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Operating conditions of a waste heat boiler – partially loaded marine diesel engine system under the real tropical ambient condition

Wpływ tropikalnych warunków otoczenia na współpracę kotła utylizacyjnego z silnikiem okrętowym obciążonym częściowo

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Key words: charging air, parameters of exhaust gases, steam production

Abstract

Due to the economical crisis many ship owners introduced new ways of improving the economic efficiency of a ship. This has exerted an influence on main engine operating conditions due to the reduction in fuel consumption. The loading range of engines during sea passages has significantly changed. It has also changed operating conditions of the waste-heat boiler which is connected with ships prime mover. The following paper deals with operating conditions of the waste heat boiler powered by exhausts of the marine slow-speed long-stroke diesel engine of the ship which was operated under the "Super Slow Steaming" program in the tropical area.

Słowa kluczowe: powietrze doładowujące, parametry spalin, produkcja pary

Abstrakt

Ze względu na kryzys gospodarczy wielu armatorów wprowadziło nowe sposoby na poprawę efektywności ekonomicznej statku. Miało to wpływ na warunki pracy silnika głównego ze względu na zmniejszenie zużycia paliwa. Skala obciążenia silników podczas drogi morskiej zmieniła się znacząco. Zmianie uległy również warunki pracy kotła utylizacyjnego, który powiązany jest z napędem statków. Niniejszy artykuł opisuje warunki pracy kotła utylizacyjnego zasilanego statkowym silnikiem wolnoobrotowym o dużym skoku tłoka, który na obszarze wód tropikalnych brał udział w programie „Super Slow Steaming".

Introduction

Economic reforms introduced by many ship owners were basically focused on the reduction of fuel consumption of operated ships, which entails necessity for long term operation of marine diesel engines under significantly lower load than was calculated during the ship designing process. This resulted in developing of the new systems of operating of marine prime movers. The first introduced system was so called "Slow Steaming" where reduction of fuel consumption required limitation of long term engine load to less than 60% of its rated power. Development of this idea lead to defining new conditions for marine engines operational conditions called 'Super Slow Steaming', where the reduced sailing speed caused decrease in engine load to 30% of its rated power. Delayed delivery time of the shipped cargo was accepted by the market and recipients. For safe ship navigation and engine plant operation, there have been several requirements [1] implemented which need to be met in order to limit the unfavorable working conditions for the engine. Manufacturers of marine engines have also developed systems of engine conversion by applying additional equipment components [1]. However, these systems are hardly ever installed on vessels already in service because of the extra costs of the equipment and its installation.

In different regions of the world the marine diesel engines are exposed to and affected by various ambient conditions. Therefore, they must be designed to keep their nominal operating parameters under both arctic and tropical areas of the world. Despite the presently produced engines are universal, the changes of the environmental parameters like sea water temperature and ambient air temperature, pressure and humidity will strongly affect the range of the temperature and pressure of charging air, range of the maximum compression and combustion pressure In consequence of above the amount of the consumed fuel depends on these parameters as the most important parameters of the medium powering the exhaust gas boiler, which are amount and temperature of the exhaust gases produced by engine.

Exhaust gas boilers were designed to recover the waste heat energy mainly from exhaust gases of diesel engines consequently increasing overall efficiency of the ship's power plant. The level of the recovered heat depends on technical state of the boiler and parameters of its powering medias. At the ship's designing stage, exhaust gas boilers are being selected to achive the maximum production of steam under nominal operation conditions of the diesel engines defined in the norm ISO (*International Standards Organisation*) 3046/1.

Steam capacity of the exhaust gas boiler

Steam capacity of the exhaust gas boiler depends on many factors, for which symbolic representation is presented in figure 1.

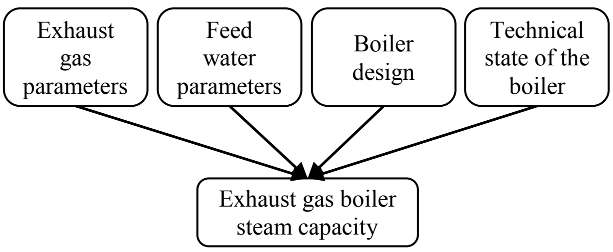

Fig. 1. The exhaust gas boiler steam capacity
Rys. 1. Wydajność spalin kotła gazowego

The basic factor determining the parameters of exhaust gases powering waste heat boiler is the level of load of diesel engine. Along with exhaust gases temperature and amount drop, the steam capacity of the exhaust gas boiler drops [2].

