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ECONOMIZER SELECTION METHOD WITH REFERENCE TO ITS RELIABILITY AT PRELIMINARY DESIGN STAGE OF SEAGOING VESSELS

METODA WYBORU EKONOMIZERA Z UWZGLĘDNIENIEM JEGO NIEZAWODNOŚCI NA POCZĄTKOWYM ETAPIE PROJEKTOWANIA STATKÓW MORSKICH

Charchalis Adam, Krefft Jerzy
Gdynia Maritime University, Faculty of Marine Engineering
Morska Street 83-87, 81-225 Gdynia, Poland

Abstract: The economizers are used for production of steam heating on en route ships. The economizers are producing steam in a heat exchange process from the ship's main engine exhaust gas. Products of the incomplete combustion of the heavy fuel oil remaining in engines, passing the boiler, collect on the heat exchange surface of the economizer. When the incorrect assumptions are made for the boiler operation conditions, the boiler steam capacity drops and fire and burning of the incomplete combustion products can occur in the economizer. To minimize combustion product quantity that collects on the boiler surface, the allowable exhaust gas pressure drop in the boiler should be taken into consideration, as well as the results from recommended exhaust gas flow velocity that is determined by main engine service load determined in the preliminary design phase of the ship. The remaining operating conditions are made in such a way to obtain high steam capacity of the boiler. It is essential at the design stage to take into consideration the future operating parameters of the combustion-steam-water installation, since these parameters depend on the choice of boiler and determined at the design stage production of steam. On the basis of operation parameters of contemporary container ships, an attempt was made to select economizer capacity in the preliminary design stage taking into consideration operation conditions of the propulsion system-steam installations unit in aspect of economizer reliability.
Keywords: seagoing ships, economizer, steam boiler, steam capacity, reliability, operating conditions

Streszczenie: Ekonomizery są stosowane do wytwarzania pary grzewczej podczas rejsów statków morskich. Para jest wytwarzana w procesie wymiany ciepła, którego nośnikiem są spaliny z głównych silników statku. Produkty niecałkowitego spalania ciężkiego oleju silnikowego (mazutu) pozostające w silniku po zakończeniu procesu spalania przechodzą następnie przez kocioł i gromadzą się na powierzchni wymiennika ciepła ekonomizera. Jeśli dla warunków pracy kotła zostaną przyjęte nieprawidłowe założenia, spada wydajność parowa układu, a w ekonomizerze może nastąpić zapalenie się produktów niecałkowitego spalania, prowadząc do pożaru. W celu zminimalizowania ilości produktów spalania, które zbierają się na powierzchni kotła, należy zawsze mieć na względzie dopuszczalny spadek ciśnienia gazów spalinowych, a także wyniki dla zalecanej prędkości przepływu spalin, która jest determinowana przez obciążenie robocze głównego silnika, określane w początkowej fazie projektowej każdego statku. Pozostałe warunki pracy są dobierane w taki sposób, aby osiągnąć wysoką wydajność parową projektowanego kotła. Istotne jest, aby jeszcze w fazie projektowej wziąć pod uwagę przyszłe parametry robocze układu spalinowo – parowo – wodnego, gdyż te parametry zależą od wyboru kotła i określają, już we wstępnej fazie projektowej, proces wytwarzania pary. Na podstawie parametrów roboczych współczesnych kontenerowców podjęto próbę wyboru zdolności produkcyjnej ekonomizera już we wstępnej fazie projektowania statku, biorąc pod uwagę warunki robocze układu napędowego oraz instalacji parowej w aspekcie niezawodności ekonomizera.
Słowa kluczowe: statki żeglugowe, ekonomizer, kocioł parowy, wydajność parowa, niezawodność, warunki robocze

1. Introduction

Seagoing ship can be divided into technical hull-navigational, energy-drive and destination units [1]. The energy-propulsion unit includes all machinery and equipment and devices to generate heat energy in steam form. The main destination of heat steam on the ship is to heat the heavy fuel oil to the proper combustion level process in the main engine and diesel generators. Results from the economizer's reliability in producing steam from the combustion gas of the main engine are essential for performing an objective function of the ship.

