Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

MARINE TURBINE APPLICATION IN WASTE HEAT RECOVERY SYSTEMS

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Abstract

This study shows an analysis of a ship power plant with waste heat recovery systems – Thermo Efficiency System (TES) with main engine exhaust gases utilization and exhaust power gas and steam turbines application. The systems were compared each other. The energetic efficiency in chosen waste heat recovery systems was compared. The advantages and disadvantages of turbines application in waste heat recovery systems were listed in a summary.

Keywords*: turbine, engine, waste heat energy, recovery, ship, power plant,*

1. Introduction

Ship's engine room efficiency determines the stage of the heat, which is received by fuel oil combustion in the main components of her power plants. Modern solutions of ship's power plants ensure the biggest possible efficiencies of converting fuel oil chemical energy for other aspects. One of the methods increasing efficiency of the power plant is recovering the heat which is lost with exhaust gases, main engine cooling water and charging air [2, 3, 4, 5]. Solution of this problem is possible through maximization of waste heat recovery generated by marine diesel engines and applying it in other installations to produce heat, electric and mechanical or combination of these energies. As a consequence of increasing main propulsion unit power of modern ships (increasing its deadweight), is forming a surplus energy which is produced in exhaust gas boilers as heating steam. In these circumstances, applying the combined waste heat recovery systems with exhaust gas and steam turbo generators is rational. There are a lot of waste heat recovery systems possible to apply on the motor ships. Their configuration depends on type of the vessel, her capacities, operating speeds and the output values implemented by the main propulsion plant [2]. Selection of the system solution on the specific ship should be result of widely comprehended, penetrating technical-economical analysis, based on solid mounts of thermodynamic and reliability analysis – methods keeping the engine room mobility.

2. Waste heat energy availability

Main and auxiliary engines are sources of waste heat energy in ship's propulsion plant. Quantity of these streams are diversified, energy included inside is not utilized fully. Waste heat energy losses size depend on main propulsion plant which has been used (diesel engine or/and gas turbine). Low speed diesel engines have the highest thermal efficiency which is formed in range between 45÷55% (for comparison the turbine engines have lower thermal efficiency even 20%) [3, 4, 7]. Waste heat energy include heat losses of an exhaust gases, scavenging air and cooling water streams.

Increasing ship's energetic power plant efficiency is lashed with taking off assist of huge, available waste heat energy streams coming from main components of the system. On the pictures no. 1, 2 there are adequately heat balance diagrams of marine low speed diesel engines without and with recovery of energy, 12RT-flex96C type [9] and 12K98ME/MC type [8] on Fig. 3 and 4. Both of the engines evolve the 68640 kW output power which is realized with 94 rev/min.

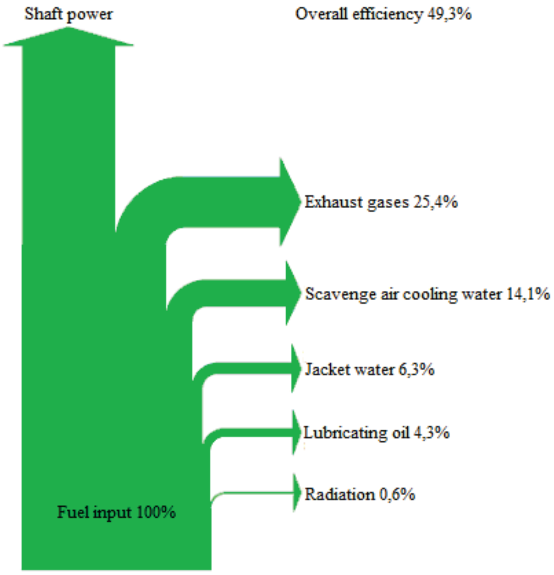

Fig.1 Heat balance diagram of marine low speed diesel engine 12RT-flex96C type [9]

In WARTSILA solution, both waste heat recovery system uses exhaust gas stream generated by main propulsion plant and scavenging air and cooling water streams. The biggest, possible waste heat recovery stream is carried by exhaust gases leaving the main engine. The lesser are: scavenge air, cooling water and lubricating oil streams. Systems offered by MAN B&W utilize only the exhaust gas stream. Overall efficiency of these engines without recovery is equal in total 49,3%.