It may be assumed, that except due to unmodified construction of the boiler, the feed water is characterized by constant parameters during ship's operation. Above situation may be changed only in case of incorrect operation of the condensate system. The most common abnormality having an influence on steam capacity of the boiler is to low temperature of the feed water. However, the new auxiliary systems which were designed for automatic control and adjustment of the feed water temperature become very helpful in this mater. In the last few years, such equipment has become quite standard being attached to the hot wells (*tanks collecting condensate and water refilling the steam system*). Additional advantage of these systems is the possibility to keep high and stable temperature of the boiler feed water which reduces amount of the diluted oxygen. This significantly helps to reduce corrosion of water pipes and elements of the boiler keeping high level of the technical state of the water side of the boiler

During standard operation of the exhaust gas boiler, based on manufacturer's recommendations, technical state of smoke side remains unchanged. The most important routine maintenance, having the greatest influence on this state, is the regular removal of the soot deposits which build up on the heating elements and periodical cleaning. Such a cleaning process is naturally accelerated during operation of the ship with its nominal speed as a result of the high velocity of exhausts flowing through boiler causing 'sweeping out' of particulars which were stuck to the heating elements. Operation of the low loaded diesel engine results in significant drop in the velocity of the exhaust gases flowing through exhaust gas boiler which reduces the 'self cleaning' effect [3]. Extending such a situation leads to continuous, higher accumulation of soot inside the boiler. As a result, the heat exchange phenomenon is reduced causing a drop in the boiler's steam capacity. With constant steam consumption, which depends on the engine room design, the steam pressure in the main supply line will continuously decrease.

Bearing in mind the above presented facts resulting from norms of operation for ships power plants, it may be assumed that exhaust gas boiler's steam capacity mainly depends on its technical state (*controlled amount of build ups covering the heat exchange surfaces*), as well as the parameters of exhaust gases (*temperature and mass flow*) powering the boiler. Consequently, the main affect on these parameters have the real ambient and operating conditions of the ship.

The pressure of steam produced by exhaust gas boiler has been recorded on a container ship operating during summer period on the area in the Mexican Gulf under the 'Super Slow Steaming' conditions. Prior to recordings, smoke side of the boiler was mechanically cleaned by the crew and frequency of soot blowing has been increased. During a week long sea passage steam pressure was kept constant and stable. All heat consumers (*heaters, heating coils*) have been working without any restrictions.

Parameters of the exhaust gases powering the waste heat boiler

It may be assumed, that basic parameters of the exhaust gases (*temperature, mass flow*) became constant and unchanged in some ranges whilst load of the marine diesel engine remains stable. Along with engine load drop with reference to the nominal value, the amount of produced exhaust gases drops as well, however temperature maintains an increasing tendency in some ranges of the engine load. The temperature of the exhaust gases powering waste heat boiler was recorded on a ship equipped with high power low speed marine diesel engine operated under 'Super Slow Steaming' and 'Slow Steaming' conditions (Fig. 2). The engine, by no means, was prepared for long lasting work at very low load.

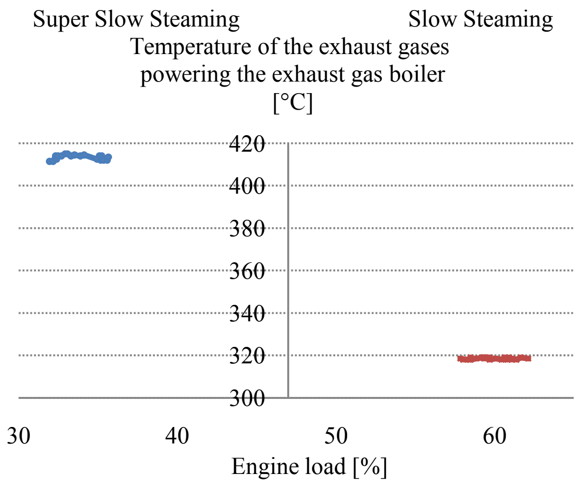

Fig. 2. Temperature of the exhaust gases powering the exhaust gas boiler
Rys. 2. Temperatura spalin zasilająca spalinowy kocioł gazowy

For the invariable loaded diesel engine the level of the exhaust gases temperature powering the waste heat boiler depends on a large degree to parameters of ambient air, are depends on area of operation of the ship. Standard ambient and operating conditions for marine diesel engines were defined, but to standardize ship's power plant designing process maximum values were determined as follows:

– temperature of the ambient air $t_{PO} = 45°C$,
– relative humidity of the ambient air $\phi_{PO} = 60\%$,
– temperature of the charging air's cooling water $t_{WC} = 32°C$.

