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Design of Waste Heat Recovery System for the Scavenge Air of the Marine Diesel Engine

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Abstract

In order to reduce the consumption of fossil fuels during transportation and to improve the thermal efficiency of diesel engines, waste heat and power generation systems are increasingly being used on ships. The aim of this paper is to design a waste heat recovery system for the scavenge air of the marine diesel engine. The thermodynamic models were developed. Single-objective optimization designs was performed. The single-objective optimization algorithm uses Genetic Algorithm (GA). The optimization results show that thermal efficiency is 12.23%.

Keywords

Waste Heat Recovery; Scavenge Air; Optimization.

1. Introduction

In order to cope with the challenges brought about by the continuous deterioration of the global climate, my country proposed at the 75th United Nations General Assembly the development goal of "reaching the peak of China's carbon emissions by 2030 and achieving carbon neutrality by 2060" [1]. Countries such as Europe and the United States have also successively put forward the goal of achieving zero net carbon emissions by 2050 [2]. For the shipping industry, greenhouse gas emissions from shipping activities account for 2.2% of total global emissions. Therefore, as early as 2014, the International Maritime Organization (IMO) proposed to reduce the carbon emissions of ships by at least 50% by 2050 [3]. In addition, on October 5, 2021, the International Chamber of Shipping (ICS) submitted to the IMO a plan for the shipping industry to achieve net zero emissions by 2050, requiring countries to take urgent measures to achieve this goal [4]. At present, there are many technical means to help ships reduce carbon emissions, among which the ship waste heat power generation technology is considered to be the most effective method [5]. Therefore, it is of great significance to study ship waste heat power generation technology. The use of ship waste heat power generation technology can help the shipbuilding industry reduce fuel consumption and carbon dioxide emissions, and improve the efficiency of fossil energy utilization [6].

At present, most of the large ocean-going ships use a low-speed two-stroke diesel engine as the main propulsion device [8]. Although the thermal efficiency of a two-stroke diesel engine can reach 48~51%, from the perspective of energy balance, half of the energy is still discharged to the environment through exhaust gas, intercooler and cylinder jacket water. According to a report by MAN B&W Diesel, the company's 12S90ME two-stroke diesel engine outputs 49.3% of the fuel energy under 100% maximum sustainable power conditions, and the heat removed by the exhaust gas, intercooler and cylinder liner cooling water are respectively It accounts for 25.5%, 16.5% and 5.6% of the fuel energy, as shown in Figure 1-2. It can be seen from the figure that a large amount of waste heat is discharged into the environment. The traditional waste heat recovery method is generally to use waste gas boilers to recover waste gas to generate steam, and then use these steam to heat fuel oil and domestic use. Or use cylinder liner cooling water for desalination of seawater and refrigeration. However, the traditional method can only

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utilize part of the waste heat, and there is still a large amount of waste heat that cannot be fully utilized.

Therefore, converting the ship's waste heat into electric energy is an effective means of deep utilization of waste heat, which can not only save a lot of fuel by supplying power to the ship's electrical equipment, but also optimize the configuration and capacity of the ship's diesel generator set.

At present, there are many literatures on the use of exhaust gas to generate electricity, but the literature on the use of scavenging air is still very small. Therefore, this paper designs a waste heat power generation system for scavenging air.

Organization of the Text.

2. ORC Configuration

The Organic Rankine Cycle (ORC) power generation technology is currently the most promising technology in the medium and low temperature thermal power generation system. The ORC power generation technology is similar in structure to the water vapor Rankine cycle power generation system, but the fluid working medium is changed from water to organic refrigerant. The structure of the ORC power plant is shown in Figure 1 below. As can be seen in Figure 1, the ORC power plant mainly consists of an evaporator, a pump, an expander/turbine, a condenser and a generator.