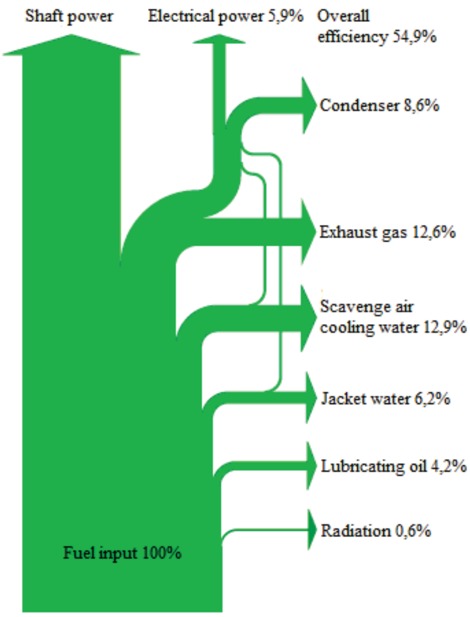

Fig. 2 Heat balance diagram of marine low speed diesel engine 12RT-flex96C type cooperating with waste heat recovery system [9]

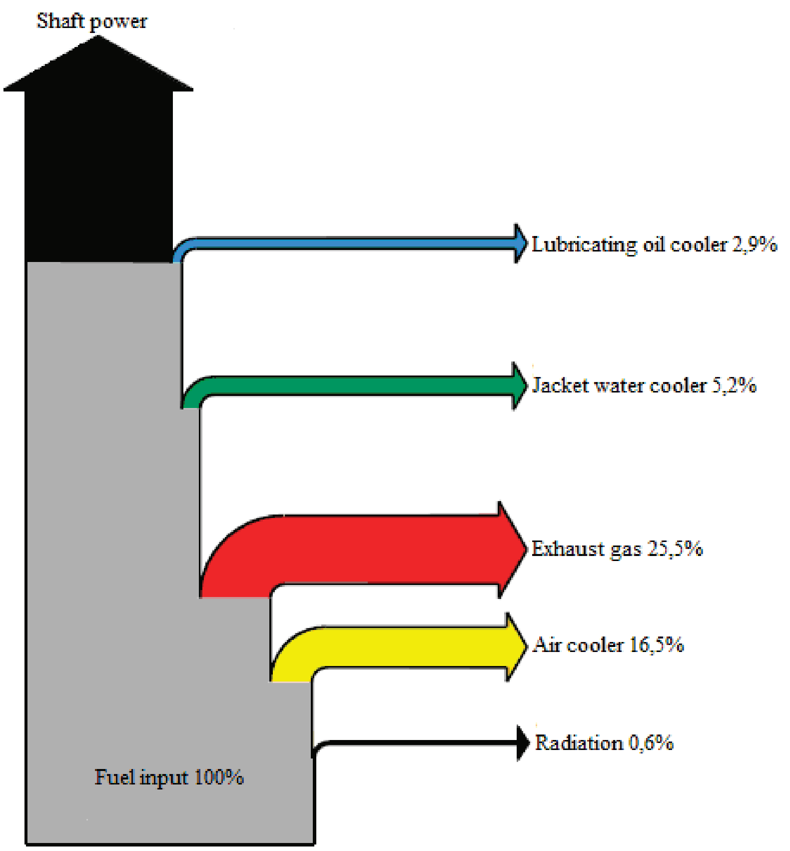

Fig. 3 Heat balance diagram of marine low speed diesel engine 12K98ME/MC type [8]