Such conditions are typical for subtropical and tropical areas. These were defined on the same level in norms issued by ISO and IACS (*International Association of Classifications Societies*). However, engine manufacturers are not obliged to carry out shop tests of the newly built engines under such a conditions.

Parameters turbochargers feed air

The layout of ducts transferring air from outside of the ship to engine turbochargers exerts an influence on parameters of an air in the charging air receiver. Nowadays, mainly there are two different transfer systems of air: direct blowing on turbochargers suction by separately run ducts and blowing to the engine room only (*central systems*) [4]. Measurements taken on ships pointed out that temperature of the various areas of engine room depends on the system of the air supply and what follows, temperature of the air being delivered to turbocharger suction depends on it as well.

In case of direct blowing system, this temperature and ambient air temperature are usually equal. Insignificant increase of 1÷2°C of this parameter may be noticed in extremely hot engine rooms. Although very high mass flow of air through the ducts, it can heat up to some degree.

However, in case of central ventilation system of engine room, the air reaching suction side of turbochargers has higher temperature in comparison with direct blowing system. First of all, it results from considerably increased warming up of the air by heat emitting equipment installed in engine room, which mainly are:

– diesel engines,
– electrical motors,
– oil fired and waste heat boilers,
– exhaust gases manifolds and ducts,
– cooling water pipes,
– lubricating / cooling oil pipes.

On the area of the Mexican Gulf, during the summer time (*tropical ambient conditions*), there were recordings taken of temperature in engine room equipped with main engine type 7RTA84 ($N_N = 28\ 300$ kW), four auxiliary engines type STX-9L28/32H ($4 \times N_N = 1800$ kW), combined oil fired – waste heat boiler type PARAT ($D_P = 3750$ kg/h) and hybrid (*direct / central*) air blowing system. The symbolic sketch of the air ducts presented on figure 3. The whole engine room was supplied with air from the central system using short branches, but the main engine turbochargers were feed from separated ducts supplying the air straight from the fan room. During carried out recordings the ambient temperature was $t_{OT} = 36°C$. Recorded temperatures for the separated compartments of engine room were as follows:

- suction filters of the main engine turbochargers $t_{OT-1} = 36°C$,
- auxiliary engines room $t_{OT-2} = 41°C$,
- lubricating oil separators and fuel separators room $t_{OT-3} = 44°C$,
- high temperature cooling water pumps and boiler feed water pumps room $t_{OT-4} = 43°C$,
- auxiliary blowers and low temperature cooling water pumps room $t_{OT-5} = 41°C$,
- exhaust gas boiler room $t_{OT-6} = 41°C$.

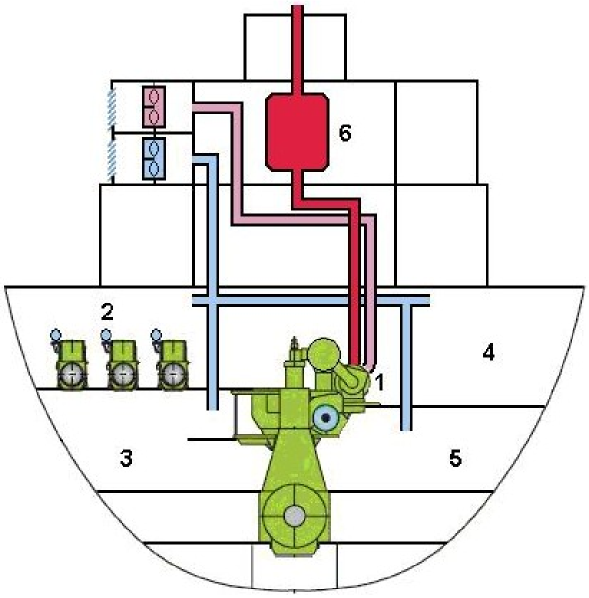

Fig. 3. Engine room air supply system
Rys. 3. System wentylacji siłowni

Along with changes in ambient conditions, the humidity of the air supplied by fans to the engine room is changing. Changes in the amount of water passing through turbochargers depend on this parameter. Water delivered to the engine combustion chambers reduces maximum temperatures and pressures in cylinders which leads to lower temperatures of exhaust gases. Under the real tropical ambient conditions the high limit of the air humidity defined by ISO and IACS is very often exceeded. Recordings taken during summer time on the area of Brazilian coast and Mexican Gulf pointed out that humidity of the air has never dropped below 80%. Additionally during quite frequent tropical storms in this area of the world it exceeds 90%.

