power plants. In each of them 850 kW main, medium-speed diesel engine is installed, which drives one of two azimuthal propellers placed fore and aft. In each of the power plants one electric energy generating set is provided. The ship is fitted with a very effective and economic heating system for its accommodations, which makes it possible to maintain in them 22°C temperature at the ambient temperature of -20°C.

SHIP HEATING SYSTEM APPLICABLE TO SHIPS

On the sea-going ships the energy obtained from fuel oil combusted in boilers is mainly used for heating the accommodations and heating such working media as e.g. fuel oil, lubricating oil and water. For this purpose waste energy is also utilized to different degree. Water steam and, rather rarely, special heating oils are used as heating media. Water or air is applied to a smaller extent on ships of the kind. These media, however, are broadly used on coasters and inland navigation ships equipped with diesel engines, such as shuttle ferries, tugs etc, because not very high heating temperatures are required for fuel oil to them. Also, electric energy is quite often applied for heating purposes on ships of the kind in contrast to the sea-going ships.The steam-heating systems are well known because they are commonly used on sea-going ships. This also applies, however to a smaller extent, to oil heating systems. A comparison of both systems is presented a.o.in [1,2].

There are two kinds of the water-heating systems : open and closed one.

In the water-heating system heat energy is usually transferred to the water within an oil-fired or waste-heat boiler, or an electric water-heater. The hot water is supplied to heat receivers by means of a circulation pump and piping system. (The circulation pump is not necessary if hot water is used only for heating accommodations.) In the open heating system temperature of water is to be maintained below 100°C. Therefore such systems can be applied on the ships where required heating temperatures of working media do not exceed 60÷70°C. It practically limits application of the systems only to small ships fitted with the engines combusting diesel oil. Application of an open water-heating system can be justified if the heat recovered from the supercharging air cooling water is mostly used for heating low-temperature heat receivers (below 85°C) [2].

The closed water-heating system is a pressure system, as its equalizing tank (if any) is not connected to the atmosphere, and in this way it is possible to obtain heating temperatures greater than 100°C. However it is necessary to apply rather high pressures to get the temperature of about 150°C required for heating fuel oil. Due to a.o. this reason the water-heating systems are rarely applied on the sea-going ships.

The main advantage of the water-heating systems is providing easy control of water temperature at inlet to the receiver, depending on its heat demand.

On the shuttle ferry in question an open water-heating system was applied.

DESIGN OF THE HEATING SYSTEM APPLIED ON 50 SLS SHUTTLE FERRY

On the shuttle ferry in question the open water-heating system is used equipped with an acummulation tank and circulation pump. The hot water is pumped to the radiators installed in passenger accommodations, crew cabins, wheelhouse and engine rooms. Heating of any working media is not necessary as the main engines use diesel oil only. Moreover, the sanitary water installation is fitted with an electric water-heater of 1000 l capacity and 6 kW power demand. The heat necessary for heating the water within the heating circuit, is recovered from the water cooling the main engine cylinders. The heat is tranferred with the use of plate heat exchangers. The circulating water heated in the exchangers flows into the accumulation tank of 25 m^3 capacity. The tank is well insulated and seated in such a way as not to adhere to the hull side structure, to minimize heat loss. During the ferry's normal service water temperature in the tank reaches about 75°C. The tank capacity was so selected as to obtain, after 12 hours from main engine stopping, air temperature not lower than : 20°C in crew cabins, 15°C in passenger accommodations, and 2°C in the engine rooms.

An electric water-heater of 45 kW power demand was installed for heating the circulating water during long (i.e. exceeding 12 h) lying of the ferry at shipyard's quay, or service stopovers. A blok diagram of the heating system fitted with the accumulation tank is shown in Fig.1.

