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NEW WORKING CONDITIONS OF A MARINE DIESEL ENGINE-WASTE-HEAT BOILER SYSTEM

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Abstract

In the paper, there have been described typical working conditions for a waste-heat boiler fed by exhaust gases of a high power slow speed marine diesel engine. New ways of correcting economic calculation of a ship operation depending on „unloading" engines of newly constructed units' main propulsion system, as well as, the attempts of adapting the methods in question to already operated vessels have been dealt with. Moreover, the trends in changes of selected work parameters of the diesel engine waste-heat boiler system based on real operational conditions of a ship propelled by unloaded engine have been characterized. Dangers and possible discomforts affecting the waste-heat boiler working in „Super Slow Steaming" system have been emphasized.

Key words*: unloaded engine, real operational conditions of a ship, steam deficiency*

1. Typical working conditions for a marine engine- waste-heat boiler system

Waste-heat boilers are installed on vessels as elements of waste gas energy recovery. A usual period of time for full use of potentials of a marine engine - waste-heat boiler system waste gas energy recovery appears a "sea journey". It is the time of vessel operation when the engine load is maintained on almost constant level. Such a long lasting engine load during a voyage ranges between 85÷95 % of its rated load. The level of the engine load results from the construction basics determined while designing elements and parameters of an engine working process. Within the load range, the engine produces exhaust gases of such parameters (*the amount and temperature*), that a sufficient amount of heating energy for safe and effective ship operation is provided. Any changes of the engine working parameters caused by exhaust gas changes shall affect waste-heat boiler working parameters.

Possible changes of the engine load at a set sailing speed may be the result of the following:

- sea rolling;
- change of wind direction;

- altering a ship's course.

However, the above mentioned phenomena cause negligible oscillations or engine load changes without any significant influence on average parameters of exhaust gases. This is typical for currently mostly used two stroke slow speed long stroke marine engines, which has been recorded for three various settings of the load level of the 8RTA96C type of engine manufactured by WARTSILA (*Fig.1*).

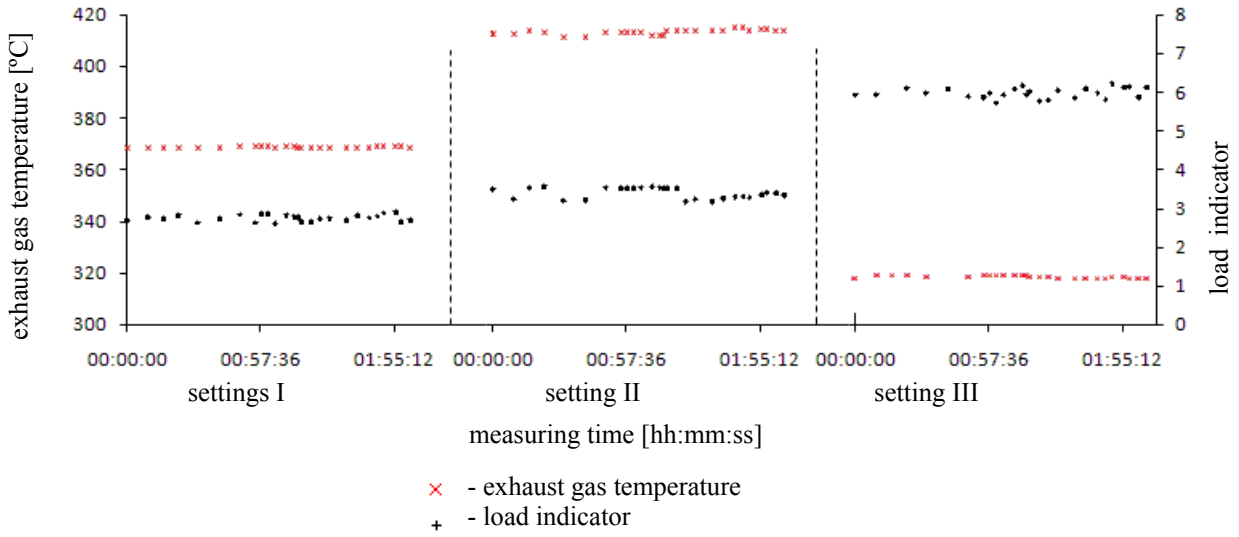

Fig. 1. Changes in exhaust gas temperature resulting from engine load fluctuations