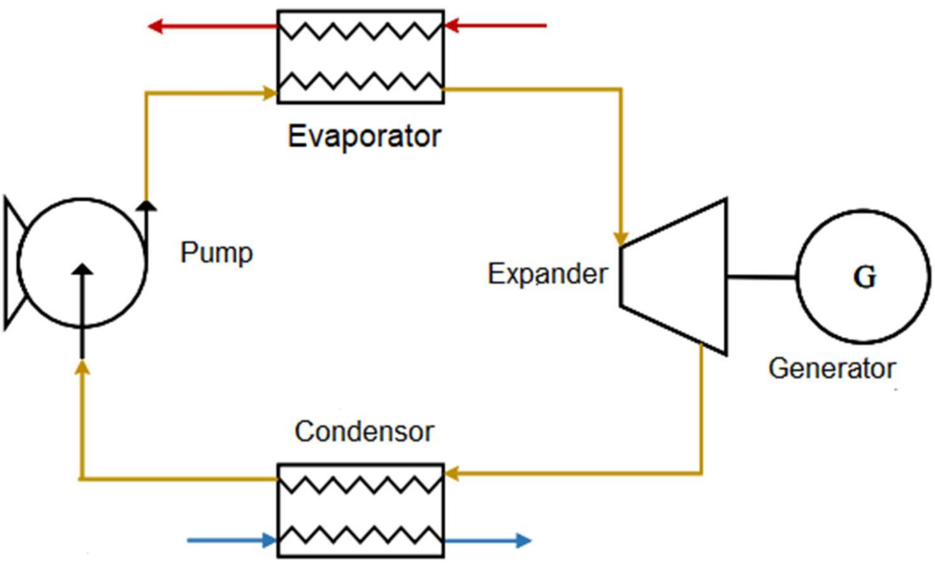

Figure 1. Configuration of the ORC

The working principle of the ORC power generation system is that the working fluid in the supercooled state absorbs the heat of the heat source in the evaporator, turns it into high-pressure superheated steam, drives the turbine or expander to do work, and drives the generator to generate electricity. After the high-pressure superheated vapor comes out of the turbine, it becomes a low-pressure superheated vapor, which is condensed in the condenser to become a supercooled liquid. The working fluid pump sends the supercooled liquid from the condenser to the evaporator to complete a basic cycle. The T-s diagram is shown in Figure 2 below.

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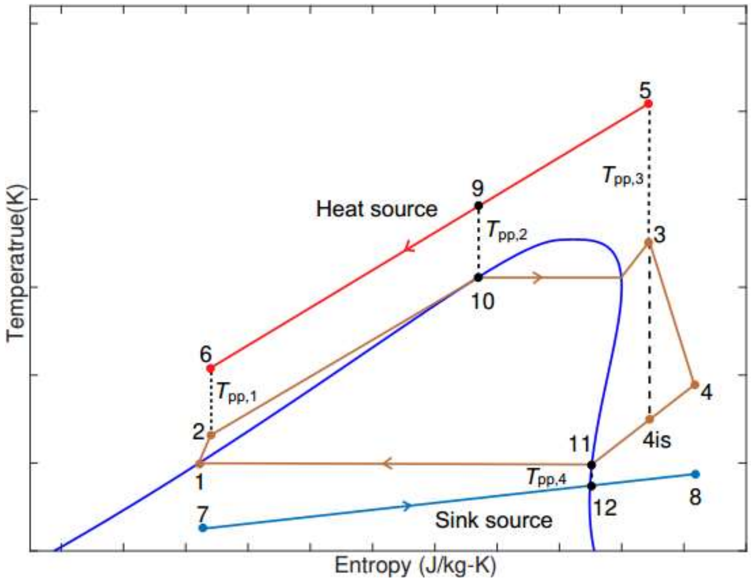

Figure 2. T-s diagram

2.1. Thermodynamic Model

The evaporator is analyzed according to the first law of thermodynamics, and the established energy equation is as follows:

$$Qev = mr(h3-h2) \tag{1}$$

$$Qev = mhscp(Thsin-Thsout) \tag{2}$$

The power output by the expander can be calculated by the following formula:

$$Wex = mr\ (h3-h4) \tag{3}$$

The power consumed by the pump is calculated as follows:

$$Wpu = mr\ (h2-h1)/\eta pu \tag{4}$$

The power consumed by the pump is calculated as follows:

$$Qcon = mr(h4-h1) \tag{5}$$

$$Qcon = mswcp\ (Tswout-Tswin) \tag{6}$$

The net power output by the generator is:

$$Wnpo = Wex-Wpu \tag{7}$$

Efficiency is:

$$\eta = Wnpo/Qev \tag{8}$$

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2.2. Optimization

In the actual optimization design, in order to maximize the output power of the power generation device, a single-objective optimization algorithm is usually used to solve the problem. The single-objective optimization algorithm chosen in this paper is the Genetic Algorithm (GA). GA is a meta-heuristic algorithm that can quickly and accurately find the optimal solution when the solution space is large.

During the optimization process, the relevant decision variables cannot exceed the bounds set by the relevant values. If the heat source is flue gas, the outlet should be more than 10 degrees above the dew point temperature to avoid corrosion.

