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METHODS OF REDUCTION OF FUEL CONSUMPTION AS MEANS FOR CO_2 EMITTED BY SEAGOING SHIPS MINIMISING

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Abstract

The subject of paper is to focus the problem of carbon dioxide emission from seagoing ships. The paper presents analysis of possibilities of fuel consumption minimizing and this way reduction of carbon dioxide emission from seagoing ships. However, The VI Amendment to MARPOL Convention concerning prevention against air pollution by seagoing ships did not take into consideration carbon dioxide emission, the importance of this problem was perceived by international organizations among others by IMO. As a result corrections in VI Amendment to MARPOL Convention were introduced thus forcing reduction of CO_2 emission by seagoing ships.

Among means reducing emission of carbon dioxide into atmosphere the following are mentioned: construction modifications of new built ships i.e. reduction of ship speed, optimization of main engine and propeller selection, optimization of ship hull shape, application of resistance reducing hull coatings, use of alternative (ecological) fuels and utilization of propulsion plant waste heat.

In turn, for ships already in operation methods for fuel consumption and carbon dioxide reduction can be individual for each ship full monitoring of main engine operational parameters and measurement of waste heat utilization rate.

According to opinion of paper authors, the minimizing of carbon dioxide reduction can be mainly achieved by utilisation of exhaust gases heat for electric power production in steam turbo alternators running in one- or two stage steam pressure systems. The analysis executed in the paper of one- and two stage steam system advantages shows that one stage steam system is more economically profitable in practice application.

Keywords: *greenhouse gas, carbon dioxide, fuel consumption, waste head utilisation*

1. Introduction

Name greenhouse gases belongs to components of Earth atmosphere, which due to physical and chemical properties can prevent release of infrared radiation from Earth into space thus causing increase of Earth surface temperature and this way creating phenomena named greenhouse effect. The greenhouse effect is mostly caused by water vapour (95%) and carbon dioxide (3.62%). They are accumulated in atmosphere due to natural nature processes as well as due to human activity. Worldwide emission of carbon dioxide in the year 2011 achieved 33.5 Gtons, in which 3% was caused by seagoing ships. The VI Amendment to MARPOL Convention brought into power in May 19th 2005 concerning prevention against air pollution by seagoing ship did not contain restrictions in carbon dioxide emission. The danger of carbon dioxide emission was quickly noticed by international boards including IMO. In July 2011 the VI Amendment was completed by Forth Chapter in power from January 2013. It has to force reduction of carbon dioxide emission from seagoing ships. Means for decrease of carbon dioxide emission imposed by Convention are:

- each classic seagoing ship of 400 BRT and higher should have Ship Energy Efficiency Management Plan (SEEMP) and stated Energy Efficiency Operational Indicator (EEOI). SEEMP is an instrument helping owners in effective energetic management of ships. The plan should take into consideration IMO guides according to Resolution MEPC.213(63). In turn the EEOI Indicator is the mean for ship operational parameters monitoring, among others actual fuel consumption and propeller contamination. This make possible to decide about change of engine fuel settings or propeller cleaning necessity,

– introduction of Energy Efficiency Design Index (EEDI) for new build ships.

Energy Efficiency Design Index EEDI requires for new built ships changes in design to obtain reduction of carbon dioxide emission by means as follows:

1. Reduction of ship steaming speed.
2. Increase of energetic efficiency by waste heat utilisation.
3. Reduction of main propulsion power.
4. Fuelling of ship engines with ecological fuels LPG and LNG.
5. Optimisation of hull shape.
6. Optimisation of thrusters shape.
7. Application of paints reducing hull resistance.

From above mentioned EEDI means the main engines waste heat utilisation is expected to be the most profitable in energetic efficiency increase. The largest part of waste heat streams from diesel engines are exhaust gases. They consist about 25% of whole energy delivered to engine in fuel. Possibilities of diesel engines exhaust gases energy utilisation is the subject of analysis described in this paper.