2. On unloading the engines

In real operational conditions of a ship the basic parameter determining the engine load level is the sailing speed. To reach the engine maximal efficiency at an assumed sailing speed, which, at the same time, means the smallest fuel dose for producing a power unit, while the designing process the engine component parameters get adjusted in such a way that they immediately affect it (*injection pump setting, cam setting, adjustment of turbochargers*).

The worldwide economic crisis, which has contributed to economy slump, has also affected the organization of the transport fleet. Due to decreasing number of shipping orders, a number of ship owners had to make use of drastic solutions like reduction of the number of operating vessels and the operated ports. Since the main expenditure of an operated vessel is the cost of fuel, sailing speed limits turn out a frequent way of cutting the costs used by ship owner. Thus, a new period in the schedule of a ship operation: „a reduced speed sea journey" appears. This is connected with the engine loaded with significantly lower than the assumed power, at its designing stage, for a long period of time. So far, this type of engine operation has been regarded as temporary. Marine engine manufacturers have conducted analyses of the possibilities of loading engines with lower than previously assumed powers at the designing stage. The first solution was so called „Slow Steaming" with the reduced sailing speed causing the long lasting engine load decreased to less than 60 % of its rated power. To provide safe navigation and power plant operation, there have been worked out several requirements [1] to be met in order to limit the engine unfavorable working conditions.

The basic requirements are:

- the regime of maintaining fuel parameters (*viscosity, temperature*) within the range defined by the manufacturer (*in regard of the fuel type*);
- the regime of maintaining water temperatures of low and high temperature engine cooling system;
- strict control of the injection valve operation aiming at detection of any malfunctioning leading to shortened periods between the scheduled overhauls;
- frequent checks of easily polluted components (*charge air receiver, charge air non-return valves, under piston spaces, exhaust manifold, waste-heat boiler*).

Engine manufacturers have developed systems of engine conversion by applying additional equipment components [1]. The systems allow for engine steady operation at their low load without the need of supporting charge air system by auxiliary blowers. Another advantage of their application is the reduced pollution of the charge air system and the exhaust gas outlet at the reduced specific fuel consumption. Because of extra costs of the equipment and its installation, the systems are hardly ever installed on vessels already in service.

The idea was developed by defining vessel's new operational conditions called „Super Slow Steaming", where the reduced sailing speed resulted in the decrease of engine potential power to 30 % of its rated power, providing the recipients accepted the prolonged delivery time of the shipped cargo.

3. Changes in selected parameters of a marine engine - waste-heat boiler system

At winter time, (*ambient temperature* t_O*=2 ºC*), in real ambient conditions of a ship operation, a direct recording of selected working parameters (*Fig.2*) of a marine engine - waste-heat boiler system when reducing the engine load to less than 30 %, corresponding to „Super Slow Steaming" working conditions, was carried out. The measurements were taken on a ship equipped with the AQ2 smoke tube boiler of 482 m^2 heat exchange space, manufactured by AALBORG, fed by exhaust gases of a slow speed, long stroke 8RTA96C type of engine, manufactured by WARTSILA.

The engine, by no means, was prepared to long lasting work at very low load. In the presented diagram three characteristic areas can be outlined:

- I area-within 60 % range of the engine rated load with the engine prepared for steady economic work during standard sea journeys;
- II area-temporary period of decreasing engine load, which typically appears while ship maneuvering at a reduced speed (*mooring, anchoring, drifting*);
- III area-engine working at along lasting load below 30 %.

