Optimizing the energy efficiency of vessels using recovery boilers

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Abstract. In general, the energy requirement on board the ship is divided into three categories: propulsion power, auxiliary electric power and auxiliary thermal power. The WHRS system uses the energy dissipated from the exhaust gases, but also it can be used the energy from the main engine cooling water system (high temperature freshwater cooling circuit) and the air system by applying a WHR heat exchanger element to the main engine. The application of CFD in the analysis of heat exchangers is somewhat limited, being able to be used in the initial dimensioning thus reducing the number of prototypes and offering a clear image of the phenomena of heat transport from the equipment. In the economizer the water supply will turn into steam, so the problem to be solved is the two-phase flow with two different properties and the phase transformation of water from liquid to steam. These two phases are mixed in the economizer tubes at the macroscopic level. The two phases can coexist in dispersed form, droplets or steam bubbles. In the fluid field can coexist phases with different densities or different speeds.

1. Introduction

Referring to auxiliary thermal power, heat is commonly required to have three significant bearings: team comfort, fuel warming, and fresh water generation. Like the auxiliary electric loading, different sorts of the ship required or a specific measure of heat, just as on account of oil tanks (for warming the load with low consistency) or on account of cargo ships, for the salace of those on the shore.

The WHRS system uses the energy dissipated in the exhaust gases, but it also uses water energy to produce the cooling of the main engine (the main-temperature freshwater cooling circuit) and can use an aerial application for a WHR heat exchanger element to the main engine.

In other innovations, the Organic Rankine Cycle (ORC) can be utilized for the recuperation of lingering deposits of the inward ignition motor product.[1]

2. Waste heat recovery systems

2.1. Power concept and arrangement on the ship

The standard of the MAN B&W type two-stroke diesel engine for WHRS is that that piece of the fumes gas stream sidesteps the primary turbocharger of the engine through a detour system with fumes funnelling.
The working standards for the WHRS system appear in figure 1. As referenced before, a WHRS framework comprises of various segments and can be planned as an independent or a joined framework. Picking a framework for a venture relies upon power request from the ship (electrical charge), working profile of the ship (working hours at various heaps of the principle engine), cost recuperation time for the proposed WHRS arrangement dependent on the track profile and space accessible on the ship.

A significant piece of choosing the best WHRS frameworks for a ship engine is its decision to guarantee the best propulsion force and speed for the ship having the most noteworthy propeller conceivable to guarantee the least conceivable fuel utilization. Much of the time, the WHRS framework will have the option to give an aggregate sum of power to the ship as an independent force source, however, can likewise work in corresponding with a diesel generator. This kind of framework requires a propelled power the executives’ framework (PMS), with which the MAN Diesel and Turbo control framework works couple.[2,3]

![Figure 1. Waste heat recovery system working principle.](image)

2.2. Power turbine and generator

The least difficult and least expensive framework comprises of an exhaust gas turbine (likewise called a force turbine) introduced in the fumes gas by-pass framework and a generator that changes over the turbine load into power on board the ship, see figure 2. [4] For power turbine arrangements, the primary beneficiary of the engine will be outfitted with two fumes gas associations, one for the motor fumes gas stream (EGB) and one for the force turbine. The force turbine connection ought to, for the most part, be bigger in light of the fact that the force turbine unit is commonly discarded a couple of meters from the fundamental engine.

The fumes gas circuit with the control valve is a piece of the engine conveyance and will be tried on the seat with the motor. The MAN Diesel and Turbo TCS-PTG power extend appears in figure 2. TCS-PTG speaks to the supposed Turbo Compound System - diesel turbine generator and is a MAN Diesel and Turbo product.[2]
The force turbine is driven by a piece of the fumes gas stream that sidesteps the turbochargers. The force turbine creates an extra yield power, which relies upon the measure of sidestep gas. The PTG WHRS arrangement can be independent as well as an equal wellspring of power for the ship as shown in figure 3. The detour valve for the fumes gases will be shut at an engine intensity of not exactly about 40% MCR if the utilization of intensity for the force turbine is accessible for financial activity. The utilization of a TCS-PTG WHRS arrangement will give a recuperation proportion of 3-5%, contingent upon the size of the fundamental engine.[2]