2. Description of Thermo Efficiency System (TES) utilising exhaust gases energy

The scheme of TES system is shown in Fig. 1. It consists of waste heat boiler 5 heated by main engine exhaust gases, steam turbine 6, gas turbine 3 named power turbine and common generator 7 driven by both turbines.

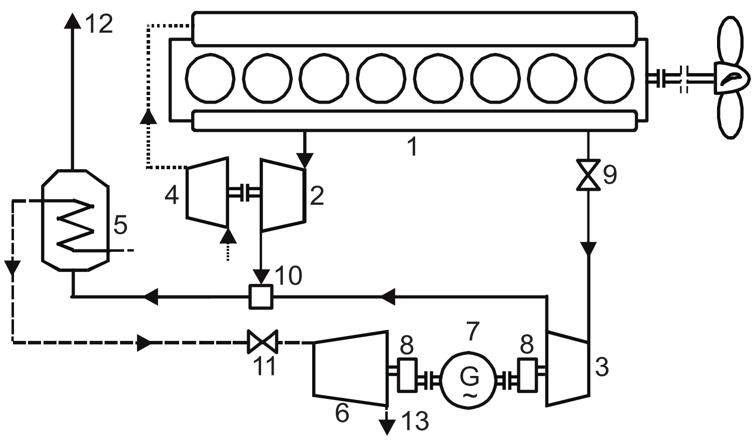

Fig. 1. Thermo Efficiency System: 1 – main engine; 2 – turbocharger turbine; 3 – power turbine; 4 – scavenging air compressor; 5 – waste heat boiler; 6 – steam turbine; 7 – generator; 8 – clutch; 9 – by-pass valve; 10 – mixing chamber; 11 – throttle valve; 12 – exhaust pipe; 13 – steam outlet

Waste heat boiler 5 generates saturated steam for ship heating purposes and superheated steam for steam turbine drive. Power gas turbine is driven by part of main engine exhaust gases. The power of gas turbine depends on by-pass valve 9 opening. The rest of exhaust gases is used for scavenging air turbocharger drive. If more gases is used for power turbine drive the amount of scavenging air decreases. In the same time the temperature of exhaust gases in mixing chamber increases and waste heat boiler capacity also increases. By-pass valve is closed at partly load of main engine (below 50% SMCR) when exhaust gas temperature decreases.

Gas turbine drives generator via reduction gear and overspeed clutch. The coupling protects gas turbine against overspeeding in case of generator trip.

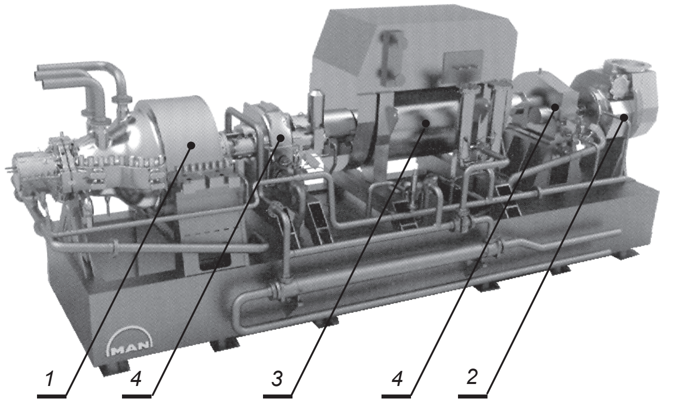

Fig. 2. Turbine generator set MAN type TES: 1 – steam turbine; 2 – gas turbine; 3 – generator; 4 – reduction gear

MAN offers turbogenerator set type TES shown in Fig. 2 and ABB offers turbogenerator set type PTL (Fig. 3) used on large container ships. In case of electric energy “surplus” the control systems reduces amount of superheated steam-to-steam turbine by throttle valve. Excess of steam produced in waste heat boiler is dumped to dumping condenser. If turbogenerator operate in parallel with diesel generators an automatic power sharing is applied.