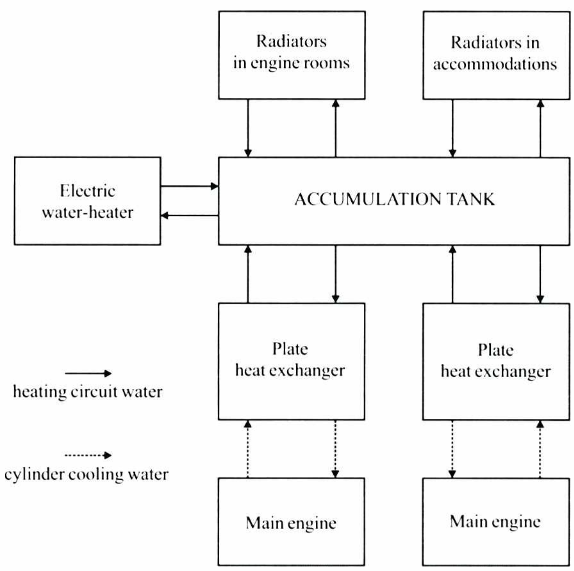

Fig.1. Block diagram of the heating system of the shuttle ferry

In the heating systems with the accumulation tank it is important to know the time of heating the water in the tank as well as the time counted from the moment of stopping the main engines up to the instant when it is still possible to supply the heat receivers installed on the ship, with the water from the accumulation tank, hot enough for keeping the assumed air temperatures.

A simple mathematical model of the accumulation tank was elaborated to assess its thermodynamic characteristics, thus making it possible to perform computational simulations.

SIMPLE DYNAMIC MODEL OF WATER-HEATING PROCESS IN THE ACCUMULATION TANK

The system under consideration consisted of the tank and plate heat exchanger. To simplify the problem a quasi-dynamic model of the exchanger was assumed without accumulation effects as time constants in the thermodynamic processes occuring in the exchanger could be neglected when compared with those in the tank. The tank can be represented as a heat exchanger model of aggregate parameters. A physical scheme of the model is shown in Fig.2.

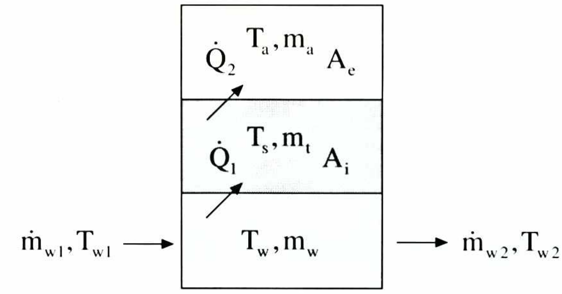

Fig.2. Physical scheme of water-heating process occurring in the tank

Notation : m_w – mass of water in the tank, m_t – tank mass, m_a – air mass surrounding the tank, T_w – temperature of water in the tank, T_s – temperature of steel shell of the tank, T_a – air temperature, T_{w1} – water temperature at inlet to the tank, T_{w2} – water temperature at outlet from the tank, $\dot{m}_{w1}$ – mass flow rate at inlet to the tank, $\dot{m}_{w2}$ – mass flow rate at outlet from the tank, $\dot{Q}_1$ – heat flow rate transmitted from water to tank shell, $\dot{Q}_2$ – heat flow rate transmitted from tank shell to surrounding air, A_i – internal surface area of tank shell, A_e – external surface area of tank shell.

The assumption of the model of aggregate parameters is equivalent to that of ideal mixing of water and reaching the same temperature in any point of the water space. Also, the same temperature was assumed to occur in any point of the steel shell of the tank as well as in any point of the air surrounding the tank. It was also assumed that the surface film conductance from water to steel, α_1, and that from steel to air, α_2 , was constant. On assumption that water is an incompressible medium it yields from mass balance that mass accumulation does not occur in the modelled process, hence : $\dot{m}_{w2} = \dot{m}_{w1}$.