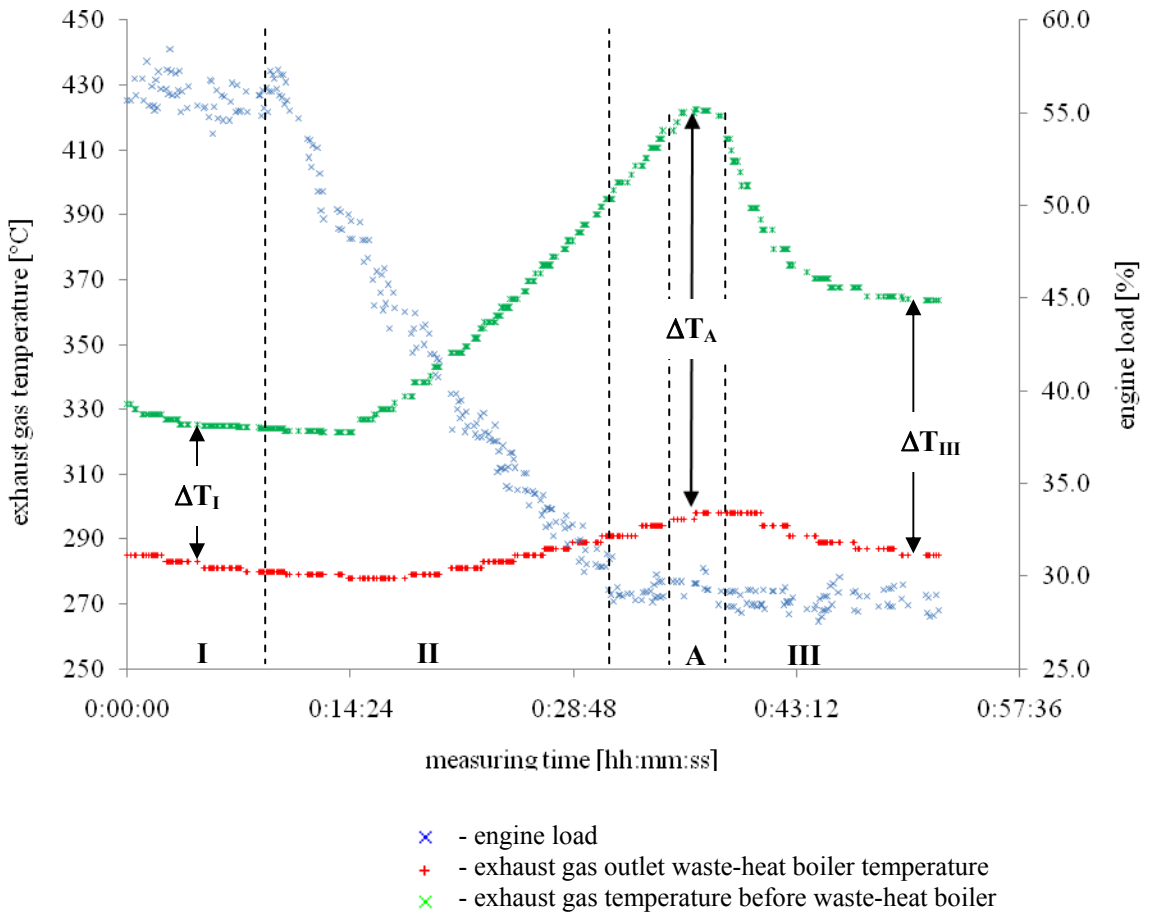

Fig. 2. Changes in the selected parameters of the Main Engine – waste-heat boiler system