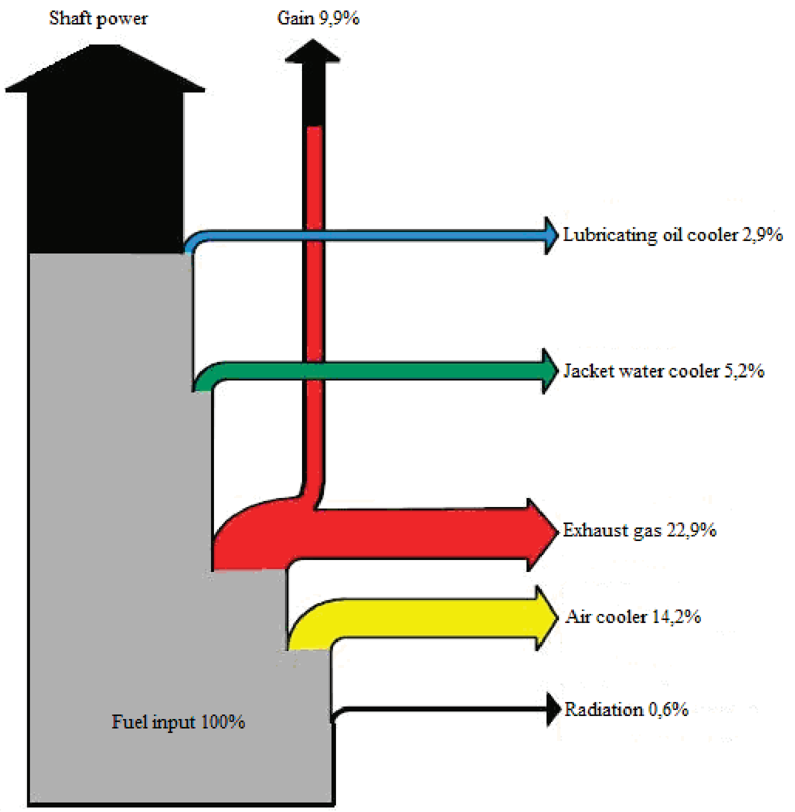

Fig. 4 Heat balance diagram of marine low speed diesel engine 12K98ME/MC type cooperating with waste heat recovery system [8]

3. Waste heat recovery systems

There are a lot of waste heat recovery systems with exhaust and steam turbines [7, 8, 9]. They are representing various energetic efficiency.

In this study, the standard, referencing solution of waste heat recovery system is system with exhaust power gas turbine, working according to the scheme shown on Fig. 8. The basic waste heat recovery system consists of a main engine with high efficiency turbochargers, exhaust power gas turbine via reduction gear and clutch driven AC generator. The energy of exhaust gases, leaving the main engine, is partly recovered in a turbochargers to compress, charge air or supply the exhaust power gas turbine driving the generator. About 10% of exhaust gas leaving the main engine is used to drive the generator [8]. The exhaust gases are being carried off through the cumulative manifold to the funnel in which there dampers installed and then to the atmosphere.

This solution is an alternative source of producing an electric power and now it is being introduced to the new building ships.

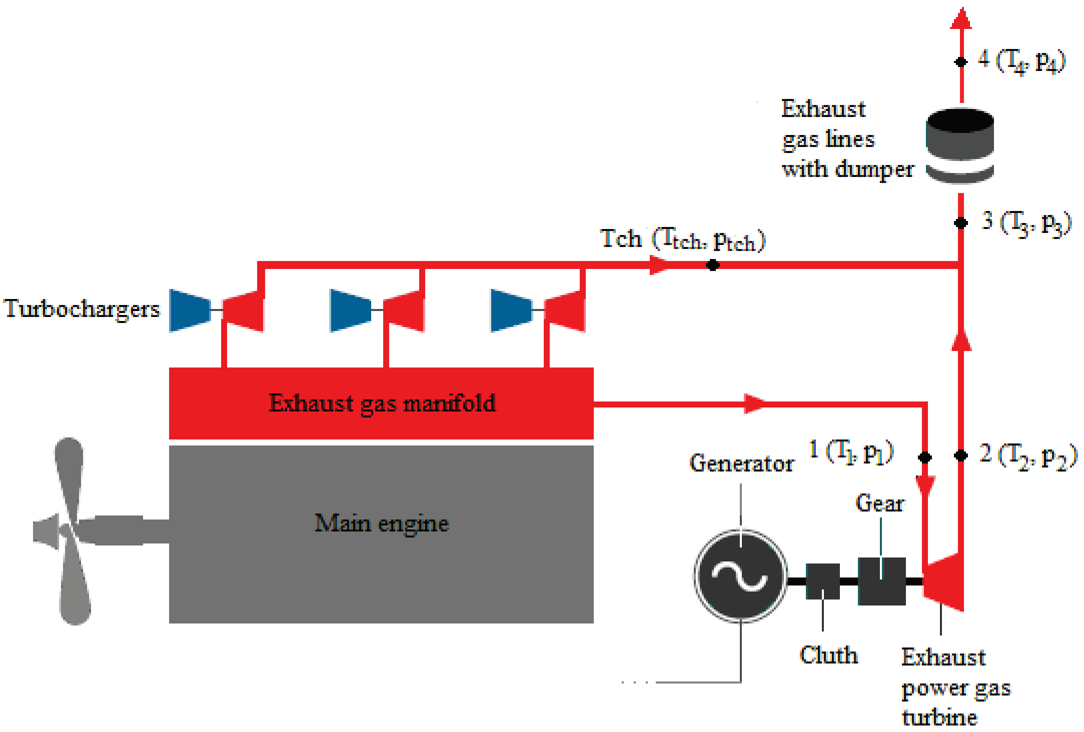

Fig. 5 Waste heat recovery system with exhaust power gas turbine [8]

Engine working waste heat recovery system (Fig. 8) is equipped with an air waste gate, stifle valve aim at keeping the normal cylinder pressure without the other restrictions at the very low intake air temperatures. At present, the propulsion plant cooperating with waste heat recovery systems can work at the intake air temperatures maintaining at the level of –5 to 35 centigrade. After exceeding the maximal pressure in a cylinder, the flow rate of exhaust gases feeding the exhaust power gas turbine, turbine and generator rotor speed would increase. It will cause the generator load disturbance.