In the analyzed process thermal energy is accumulated in mass of water, steel shell of the tank and air surrounding the tank as well. The accumulated energy makes internal energy (of water, steel and air, respectively) increasing. From energy balance equations for each of the media the following expressions were obtained :

for water :

$$\frac{dT_w}{dt} = \frac{1}{m_w c_w}\left[\dot{m}_{w1} c_w (T_{w1} - T_{w2}) - \dot{Q}_1\right] \tag{1}$$

for steel :

$$\frac{dT_s}{dt} = \frac{1}{m_t c_s}\left[\dot{Q}_1 - \dot{Q}_2\right] \tag{2}$$

for air :

$$\frac{dT_a}{dt} = \frac{\dot{Q}_2}{m_a c_a} \tag{3}$$

where:

c_w, c_s, c_a - specific heat capacity of water, steel and air, respectively

t - time

Temperatures of the particular media are measures of their internal energy.

The heat exchange equation between water and tank steel walls (4), together with that between the walls and surrounding air (5) is complementary to the above given equations :

$$\dot{Q}_1 = \alpha_1 A_i (T_w - T_s) \tag{4}$$

$$\dot{Q}_2 = \alpha_2 A_e (T_s - T_a) \tag{5}$$

Integration of these differential equations in order to determine new values of the accumulative variables at the next instant of time is performed by means of the Euler's method – based procedure provided in CADES software [3].

SCOPE AND RESULTS OF THE ACCUMULATION TANK INVESTIGATIONS

The computational investigations were carried out for two working media : water and heating oil as in the heating system in question it was also possible to apply oil instead of water. The alternative application of the heating oil instead of water on the considered ferry can be justified by the kind of water region in which it navigates. Low ambient temperatures, during a longer stopover of the ferry at coincidence of unserviceability of its electric water heater, could cause water to freeze inside the system, and in result its failure.

Therefore the heating and cooling processes of the water as well as oil contained in the tank were examined.

In the case of heating the initial temperature of 20°C of a medium filling the tank was assumed for calculations. It was also assumed that during the heating process the circulation pumps of the heating system do not operate. Hence, if minor energy loss to the tank surrounding is neglected, the entire energy received from the engine cylinder cooling water is accumulated in the mass of a heating medium (either water or oil) and of the tank structure itself. For calculations the cylinder cooling water temperature of 90°C was assumed.

Results of the calculations are presented in Fig.3.

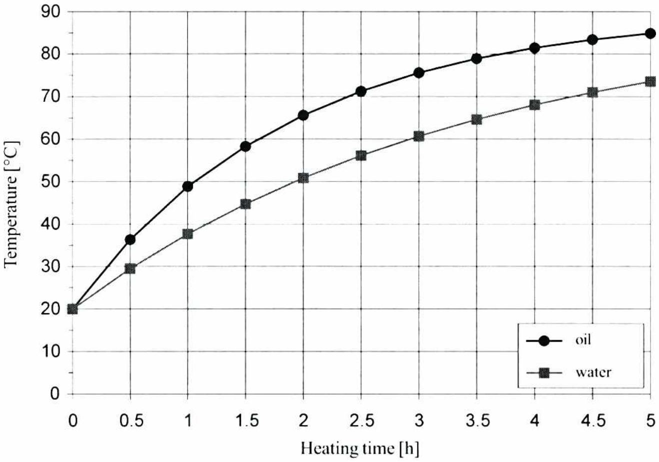

Fig.3. Increasing temperature of water and oil in the tank versus time of heating

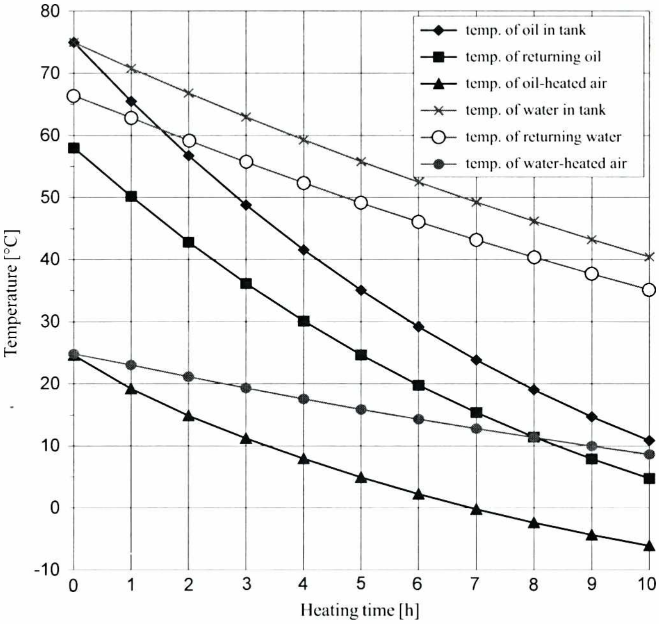

Fig.4. Courses of the temperature drop with time after stopping the main engines : of the water and oil contained in the tank, the water and oil returning to the tank from the heating system, and of the air in the accommodations