Different definitions of reliability can be found in the literature [1], [2], [3], [4]. In those documents can be distinguished such basic concepts as: properties, probability, time, operating conditions. According to Grzesiak [3], reliability determines proper performance of the activity in the assumed time in the area of forcing factors. Generally, reliability is defined as the probability of defined job realization in a specified time and operating conditions [5]. In this article, the reliability issue is considered within the range of fulfilment of the assumed economizer operating conditions, to obtain maximum steam capacity, keeping the failure-free operating conditions caused by either product ignition on the surface of the boiler or a significant drop in steam capacity of the boiler. Those conditions must be taken into consideration in the design assumptions of the economizer already in the preliminary design stage. For proper economizer selection, the parameters of the heating seam produced in the economizer, main engine operating load referred to its nominal value, combustion gas temperature before and after the economizer, boiler water temperature, legal regulation of the chemical compound level emission in the combustion gases and sulphur content in the heavy fuel oil, low temperature corrosion, combustion gases pressure drop in economizer etc, should be considered.

2. Research object

For the purpose of seagoing ship economizer selection, analysis is made for the kind and type of the boiler installed on the container ship [6], [7], [8], [9], [10], [11]. The developing trends and database structure according to number and class of the container vessels has been presented in [12], [13]. In the majority of the cases, economizers on ships are saturated vapour producing independent systems. Those boilers are rarely combination boilers with supportive oil fired boilers. Smoke tube solutions can be found on older ship types. On new ships, water tube boilers are applied, a water tube with forced circulation. It is presented in figure 1 a type of economizer

for the heat exchange surface in vertical smoke tubes (a) and horizontal water tubes (b).
Economizers with smoke tubes are a rare solution due to the necessity of a steam drum use and the blocking tube tendency, in which the combustion gases flow and frequently fail.
Economizer for heating steam with horizontal water tubes is taken for tests.

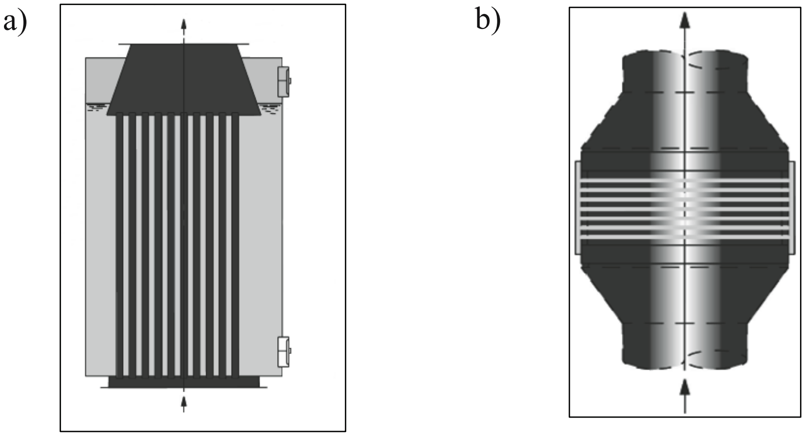

Fig. 1. Exhaust gas boiler types [14]: a) vertical smoke tubes, b) horizontal water tubes

2.1. Test methodology

Economizer selection for ships depends on operation pressure determination of the steam p_r [MPa], and steam capacity of the boiler D [kg steam/h]. Operational pressure of the boiler depends on the heavy fuel oil temperature at the inlet into the main engine. Assuming that combustion engines for seagoing ships are fed with heavy fuel oil with a viscosity up to 700cSt (50°C), take the boundary limit of heavy fuel oil temperature t_{PAL} = 150°C as shown in figure 2.
Taking into account the working conditions of the economizer, it is necessary, already during the preliminary design stage, to assume the main engine load of the vessel in relation to its nominal power, the exhaust temperature difference and the inlet values, T_1, and outlet of the boiler T_2, feed water temperature T_{wz}, the parameters of the generated steam, the confinement heat coefficient φ_i, etc.