The **III** area presented in the diagram corresponds with the engine working conditions according to „Super Slow Steaming". In the area it is essential that, after the time of stabilizing, the exhaust gas outlet temperature of the waste-heat boiler is maintained on the exhaust gas temperature level adequate to the engine load in the **I** area, in spite of the increase (*30 ºC*) of the inlet exhaust gas temperature. Using simplified methods of determining the amount of outlet exhaust gases produced by the marine engine [2,3], it has been stated that within the engine load range their amount drops to the level of 31 % of production in the rated load conditions. Such changes in exhaust gas parameters do not turn out indifferent to the amount of steam production, which can be determined from the dependence (1). Limiting the amount of the produced steam may lead to disturbances of power plant heating systems. Especially, nowadays when residual high viscosity fuels (*500÷700 cSt at 50 ºC*), which demand higher transport temperatures between the tanks (*minimum 50 ºC*), and the injection temperature into the engine cylinders (*minimum 145÷150 ºC*).

$$\dot{m}_p = \eta \frac{\dot{m}_S \, c_S \, (t_s - t_z)}{x \, i'' + (1 - x) i' - i_{WZ}} \left[\frac{kg}{h}\right], \qquad (1)$$

where:

$\dot{m}_p$ [kg/h] – the mass flow of the produced steam of x specific humidity,
η – efficiency of the waste-heat boiler (*as a heat exchanger)*,
x – waste-heat boiler outlet steam humidity,
i'' [kJ/kg] – specific enthalpy of saturated dry steam at the steam pressure inside the boiler,
i' [kJ/kg] – specific enthalpy of boiling water inside the boiler,
i_{wz} [kJ/kg] – specific enthalpy of the boiler feed water,
$\dot{m}_S$ [kg/h] – the mass flow of the exhaust gases feeding the waste-heat boiler,
c_S [kJ/kgK] – specific heat of exhaust gases within $t_1 \div t_2$ temperature range,
t_1 [K] – waste-heat boiler exhaust gas inlet temperature,
t_2 [K] – waste-heat boiler exhaust gas outlet temperature.

It is worth focusing on a special area A, where the waste-heat boiler exhaust gas inlet temperature reaches its maximum, that is, a level higher by 100 ºC than the temperature corresponding to the engine economic load. For a vessel operating in tropical conditions the further increase of the parameter [4] needs to be expected. At so high temperatures of exhaust gases flowing through the components of the exhaust system the true danger of high temperature corrosion of the boiler construction elements increases [5]. The noticed increase in the engine exhaust gas temperature is mainly due to insufficient amount of air supplied for the combustion process in its working spaces. One of the real solutions improving the situation can be switching on Main Engine auxiliary blowers, which, however, even on ships designed and constructed in the recent years have not been prepared to continuous working. Especially in the switch area there may appear overloads of the engines driving the auxiliary blowers, as well as, the damages of components of electric circuits controlling their work. That is why that period while the engine operation should be possibly shortened.

4. Summary

For the sake of cutting the costs of vessel operation, many ship owners have decided to reduce sailing speed of their newly constructed and already in service units. Significant power decrease of the main engine, unprepared for such operational conditions, appears to have impact on the work of the waste-heat boiler. The reduced amount of exhaust gases feeding the boiler in true ship operational conditions may lead to steam deficiency. As a result of that, the work of heating systems as well as the electric power generation may be disturbed. This may be even worsened in case of ships operating in low ambient temperature regions. That is, when supporting the work of the waste-heat boiler by the oil fired boiler may turn out indispensable, which, however, shall reduce the assumed profits.

In case of waste-heat boilers, a significant phenomenon affecting their work is the effect of so called self cleaning [6]. Due to considerably limited flow of exhaust gases feeding the boiler, the effect may completely disappear, which results in much faster pollution of the boiler heat exchange spaces.

During a ship operation this means constant limitation of the boiler heat exchange process, as well as, the growing danger of fire due to the accumulated flammable pollution. It is of special importance when referred to water pipe boilers equipped with elements intensifying heat exchange (*plates, bands, pins…*). The real danger of fire may be prevented only by more frequent cleaning of the boilers. However, the operation may be conducted only during a ship's lay time.

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