From Fig.3. it can be concluded that the water in the tank attained the temperature of about 75°C after 5 hours of heating, and the oil – already after about 3 h. The shorter heating time period of the oil results from its two times smaller specific heat than that of water.

Moreover it was investigated how much the temperature of water or oil in the tank would drop after 10 h from the main engine stopping and with the heating system still operating. The ambient temperature of -20°C was assumed (during normal service of the ship in these conditions the heating system demands 120 kW power input). Results of this phase of calculations are presented in Fig.4. Additionally, courses of the temperature drop with time of the water and oil flowing back into the tank from the heating system, as well as of the air in the accommodations, are also shown. In order to simplify the considerations all radiators were substituted by one collective heat exchanger of 120 kW power output.

It results from Fig.4. that the cooling process of the heating oil, and thereby dropping the average air temperature in the ship accommodations, proceeds much faster than in the case of water used as a heating medium. This is also because of the smaller specific heat of oil than that of water.

PROPOSED MODIFICATIONS OF THE APPLIED HEATING SYSTEM

Heating oil instead of water

Substitution of water, the applied heating medium in the system in question, by heating oil can be justified in the case if it is important to fast achieve full serviceability of the system, in other words – to obtain a short time of reaching, by the heating medium, its required temperature, of 75°C in this case. In result however, after stopping the main engines cooling of the ship accommodations will occur faster. On the other hand the system would be protected against influence of low temperature in the case of a failure of the electric heater, or voltage decay in the electric network.

Oil-fired boiler instead of electric heater

Another worth-mentioning proposal could be substitution of the electric heater provided to operate during long stopovers of the ferry, by a highly efficient oil-fired boiler for heating water, based on the condensation technique. A 43 kW boiler of a worldwide recognized producer was taken into consideration. The boiler is characterized by relatively small gabarites (1044 x 877 x 600 mm) and mass (327 kg) in comparison with those of the currently applied, PE 45 electric water heater (of 355 mm diameter, 1527 mm length and 190 kg mass). Therefore it can be stated that the proposed substitution would not lead to a significant increase of space demanded in the engine room.

An additional advantage would be the fact that, due to fitting the boiler with a special oil burner with hot gas recirculation, the fuel oil could be entirely combusted without any soot and at very small emission of toxic compounds such as NOx and CO.

However the main advantage of the proposal is possible lowering of operational cost. Cost of 1 kWh of the energy produced by the boiler, if firing a light fuel oil of 42,600 kJ/kg net calorific value is assumed, is by 25% lower than purchase cost of 1 kWh of electric energy in a port (based on the prices valid in Poland in July 2000). If an additional fee for switching – on the electric power of the energy consumer (45 kW in this case) is taken into account, it turns out that the amount of fuel oil purchased for the money will be sufficient for production of about 990 kWh of heat energy in the boiler. Hence the amount of fuel oil would be sufficent for heating the ferry during its almost 22 h stopover.

Moreover at price terms offered by other electric energy suppliers, unit cost of the energy obtained from combusting the fuel oil could be even two times lower than that of the electric energy purchased in a port.