Adopting the main engine to work at lower intake air temperatures involves the costs of fuel oil consumption, however the rate of recovered energy compensates this disadvantage.

Exhaust power turbine is working in the range 55÷100% of main engine load. Exhaust gas outflow is controlled by orifice on the outlet of the exhaust gas receiver, keeping the constant value of exhaust gas flow rate feeding the power turbine. In this way, the constant turbine load rate is being kept. With the main engine output lower than 55%, the exhaust gases feeding the turbine are being cut off. The air flow which is given by turbochargers is too low to generate properly large exhaust gas flow rate to ensure stabilized turbine load rate. Expand stage and exhaust gas flow rate value are compared with suitable turbochargers parameters. Turbine outlet exhaust gases temperature is close to the temperature after the turbocharger.

Basic waste heat recovery system (Fig. 5) is often compared to the system with the exhaust gas boiler and steam turbine driving the generator. These systems are different in respect to the configuration and outputs. On the picture 6 there is waste heat recovery system with steam turbine feeding the steam from exhaust gas boiler [9].

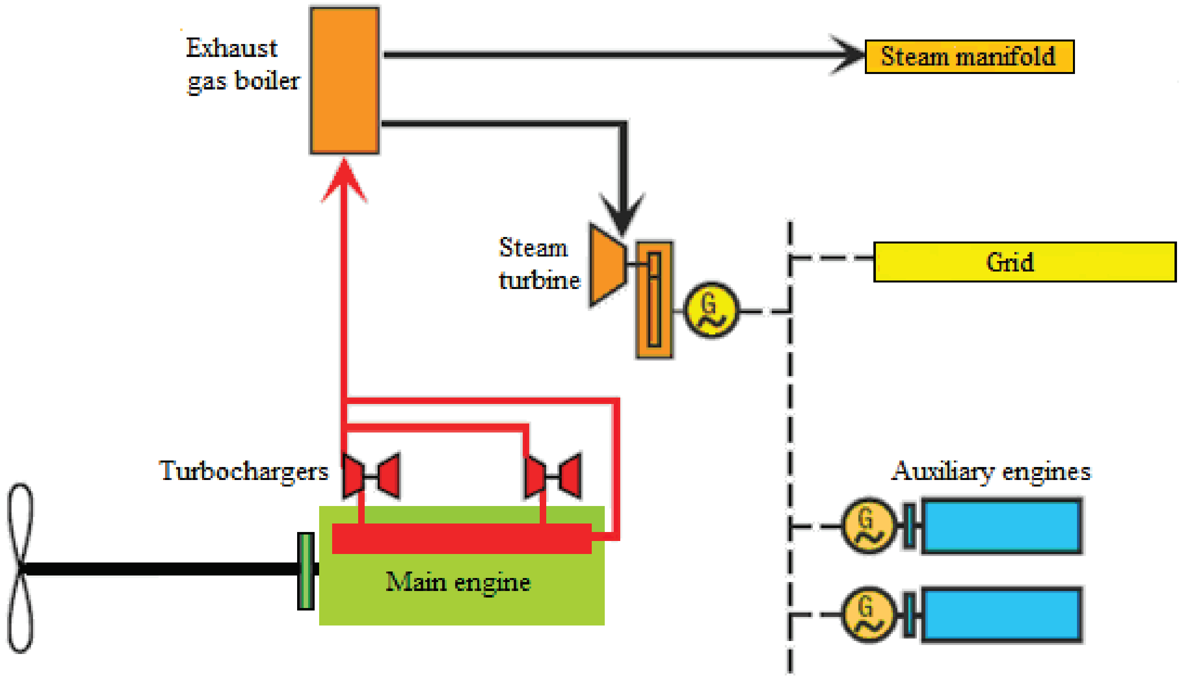

Fig. 6 Waste heat recovery system with an exhaust gas boiler and steam turbine [9]

On the Fig. 7 there is waste heat recovery system with an exhaust gas boiler exhaust power gas turbine and shaft generator. This system consists of main engine, turbochargers, exhaust gas turbine mechanically connected with the generator, exhaust gas boiler, shaft generator and self-contained auxiliary engines feeding the common board grid Described system differs from above one in relation to waste heat energy division between turbines.