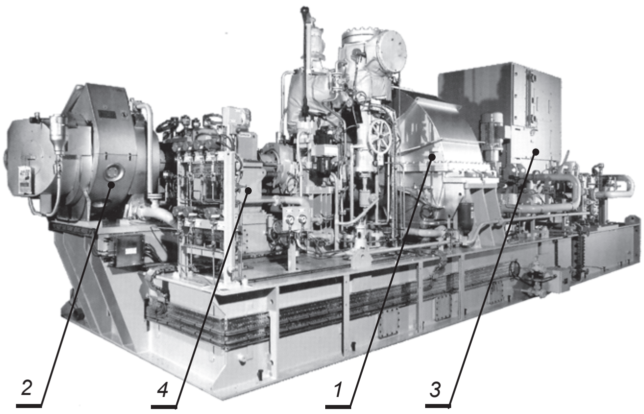

Fig. 3. Turbine generator set ABB type PTL: 1 – steam turbine; 2 – gas turbine; 3 – generator; 4 – reduction gear

Total fuel consumption of diesel engines depends on maximum firing pressure. In case of heat utilising systems TES maximum firing pressure of main diesel engine is higher than in standard systems, however due to extra power produced the specific fuel consumption decreases considerably.

3. Types of boilers and steam systems used in utilising systems TES energy

There are two types of boilers and two configurations of steam systems i.e. single-pressure and dual-pressure used in Thermo Efficiency Systems (**TES**) for utilisation of diesel engines exhaust gases energy.

3.1. Single-pressure systems

In single-pressure system as shown in Fig. 4 the boiler, 1 heated by exhaust gases from main diesel engine generates saturated steam for ship heating purposes and superheated steam for turbine drive. Both kinds of steam have the same pressure. On the diagram (Fig. 4) separate steam drum 2 of waste heat boiler is used, but also fuel oil fired boiler drum can be used as steam vessel. Feed water is pumped by feed pump 11 from hot well 12 to steam drum through preheater (economiser) 4. In this system as waste heat used for utilisation only exhaust gases energy is used.

Due to low temperature of exhaust gases from low speed diesel engines there is a risk of gases overcooling in boiler and danger of low temperature corrosion (sulphur corrosion). In addition, low speed of gases flow can cause wet deposits on boiler heating surface. To protect against these unfavourable processes absolute pressure 7 bars is recommended in single pressures systems operation. At this pressure, temperature of saturated steam is about 165°C and superheated steam 270°C. The steam turbine used in the system is multistage, single pressure, condensate type.

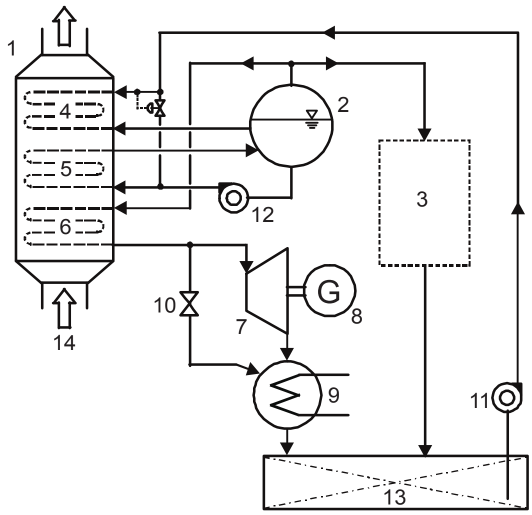

Fig. 4. Single-pressure steam system: 1 – single pressure exhaust gas boiler; 2 – steam drum; 3 – saturated steam receivers; 4 – feed water heater; 5 – evaporator; 6 – superheater; 7 – steam turbine; 8 – generator; 9 – condenser; 10 – dump valve; 11 – feed pump; 12 – circulating pump; 13 – hot well; 14 – exhaust gas

3.2. Dual-pressure systems

In dual pressure, system shown in Fig. 5 the superheated steam used for steam turbine drive has higher pressure than saturated steam for heating purposes. Absolute pressure of superheated steam is about 11-12 bar and saturated steam about 4-5 bar. In this design, there is no low pressure water preheater used to avoid exhaust gases overcooling, which can result in low temperature corrosion and wet, greasy deposits on boiler heating surface.