CONCLUSIONS

- The presented results of the computational investigations of the accumulation tank and heat exchanger by means of their simplified mathematical model, confirm that the size of the tank was appropriately selected at the assumed conditions of the heating system in question.
- The selected solution of the heating system with the accumulation tank can be deemed very effective from the point of view of the economic profits resulting from the waste heat utilization as purchasing electric energy during long stopovers of the ferry in ports would be very costly. (However it should be noted that the economic analyses were based on the current prices of fuel oil and electric energy valid in Poland, therefore their results based on other prices valid e.g. in Norway may be different).
- Substitution of heating water by oil in the system in question would bring rather minor advantages.
- Additional economic advantages however could be obtained due to substitution of the electric water heater used during long stopovers of the ferry, by an oil-fired boiler based on condensation technique.
- Rather large mass and gabarites of the accumulation tank reducing free space and load-carrying capacity of the ship, could be considered as adverse factors in some design situations.

Appraised by Alfred Brandowski, Prof.,D.Sc.,M.E.

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2. Michalski R., Zeńczak W. : *Effectiveness assessment of the ship heating systems* (in Polish). Marine Technology 2000 Conference. Szczecin, May 2000
3. Michalski R., Zeńczak W. : *The computer aided design of ship power plants using the CADES program package*. International Maritime Technology Transactions, The Institute of Marine Engineers, Vol. 111, Part 2, 1999

FOREIGN conferences

MS 2000

In September 2000 at Las Palmas de Gran Canaria II International Conference on Modelling and Simulation was held in which three representatives of Gdynia Maritime Academy took part. They presented the following three papers :

- ⇨ *Computer simulation and experimental study of free-fall lifeboat launching behaviour* - by Zbigniew Wiśniewski
- ⇨ *Ship autopilot design in the presence of modelling errors* - by Leszek Morawski
- ⇨ *Nonlinear control of a directionally unstable ship* - by Leszek Morawski and Janusz Pomirski (with Houria Siguerdidjane, France, as its co-author)

SORTA 2000

On 23÷25 November 2000 in Rijeka XIV International Conference was held on: „Theory and Practice of Shipbuilding" to commemorate Prof. Leopold Sorta. Polish shipbuilding circles were represented by Assoc. Prof. Zygmunt Paszota from Faculty of Ocean Engineering and Ship Technology,Technical University of Gdańsk, who presented the paper titled *Hydrostatic drive of ship deck machines with the variable capacity pump and drive with the adaptive secondary control – comparison of the energy behaviour* during the session on „Marine and Electrical Engineering".

Conference

SymSo 2000
XXI Sympozjum Siłowni Okrętowych

Faculty of Ocean Engineering and Ship Technology, Technical University of Gdańsk, and in particular its Department of Ship Power Plants organized

XXI Symposium on Ship Power Plants

which took place on 16 and 17 November 2000.

The Symposium was aimed at creating a forum for exchange of technical and scientific information and experience as well as economical information in the area of design, manufacturing and exploitation of ship power plants, and enforcing the science – practice interaction in that respect.

Therefore representatives of technical universities, institutions and industrial enterprises connected with shipbuilding industry and maritime economy took part in the Symposium.

Symposium's program realized during 7 sessions, contained 33 papers prepared by scientific workers from Technical University of Gdańsk (8 papers), Gdynia Maritime Academy (7 papers) as well as Polish Naval Academy in Gdynia, Maritime University of Szczecin and Technical University of Szczecin (6 papers each).

The papers dealt with the following topics :

- Development of ship power plant devices
- Design and construction of ship propulsion-power systems
- Assessment of technical and energy state of ship power plants
- Diagnostics of technical and loading state of ship engine
- Operational characteristics of ship power plant devices and influence of external conditions on their operation
- Overall serviceability of ship power plants and their devices
- Didactics in the area of ship power plants
- Research stands for ship power plant systems and devices
- Simulators of ship power plant in operation
- Exploitation of dredge pumps on dredgers
- Cooling media for ships
- Lubricating oil as a construction element
- Marine environment pollution from ship power plants
- Operational safety of ship power plants
- Scientific research methods
- Aplications of expert systems

The Symposium was perfectly organized.
Also, representatives of the following firms :

Alfa Laval
Enertek-Caterpillar
MAN&BW Diesel A/S
Unitest
Wärtsilä NSD

took part in it presenting their production programs and recent technical solutions of their products.

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