Main exhaust gas energy stream: carrying by exhaust gases, after energy conversion in turbochargers is divided in two: exhaust gas stream heating the exhaust gas boiler and exhaust gas stream feeding the power turbine. During main engine working one part of exhaust energy stream is used to produce heating steam in exhaust gas boiler. Second part of this exhaust gas stream is converted by power turbine set mechanically connected with the generator to electric energy for the board grid. Controlling of the exhaust gas amount feeding the power turbine is realized in relation of main engine load through an orifice. About 10% of exhaust gases energy are used in this waste heat recovery system in power turbine.

Exhaust gases leaving the exhaust power gas turbine are guided to exhaust gas boiler too.

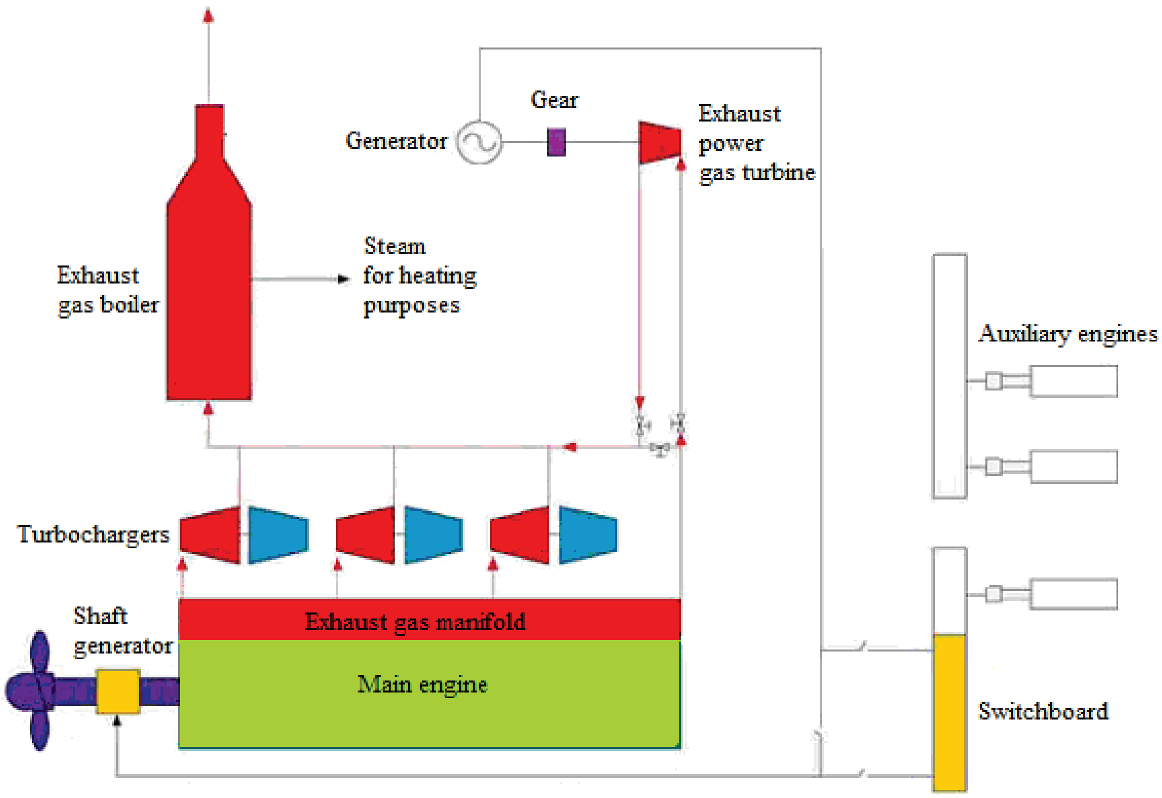

Fig. 7 Waste heat recovery system with an exhaust gas boiler, power turbine and shaft generator [8]

The efficiency of whole system is increased by a shaft generator application. This generator can work in a two variants. It can taking off the energy to the board grid or taking in assist the main propulsion plant. Engine running variant can be used for reduce fuel oil consumption amount with the reduced main engine output. The second variant is electric energy production for ship requirements, while the waste heat recovery system is stopped.

Beyond supplying the electric power, this system, allows to save the fuel oil (even to 5% per year) and essentially reduces the emission of toxic combustion substances.

Advanced waste heat recovery system, shown on Fig. 8 consists of an exhaust gas boiler, steam turbine, exhaust power turbine, synchronous generator driven by these turbines and shaft generator working for the board grid. Exhaust power gas turbine impeller connected with steam turbine impeller via power transferring system (reduction gear and clutch) drives the AC generator. Steam turbine is fed by superheated steam from the exhaust gas boiler. Shaft generator application increases whole efficiency of the system. This solution has been used for a first time on m/v Gudrun Maersk containership [9].