This will expand the steam creation power acquired for the recuperation evaporator. By introducing a steam turbine (regularly called a turbo-generator), steam creation from the recuperative boiler framework can be utilized for the creation of power. The steam turbine is introduced on a typical motherboard with the generator similarly as the force turbine. Figure 4 presents the STG solution.[2]
2.3. Power and steam turbine with a generator (ST-PT)
The power and steam turbines are based on a typical plate and, through reducers, associated with a
typical generator, see figure 5. [4] The generated power from the turbines can be precisely transmitted
to the generator by means of a gearbox with an uncommon grip. Be that as it may, as a matter of first
importance, the steam turbine will begin at 30-35% of the SMCR intensity of the primary engine
followed by the force turbine which begins the power creation from 40 to half SMCR. The
consolidated schematic outline of the WHRS ST and PT can be found in figure 6, which shows a
framework that, in numerous conditions, incredibly decreases the fuel expenses of the ship by having
the option to cover the all out power requirement.[2]

2.4. Steam and water circuit in WHRS
The WHRS framework utilizes the power from gases and additionally utilize the power from the
principle engine cooling water system (HT cooling circuit) and the air framework by applying an
exchanging component. WHR heat at the fundamental engine. Both exchangers are utilized to warm
the inventory water for the steam framework to a temperature level just beneath the dissipation
temperature for the steam pressure in the framework. The water-steam graph, figure 6, shows the
associations between the various pieces of the framework - LP and HP economizers, dissemination
siphons, water supply siphons, vacuum condenser, LP and HP tanks. The control valves before the
steam turbine spread both the beginning capacities and the likelihood to empty the steam, if essential during activity. MAN Diesel and Turbo additionally prescribes that a detour line be orchestrated the fundamental WHR component of the motor to guarantee ceaseless course through the exchanger. On the off chance that the water in the HP loop arrives at a significant level, the entrance to the chamber will be shut and the detour line will be opened and used to guarantee course through the principal component (heat exchanger) WHR engine.[5]

![Figure 6. CFD calculations for placing the guide vanes in the outlet flow.](image)

3. Use of ORC in internal combustion engines

The advantages and disadvantages of ORC are:
- The operating range (100 - 500°C).
- ORC systems are suitable where the heat source temperature has low values
- ORC systems are compact and easy to operate
- ORC systems require low maintenance
- The lifetime of ORC systems is longer, more than 20 years.

Regarding the disadvantages we have:
- The biggest disadvantage of ORC technology is low thermal efficiency (between 10% and 25%). This is due to the reduced temperature of the heat source.
- Because they operate with refrigerants instead of water, ORC systems require more stringent safety measures compared to conventional steam cycles.

To improve the energy efficiency of internal combustion engines, an organic Rankine cycle can be used to recover waste heat. Several studies analyzing the performance of ORC systems have been conducted recently. An important challenge is to determine an ORC configuration - internal combustion engine, to maximize the energy efficiency throughout the engine operating range. A mathematical model for the design of the vaporizer and condenser is made in accordance with the operating conditions of the ORC system. Then, the overall coefficient of heat transfer and the total heat exchange surface area of the evaporator and condenser are determined for the entire range of operation of the diesel engine defined according to the engine speed and load.[6]
Figure 7. Organic Rankine cycle.

The diagram of an ORC system for waste heat recovery of a diesel engine is shown in figure 7. The basic components of an ORC system are the turbine or the holder, the vaporizer, the condenser and the pump. The energy from the exhaust gases of the engine is transferred to the working fluid through a vaporizer, where at high pressure the working fluid passes from the liquid state to the superheated vapour state. Subsequently, the resulting vapours, which have a high enthalpy, extend in a holder until the condensation pressure thus generates mechanical work. The vapours from the outlet of the holder enter the condenser of the plant where the heat of the cold source is transferred. The resulting liquid is pressurized by the feed pump to the vaporization pressure, then the cycle is resumed. Therefore, the vaporizer and condenser are key components of the ORC system. Generally, there are two types of heat exchangers used for waste heat recovery: plate heat exchangers and pipe-to-pipe heat exchangers.[6,7]

4. Ship and economiser characteristics
The economizer proposed for the study is part of the HORAI SAN ship which can be seen in figure 8. The ship is an oil tank. The economist's role in a naval installation is to recover the heat of the flue gases discharged from the engine which would otherwise be lost to the atmosphere. [4,8]

Figure 8. Tanker ship Horaisan.