Thus, dual-pressure system needs alternative sources of heat for feed water preheating. It can be diesel engine jacket and scavenging air-cooling heat. Such solution needs more complicated and more expensive investments. It results in increase of generated steam amount and finally in bigger amount of electric power obtained.

If no diesel engine cooling heat is used for feed water, preheating the low-pressure saturated steam can be used for the purpose however it can result even in 16% decrease of generated steam total capacity.

4. Conditions and profits from application of Thermo Efficiency System (TES) utilising exhaust gases energy

Application of TES systems is connected with investment costs and needs careful analysis. The time of investment payback depends on power of ship main engine, operational load of main engine and region of navigation. The amount of electric energy generation increases during navigation on tropical seas. Researches and analysis of MAN [3, 4] show that for main engines about 20 MW electric energy produced in TES system is about 1300 kW while for main engines about 80 MW generation of 6500 kW electric energy is possible. For heavy fuel oil price 160 USD/ton annual fuel costs savings are 0.2 and 1.2 mill USD respectively. It is shown in Fig. 7.

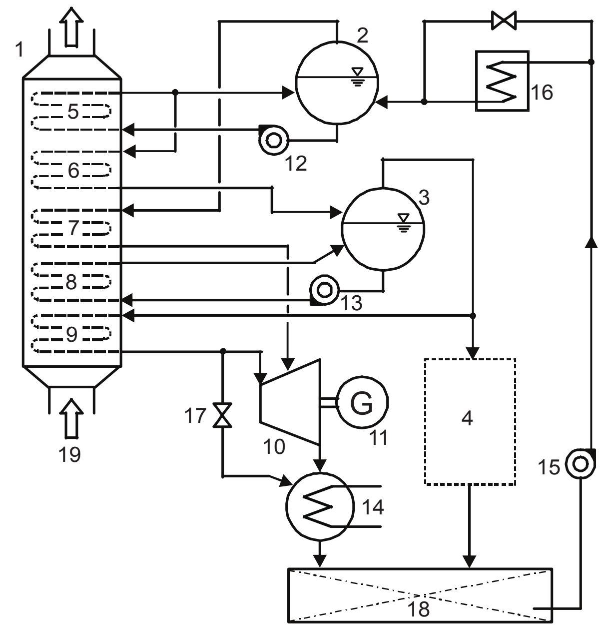

Fig. 5. Dual-pressure steam system: 1 – dual-pressure exhaust gas boiler; 2 – low pressure steam drum; 3 – high pressure steam drum; 4 – saturated steam receivers; 5 – low pressure evaporator; 6 – high pressure water heater; 7 – low pressure superheater; 8 – high pressure evaporator, 9 – high pressure superheater; 10 – dual pressure steam turbine; 11 – generator;12 – low pressure circulating pump; 13 – high pressure circulating pump; 14 – condenser; 15 – feed pump; 16 – alternative feed water heater; 17 – dump valve; 18 – hot well; 19 – exhaust gas