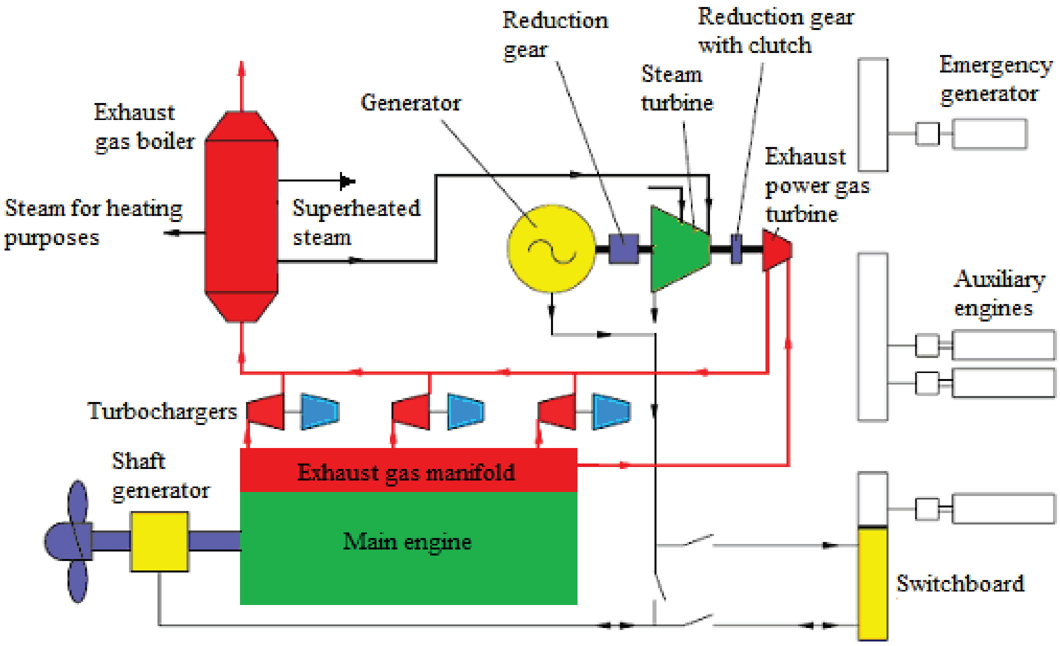

Fig. 8 Advanced waste heat recovery system with an exhaust power turbine, steam turbine and shaft generator [9]

Combined system application with en exhaust and steam turbine considerably increases its efficiency and reliability. Due to increase of an electric energy production at main engine loads above 50%, system efficiency grows even to 10% (see Fig. 9).

One possibility to improve the efficiency of the recovery of more heat without increasing the heat exchange surfaces can be applied fluidized bed exhaust boiler [1].

4. Chosen aspects of turbine application advisability in waste heat recovery systems

Economical efficiency of examined waste heat recovery systems with exhaust and steam turbines can be measure of its quality solution assessment [6]. Its final measurement will always be derivative brief fore designs accepted for the specific ship, conditions of her operating and stabilized technical – economical criterion. In this study, it was restricted to some aspects of turbine applications in waste heat recovery systems [5, 6].

Profitability of use and operate turbine in waste heat recovery system is conditioned by vessel state operating (sailing speed and the power involved by the main propulsion plant)and the time of being in its, which determines the quantity of energy possible to utilize. Modern waste heat recovery systems, with gas and steam turbines or their combination, are different due to their configuration, machines property and working parameters.

With increasing the exhaust power gas turbine output, disposal waste heat recovery streams increases in waste heat recovery system. The power turbine output increases and as a consequence the amount of the saved fuel combusted by propulsion plant increases too [9]. On Fig. 9 there are example ranges of possible output values reached by exhaust power gas turbine in relation to main engine output type 12K98ME/MC manufactured by MAN B&W [8].