Main economizer characteristics are in table 1.
Table 1. Economiser characteristics.

| EXH. GAS ECONOMISER | Type/ No. of set | Dual stem pressure / 1 set |
|---------------------|------------------|-----------------------------|
| Size                | 5909/9800/3682 mm |
| Heating surface     | 4345 m²          |
| Evaporation MAX/NOR | 18210/13540 kg/h |

With the evolution of the technologies of computerized modelling of the phenomena of nature, the focus is shifting and it will surely move from the experimental side to the simulation side in scientific research. The purpose of checking and validating numerical models is to make the model credible and accurate. The numerical model in our case is used to help make optimization decisions for the economizer of a seagoing ship and its credibility in producing accurate and accurate results should not be called into question. Numerical simulations are and remain only approximations of the real phenomena and therefore the comparison with the data extracted from reality is more than necessary. This ship is a modern ship with advanced diagnostics and automation systems.[4,8]

Figure 9 show reference economiser. The Mitsubishi Dual Steam Pressure Exhaust Gas Economizer is designed incorporating the latest heat exchanger technologies which Mitsubishi Heavy Industries Ltd has nurtured through its long experience with the manufacture of exhaust gas economizer and main and auxiliary boiler. The dual steam pressure exhaust gas economizer has a low-pressure evaporating section, high-pressure evaporating section and superheating section, each independently arranged with inlet and outlet headers and also casing supports and low-pressure steam separator which is appurtenant to the low-pressure evaporating section.

On the two monitors in figure 10, real-time data of the parameters of the ship's systems can be obtained and for the economiser, the monitor shows as in table 2:
At the propeller speed of 70.6 rpm the recorded data are:
- low - pressure steam temperature = 215°C
- high - pressure steam temperature = 209°C
- Steam temperature superheater = 297°C (Theoretically by construction 245°C)
- low - pressure steam pressure = 0.32 MPa
- high - pressure steam pressure = 0.8 MPa
- Superheated steam pressure = 0.72 MPa

5. Simulation of exploitation parameters

The three steps of the economizer work with different pressures and so the temperatures at which the water vapour becomes saturated must first be determined. The low - pressure stage LP works with the pressure of 2.9 bar and so the saturation temperature is 142°C. The HP high - pressure gear works with 7.4 bar pressure and so the saturation temperature is 172°C. The superheat step works with the pressure of 6.9 bar and so the saturation temperature is 170°C, as shown in figure 11. After the calculation, the temperature was determined to be 256°C so we can talk about superheating steam. The steam properties are given in table 3:

### Table 3. The properties of steam (stages pressure and 256°C).

| Stage | Pressure [bar] | Saturated temperature/ Calculated temperature [°C] | Enthalpy [kJ/kg] | Specific volume [m³/kg] | Specific heat [kJ/kgK] | Viscosity [mPa s] |
|-------|----------------|-----------------------------------------------------|------------------|--------------------------|------------------------|-------------------|
| LP    | 2.9            | 142/256                                              | 2977             | 0.61                     | 2.05                   | 0.018             |
| HP    | 7.4            | 172/256                                              | 2962             | 0.28                     | 2.1                    | 0.018             |
| Super | 6.9            | 170/256                                              | 2963             | 0.3                      | 2.14                   | 0.018             |
6. Conclusions
In the case of the temperatures recorded and calculated for the low and high - pressure stages, the calculated values are higher by 16% and 18% respectively, indicating worse conditions of heat transfer in these stages. In any case, the calculated and recorded values are comparable. The types of steam calculated and the one obtained in reality are identical, which shows with a clear view that the numerical model is valid. Regarding the pressures in the system, they may vary depending on the loading of the equipment after the economizer but the calculated values and the recorded ones are in a good correlation margin. By analyzing these results it turns out that the numerical model is valid and can generate credible results. It should be emphasized that the above proposals require enormous computing resources and as such an important investment in these resources will be required to perform the simulations. Currently, I am considering a collaboration with specialized research centres or those companies that have invested sufficiently in the new and modern methodologies and software of calculation with CFD, in order to achieve in the future what was proposed in the paper. Regarding the validation of the numerical model, a first remark is that there are depositing processes on the economizer pipes over time which inevitably leads to worsening heat transfer conditions and therefore the theoretical calculations only match those registered with a new economizer. On the other hand, the working parameters of the economizer vary with the load of the main engine.

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