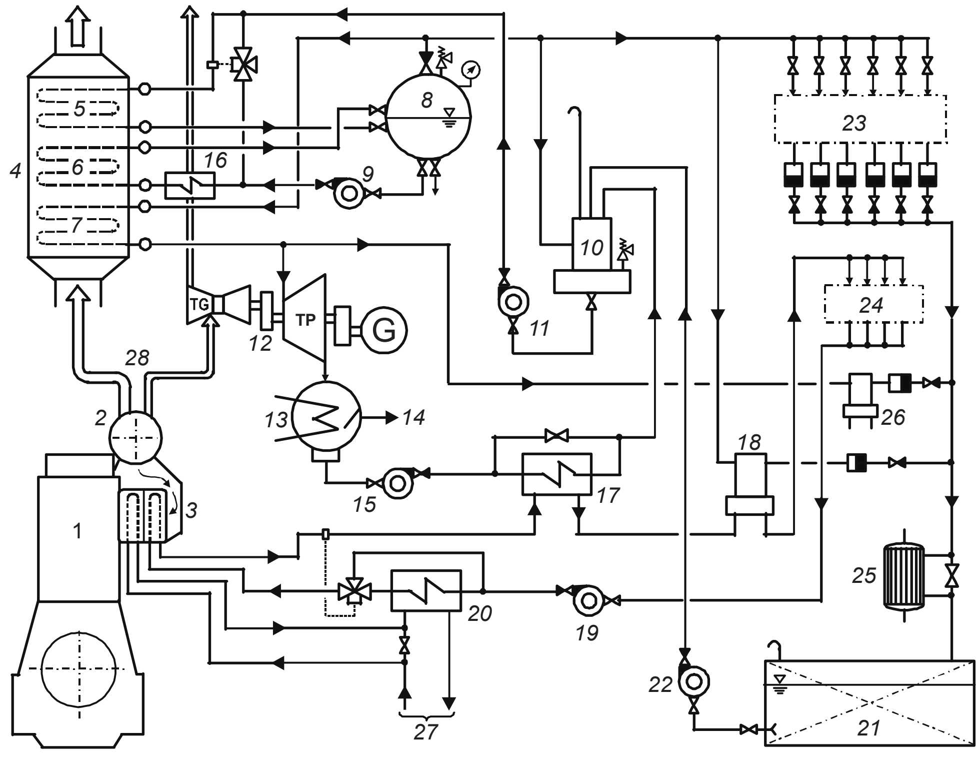

Fig. 6. Deep utilisation system utilising exhaust gases and scavenging air cooling heat: 1 – main engine; 2 – turbocharger; 3 – two-stage scavenging air cooler; 4 – waste heat boiler; 5 – internal feed; water heater; 6 – evaporator; 7 – steam superheater; 8 – steam drum; 9 – circulating pump; 10 – deaerator; 11 – waste heat boiler feed pump; 12 – combined turbine generator set (gas turbine, steam turbine, generator); 13 – condenser; 14 – vacuum system suction; 15 – condensate pump; 16 – fresh water generator water heater; 17 – condensate heater; 18 – steam water heater; 19 – heating water circulating pump; 20 – water heater; 21 – hot well; 22 – water refilling pump; 23 – heating steam receivers; 24 – heating water receivers; 25 – condensate cooler; 26 – final heavy fuel oil heater; 27 – low temperature cooling system connection; 28 – exhaust gases flow direction