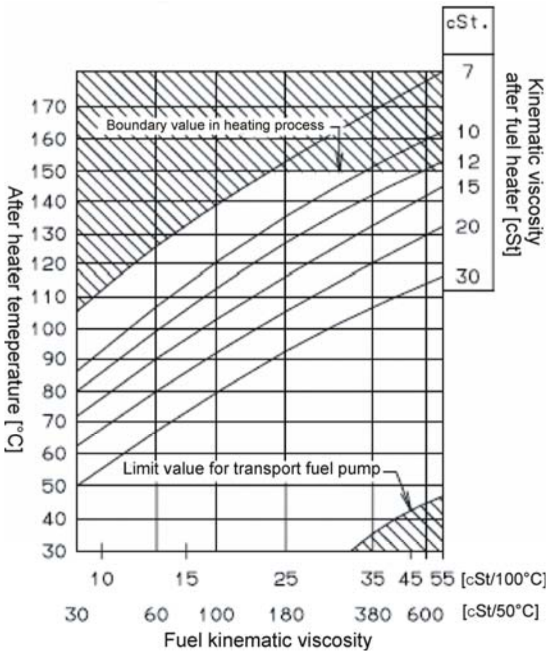

Fig. 2. Calculations of the heavy fuel oil temperature [15]

Starting from the equation for the quantity of heat contained in exhaust gas (1), the mass flow of gases through the economizer $\dot{m}_{SP}$, average specific heat for the composition of the operation exhaust gas c_{SP}, and exhaust gas temperature T_1 and T_2, at the inlet and outlet of the boiler must be specified.

$$Q_{SP} = \dot{m}_{SP} c_{SP} (T_1 - T_2)/3600 \qquad [kW] \tag{1}$$

The quantity of exhaust gases emitted by the main engine $\dot{m}_{SP}$, should be converted to service conditions. In equation (2), a correction for this engine optimisation is included $\Delta m_{O\%}$, external conditions $\Delta m_{WZ\%}$ (water temperature, air pressure and temperature, etc.) and partial engine load $\Delta m_{OC\%}$.

$$\dot{m}_{SP} = M_{L1} \cdot \frac{P_O}{P_{L1}} \cdot \frac{\Delta m_{O\%}}{100} \cdot \left(1 + \frac{\Delta m_{WZ\%}}{100}\right) \cdot \left(1 + \frac{\Delta m_{OC\%}}{100}\right) \cdot \frac{P_{OC\%}}{100} \qquad [kg/h] \tag{2}$$

To obtain the exhaust gas temperature at the inlet into the economizer T_1, there is a need to determine the temperature T_{L1}, specified by the manufacturer in the project guides for main engine, taking into account operating conditions, ie. temperature correction for the engine optimisation point Δt_O, external conditions Δt_{WZ}, and partial engine load Δt_{OC}. This is particularly important because two-stroke combustion engines burn low-quality fuels, understood as fuel with low energy properties. If the efforts of manufacturers of combustion engines, which are designed to reduce specific fuel consumption values, are added, it is ascertained that the temperature of the exhaust-driven supercharger decreased as compared to engines manufactured in the 80s by more than 100°C from ca. 370°C to 240°C for the nominal value of L1 and moderate conditions (ISO).
To determine the average value of the specific heat of exhaust gases, a third degree polynomial function is used for the exhaust gas composition specified in table 1. For all of the designated functions of exhaust gas components, the coefficient of determination R^2, was above 0.99.

Tab. 1. Exhaust gas percentage [14]

Exhaust gas	N_2	O_2	H_2O	CO_2
Percentage content	76.2%	14.0%	5.1%	4.5%

The remaining components: NOx, SOx, CO and HC, are a small value of the percentage composition of gases that have been omitted without affecting the c_{sp}.
From the value of temperature T_2 depends on the heat that will be given off by gases. The high degree of utilization of waste heat requires a reduction in the temperature as much as possible. Permissible sulphur content in fuel, compiled in table 2, is a restriction on the reduction of temperature due to the dew point.

Tab. 2. Sulphur content in heavy fuel oil [16]

<table>
<tr><th>Implementation date</th><th>Emission control area</th><th>Global remaining area</th></tr>
<tr><td>Existing regulations</td><td>1.5%</td><td rowspan="2">4.5%</td></tr>
<tr><td>March 2010</td><td>1.0%</td></tr>
<tr><td>January 2012</td><td></td><td rowspan="2">3.5%</td></tr>
<tr><td>January 2015</td><td>0.1%</td></tr>
<tr><td>January 2020 (2025)</td><td></td><td>0.5%</td></tr>
</table>

Giving the sulphur content in fuel from year 2010 onwards is proposed for amendments to Annex VI of the MARPOL convention.