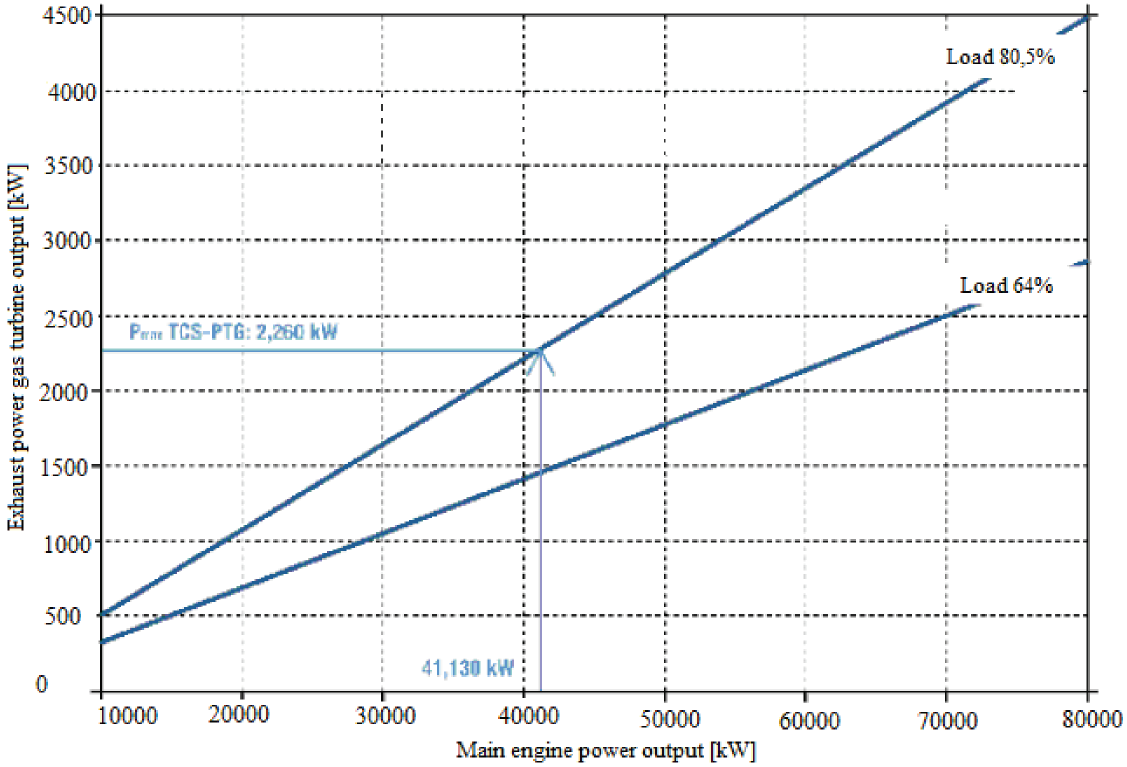

Fig. 9 Exhaust power gas turbine output waste heat recovery system in relation to main engine power [8]

With the main engine power 41130 kW exhaust power gas turbine working in TCS – PTG system evolves repayable power 2260 kW.
As a result of extracting specified outputs, there are fuel oil savings shown for the same engine on Fig. 10 in relation to exhaust power gas turbine output and main engine operating hours [8].

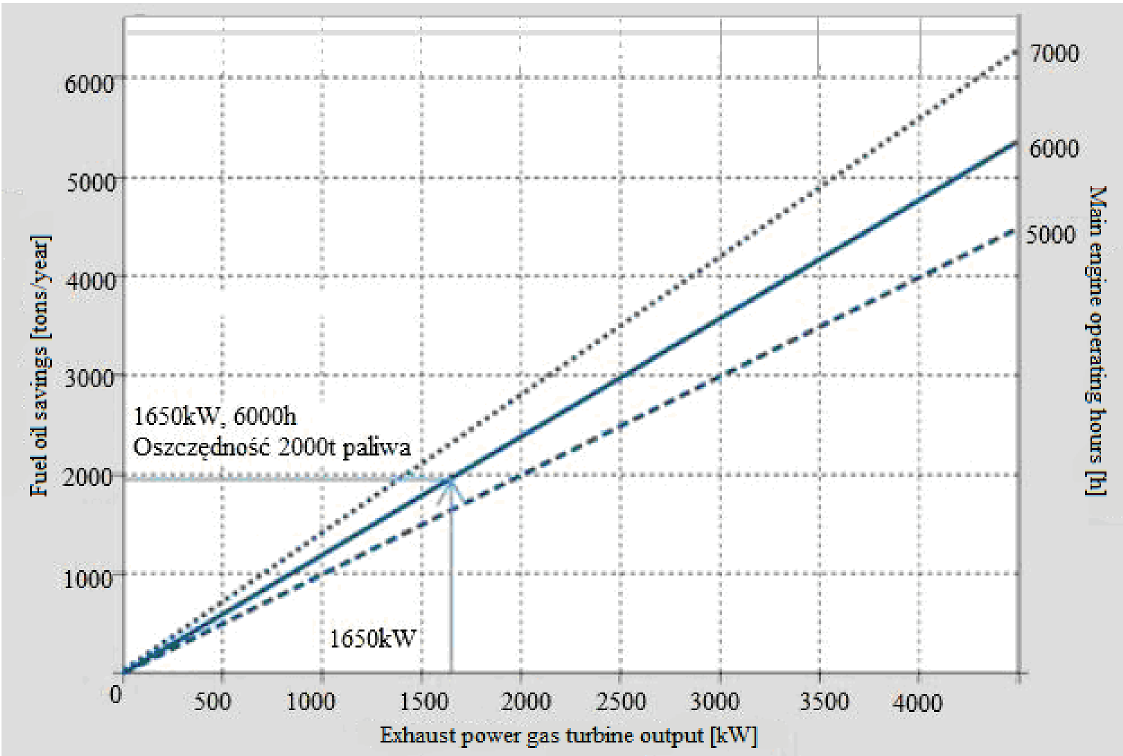

Fig. 10 Prediction fuel oil savings obtained as a result of waste heat recovery application in relation to exhaust turbine output [8]