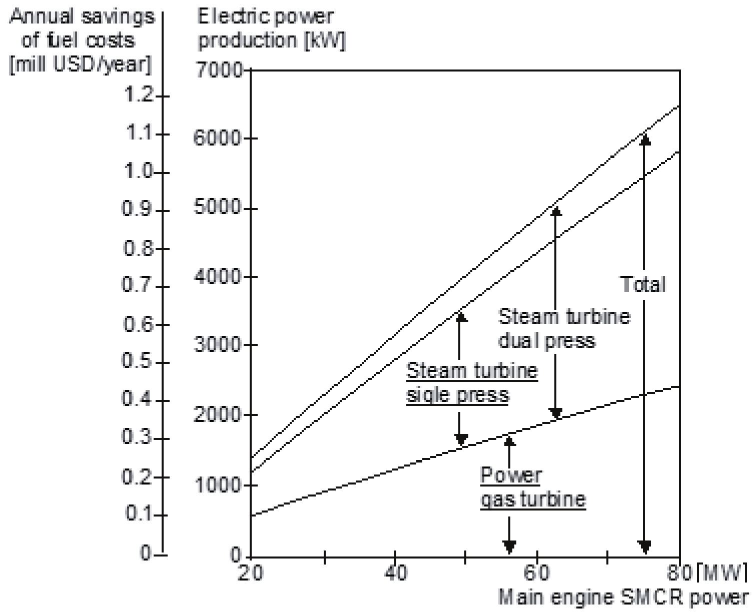

Fig. 7. Production of electric power and annual fuel costs savings of the Thermo Efficiency System as a dependency on ship main engine power [4]. Normal service: 85% SMCR, service time 280 days/year, fuel consumption: 170 g/kWh, fuel price: 160 USD/t

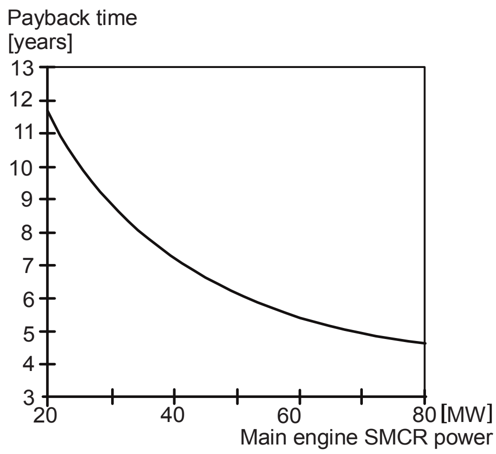

Fig. 8. Time of Thermo Efficiency System investment payback as a dependency on ship main engine power [4]. Normal service: 85% SMCR, service time 280 days/year, fuel consumption: 170 g/kWh

In addition it was found that for large engines e.g. MAN 12K98ME/MC investment payback time of TES application lasts about 5 years however for smaller power engines about 20 MW payback time can be about 12 years as shown in Fig. 8.

Calculations of MAN show that single pressure exhaust gases utilisation system TES for average sailing conditions profits in fuel oil savings about 8-10 % and dual pressure utilisation about 9-11%.

5. Conclusion

Brought to power regulations of VI Amendment to Marpol Convention extort reduction of carbon dioxide from seagoing ships. One of the most effective in the matter methods is minimising of fuel oil consumption by means of ship propulsion waste heat utilisation. The amount of carbon dioxide emission is proportional to the amount of fuel burned in engines.

Ship Energy Efficiency Management Plan (SEEMP) altogether with *Energy Efficiency Operational Indicator* (SEEMP), which make possible to determine the rate of waste heat utilisation force owners to concentrate on utilisation of waste heat streams on board the ship.

The largest part in waste heat structure are exhaust gases. That is why wide utilisation of exhaust gases heat make possible to fulfil regulations of Marpol Convention. Due to high investment costs developed utilising systems were not widely applied on seagoing ships and were used only on large container ships with main engine power about 80 MW. An example of such ships can be E-Maersk series container ships equipped with main propulsion engines type 14 RT-flex 96C 80.080 kW in power. Present regulations will extort from owners to search solutions of fuel consumption minimising, among others utilisation of waste heat streams. TES seems to be one of the most effective solution. From two offered TES systems (single- and dual-pressure), the single-pressure system is more rational because it needs considerably lower investments. Reduction of fuel consumption in dual-pressure system is only 1-2% higher than in single pressure system while investment costs can exceed estimated profits.

An example of single-pressure system applied on large container ships is shown in Fig. 6. The system operates on modern container ship propelled by engine Wartsila Sulzer type RTA, where the scavenging air cooling heat is used for heating purposes.

Up to now TES system was not widely used on seagoing ships due to high investment costs. New IMO regulations concerning applying of Energy Efficiency Design Index EEDI on new built ships will extort owners to use TES systems on all merchant fleet ships in the nearest future.

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