For special zone - the Baltic Sea, the Mediterranean and others, sulphur content in fuel is much lower than for other areas of seagoing vessels. Depending on the opportunities for supplying fuel with a sulphur content of 0.5%, an amendment may come into force in 2020 or 2025. For such a low sulphur content, it is possible to produce larger quantities of steam than take place with the current 4.5% sulphur content in the remaining refuelling areas outside of the special area. In this situation, it is necessary to reduce the operating pressure of the boiler due to the lower value of the steam temperature. Figure 3 shows the dependence of the dew point of sulphuric acid as a function of sulphur content in the fuel. It follows that the less sulphur in the fuel, the lower the exhaust gas temperature for the boiler rendering T_2 may be and a higher value of specific enthalpy [kJ/kg] can be given by exhaust gases.

Depending on the temperature difference ΔT, understood as the lowest value between the temperature T_2 of exhaust gases leaving the boiler water evaporation surface, and the temperature of saturated steam (saturation temperature) T_n, area of heat exchange between the exhaust gas and steam-water mixture in the economizer, takes a variety of values. The lower the temperature difference ΔT, the greater the heat exchange surface of the economizer.

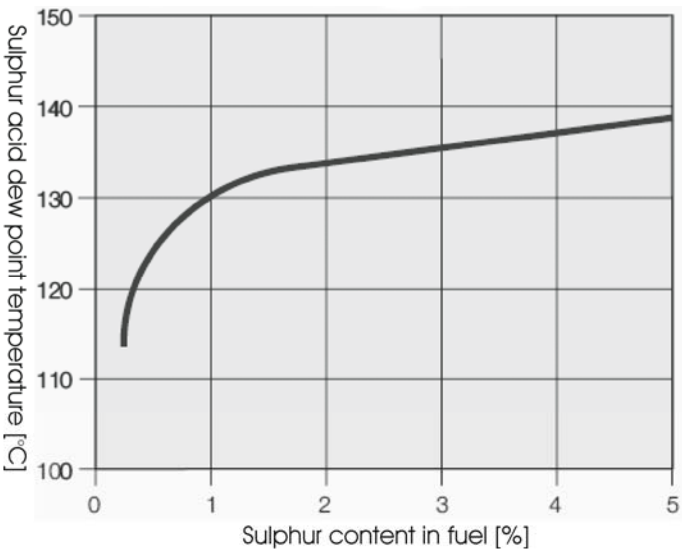

Fig. 3. Sulphur acid dew point temperature [17]

According to [18], a reduction of the temperature difference ΔT from 15 to 5 increases the performance of the economizer by only 10%, increasing the heat exchange surface of 132%. The change ΔT of 10°C causes a disproportionate increase in the cost of heat exchange surfaces produced. Therefore, for further calculation ΔT = 20°C was assumed as a compromise value because of the heat exchange surface and the utilization of heat from the exhaust gases degree.

2.2. Test results

Boiler capacity D [kg/h] was set for the maximum possible amount of steam to be produced. It is assumed that feed water enthalpy i_{wz} for temperatures in the cascade tank (atmospheric drain tank) t_{wz} = 85°C and saturated steam enthalpy i” for pre-approved saturation temperature t_n = 170°C, and operating pressure p_r = 0.7MPa, i.e. 8MPa absolute pressure. Due to the gas properties, a supply water temperature at 85°C should be maintained. The higher the temperature of feed water, the lower the gas solubility is in water and the easier it is to get rid of it in the atmospheric drain tank.

Parameter φ_i in the dependence (3) for the capacity of the economizer is known as rendering the confinement heat coefficient. Depending on heat losses to the environment and the efficiency of the boiler, the φ_i value of the range is taken $0{,}97 \div 0{,}99$. For the final calculations, $\varphi_i = 0{,}97$ was taken as the worst possible value.

$$D = \frac{Q_{SP} \cdot \varphi_i \cdot (3600)}{i'' - i_{wz}} \quad [kg/h] \tag{3}$$

On the basis of accepted parameters and functional dependences, an application was designed to calculate first the heat contained in exhaust gases Q_{SP}, and then to obtain the maximum possible capacity D_{KU} [kg/h] and power of the Q_{KU} [kW] economizer. An example of the application of the assumed and the calculated data are presented in figure 4.