Unlikely to the temperature of the air reaching suction side of the turbochargers, the amount of water transported along with the air is quite stabile. However, the design and location of the fan room has significant influence on this parameter. To avoid suction side of ventilators from being reached by either sea breezes or rain fan rooms are usually situated in higher, recessed level of the ships superstructure. However, such lengthening of air ducts from the delivery side of ventilators to the engine leads to additional intensification of heating up and increases air temperature with reference to ambient temperature. Picture taken inside the fan room unsuitably protected from the sea breezes is presented on figure 4.

Fig. 4. Fan room
Rys. 4. Pomieszczenie wentylatora

The charge air cooling

The principle for operation of the diesel engine charging systems requires cooling of the charge air. The great influence on the parameters of the air delivered from the air coolers to the receiver of the engine comes from following factors:

- load of the engine,
- ships operation area,
- charge air cooling system,
- technical state of the charge air coolers,
- technical state of the water mist catchers.

Low level of the engine load causes significant decrease in the produced exhaust gases powering turbochargers which in consequence leads to charge air pressure drop. To ensure a sufficient amount of oxygen delivered to the combustion chambers of the engine operated under such conditions, they are equipped with additional auxiliary blowers. As it was presented on figure 3, on the examined ship such blowers were installed on the level bellow turbochargers – area of higher temperature.

Presented design is applied on many ships as much cheaper compared with systems of forced air flow through all charging system. As a result a significant rise of the exhaust gas temperature can be recorded, which was shown on figure 2.

It is possible to reach low temperatures of air being delivered to the engine receiver by installing in engine room direct cooling system of charge air. This occurs as a result of using only sea water as a cooling medium without additionally installed heat exchangers and fresh water system. However, this is the only advantage of this kind of cooling. Direct cooling by sea water leads to significant increase of corrosion and continuous accumulation of particulars and small sea water life forms in the whole cooling system and all associated equipment. Therefore, nowadays this kind of cooling has almost been phased out of production and can be found on the cheapest ships only. Advanced indirect (*central*) cooling systems are more expensive in the design stage, but in the long term of ship operation proved their higher reliability and are free of listed disadvantages. As an indirect cooling medium fresh water is being used. Based on research by the marine engines manufacturers it may be said that extension of cooling systems (*additional heat exchangers, pipelines, armature*) will also lead to increase of the charge air temperature. Under tropical ambient conditions and the sea water temperature $t_{WS} = 32°C$ the minimum obtainable temperature of charge air is in range $t_{PD} = 42÷44°C$.

The technical state of coolers of the charge air has an essential influence on its parameters as well. Even a thin layer of deposits accumulated on both air and water side reduces the cooling effect and increases temperature in the charge air receiver. Additional equipment which is not an element of the cooling system, but may have great influence, especially on the amount of water getting inside the engine is the water mist catcher, which is installed between air cooler and receiver. In case of failure or excessive accumulation of builds up on its surface, water condensed during air cooling process will pass inside combustion chambers of the engine decreasing temperature of produced exhaust gases.

Conclusions

Marine diesel engines under diverse operating conditions are exposed to and influenced by changing ambient conditions as well. Some designs of engine room in conjunction with parameters of ambient conditions prove their influence on parameters of the exhaust gases produced by diesel engine and consequently on the waste heat boiler being connected with ship's prime mover via the exhaust gas manifold.

Significant is the difference in temperature of separated compartments of engine room on a ship with hybrid (*direct / central*) air supply system which, if engine is operated with very low load leads to increase of temperature of the exhaust gases powering waste heat boiler.

During carried out recordings on board of the ship operating under tropical ambient conditions it was not necessary either to start the oil fired boiler up, or to reduce steam supply to receivers despite very low ships speed and low load of main engine. Steam production of the waste heat boiler due to considerably high temperature was being kept at a stable level allowing the continued unrestricted operation of the engine room equipment.

The long lasting operation of low loaded marine engine significantly reduces phenomenon of so called self cleaning, which accelerates soot building up on the smoke side of the boiler. In conjunction with very high temperature of the exhaust gases it increases a real danger of ignition of the flammable particulars inside the boiler [3]. In the worst case such accident may lead to complete failure of the exhaust gas boiler making the ship non operational and put out of service.

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