In a case of waste heat recovery system with exhaust power gas turbine output 1650 kW, after 6000 working hours, the 2000 tons of fuel oil can be saved in a year. Such rational advantage coming from waste heat recovery system application can be gained in case of huge main propulsion plants, here exceeding 40000 kW [8].

5. Thermodynamic analysis of examined waste heat recovery system

Exhaust gases ability was analyzed to conversion part of the waste to effective electric energy with intermediate aspect reciprocating energy generated by power turbine. On the Fig. 5 there is basic waste heat recovery system with alluvial points enable the thermodynamic identification. Inlet exhaust gas parameters marked as 1, outlet parameters as 2.

Large flow rate and exhaust gases temperatures relatively keeping at the same level ensure working stability of power turbine and constant internal efficiency close to project value. On table 1 there are technical data of radial and axial power turbines applying in waste heat recovery systems manufactured by MAN B&W [8]. Expand stage turbine π_t is 3,3, exhaust gas temperature before turbine is 450^0C.

Tab. 1. Basic technical data of power turbines

Radial power turbines			
	Output [kW]	Flow rate [kg/s]	Speed [1/min]
(TCS-) PTG16	600	3.0	41,000
(TCS-) PTG18	900	4.3	34,000
(TCS-) PTG20	1,300	6.3	28,500
(TCS-) PTG22	2,300	13.0	21,500
Axial power turbines			
(TCS-) PTG55	3,400	19.0	17,000
(TCS-) PTG66	4,800	27.0	14,500

They can work in system TCS/PTG (Turbo Compound System/Power Turbine Generator) – the system taking off main engine assistance/exhaust power generator set.

For the turbines described in table 1 the disposal enthalpy drops were calculated according to the dependence [3, 4, 6]:

$$\Delta h_{sT} = \frac{P_e}{\dot{m}_{exh} \cdot \eta_{iT} \cdot \eta_{mT}} \tag{1}$$

and heat streams [4, 6]:

$$\Delta \dot{Q}_t = \dot{m}_{exh} \cdot \Delta h_{st} \tag{2}$$

The results of calculations are show in table 2. The biggest heat streams convert axial power turbines whereas disposal enthalpy drop values render that it can be even single stage turbines. Bigger disposal enthalpy drops are converted by radial power turbines, in comparison with axial they give less outputs. Higher output values gained by axial turbines are result of bigger flow rates exhaust gases conversion. Bigger turbines internal efficiencies are fostering in gaining higher axial turbine outputs, which influences on waste heat recovery system efficiency.

Tab. 2. Calculated dispose enthalpy and heat streams in turbine

Radial power turbines		
Turbine type	Δh_{sT} [kJ/kg]	$\Delta \dot{Q}_T$ [kW]
TCS – PTG 16	266,6	799,8
TCS – PTG 18	279,1	1200,13
TCS – PTG 20	275,1	1733,13
TCS – PTG 22	235,9	3066,7
Axial Power turbines		
TCS – PTG 55	210,5	3999,5
TCS – PTG 66	209,1	5645,7

5. Summary and conclusion

Heat balance diagrams analysis of marine low speed diesel engines confirms possibility and advisability use of waste heat recovery energy in marine energetic power plants. Marine engine power output, temperature of medium feeding the waste heat recovery system (exhaust gases, cooling water), pressure and flow rate factor determine the quantity of available heat in waste heat recovery system. Exhaust gas and steam turbine application takes effect in additional electric energy production, fuel oil savings and limitation of emission toxic substances to the atmosphere [8]. Exhaust gas and steam turbine cooperating increases systems efficiency especially in direction to enlarge of electric energy production. Use character of waste heat recovery system with power turbine is conditioned by continuity of steady turbine work at main engines load ranges above 50% rated power ensuring adequately large waste heat streams carrying by exhaust gases. Quantity of saved energy can be estimated after penetrating analysis of each other of waste heat recovery systems.

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Praca naukowa finansowana ze środków na naukę w latach 2009-2012 jako projekt badawczy własny nr N N509 404536.