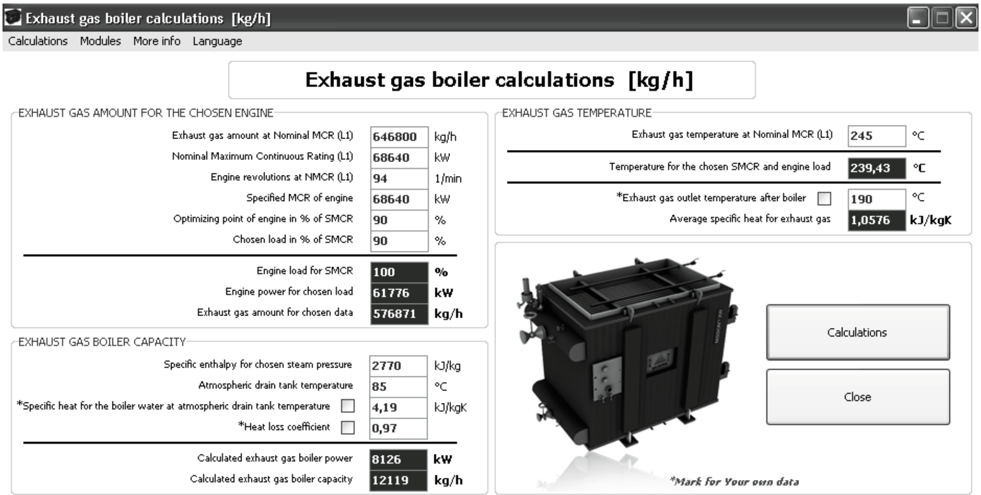

Fig. 4. Exhaust gas boiler calculation project

The application was designed in both Polish and English versions. The user fills in the data in the light coloured fields. General values are inscribed in the design guide for the chosen engine and the data resulting from individual arrangements with the operator of the designed seagoing ship. Grey boxes are the results of calculations.

It is possible to display additional calculations in the Calculations tab. An important element of the application is selected ship's engine power Specified Maximum Continuous Rating (SMCR). The engine has different crankshaft revolutions than in L1 point, for the engine layout. The exhaust gas temperature is also different and has been included in the application.

3. Conclusions

Performed analyses of boilers for container ships show that the vast majority of these boilers produce steam with an operational pressure of 0.7MPa. For this pressure, and the assumed conditions of the boiler, the maximum value of efficiency and economizer power was set using the relations and approximation functions for low-speed two-stroke engines. These engines often provide the main propulsion of merchant ships, and it is desirable that the developed application was based on a dependency with regard to these engines.

A series of calculations have been performed, during creation of the application, for the possible steam produced in the economizer due to operating conditions. The program user has the possibility to change the

operational conditions by thus determining the selection of the boiler to the seagoing ship.
The proper selection of a boiler to a seagoing vessels in the preliminary design stage can lead to a reduction in the cost of construction and operation of the vessel, while maintaining the designed steam capacity of the boiler and a failure-free steam-water installation.

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Prof. D.Sc Eng. CHARCHALIS Adam, Dean of Faculty of Marine Engineering, Director of Department of Marine Maintenance.
Professor Charchalis was a dean of Faculty of Mechanical and Electrical Engineering in Polish Naval Academy in 1994-2004. Employed as a professor Mr Charchalis works at Gdynia Maritime University since 1999. In his scientific work he deals with the problems of power plant energy of seagoing vessels, propulsion devices, ships designing, exhaust gas turbines, marine units diagnosis.Prof Charchalis created and implemented main propulsion diagnosis system of marine ships equipped with exhaust gas turbines. Prof Charchalis is an author of 3 monographs, 8 textbooks, 250 research works and thesis supervisor of 13 PhD's degrees.

Jerzy KREFFT, Msc eng an assistant professor in Ships Power Plant Department in Marine Engineering Faculty at Gdynia Maritime University.
His main subject of science interest are the problems with power plant energy of seagoing vessels especially container vessels. The research issue concerning vessels in design and operational stages.