2.3. Heat Source

The heat source comes from a two-stroke low-speed diesel engine, the model is MAN B&W 6S35ME-B9, and the data comes from the field test, the parameters are listed in Table 1.

Table 1. Heat source temperature

Item	Parameter	Unit
Temperature	422.37	K
Mass flow rate	10.33	kg/s

3. Results and Discussion

3.1. Analysis of Evaporation Temperature Effect

Evaporation temperature is a key operating parameter of ORC power plant, so this section analyzes the effect of evaporation temperature on the performance index of ORC power plant.

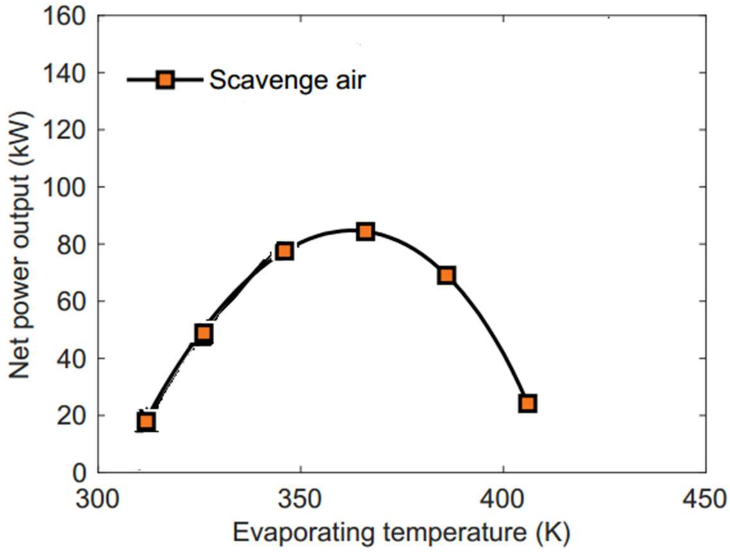

Figure 3. The effect of evaporation temperature on power

Figure 3 shows the effect of evaporation temperature on power. For ORC power plants using scavenging air as a heat source, there is an optimum evaporation temperature that maximizes power output. This evaporating temperature is 362K and the maximum power output is 84.74 kW.

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3.2. Analysis of Condensation Temperature Effect

Condensing temperature is a very important parameter in the design of ORC power plant, so it is necessary to analyze the influence of condensing temperature on various indicators of the system during design.

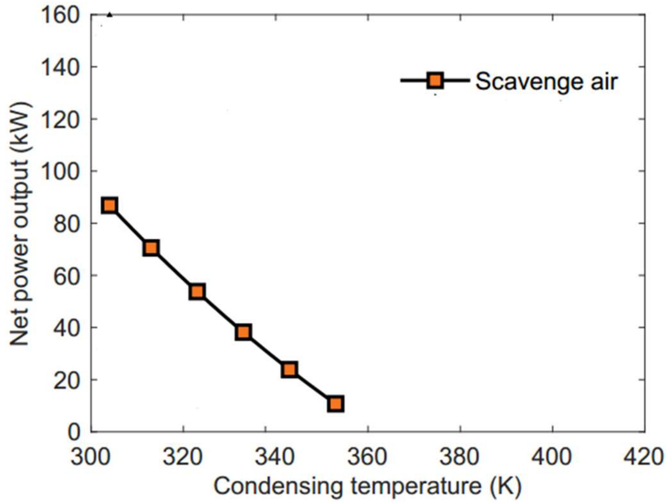

Figure 4. Effect of Condensing Temperature on Net Power Output

The effect of condensing temperature on the net output power of the ORC power plant is shown in Figure 4. It can be found that as the condensation temperature increases, the output power of the device decreases. The drop in condensation temperature has a greater impact on ORC power plants using scavenging air as a heat source. This may be because the scavenging air itself carries less heat, and the temperature of the scavenging air is lower than that of the exhaust gas, and it carries less available energy. Therefore, when designing an ORC power plant, a lower condensing temperature should be designed as much as possible.

3.3. Analysis of Single Objective Optimization Results

When performing single-objective optimization, the net output power is taken as the objective, and the optimization results are shown in Table 2 below.

Table 2. Optimization results

Item	Value	Unit
Power	83.74	kW
Efficiency	12.23	%

In Table 2, it can be found that the net output power optimization results of ORC power plants using scavenge air. The net power output is 83.74 kW and the efficiency is 12.23%.

4. Conclusion

This paper introduced the structure and working principle of the basic ORC power plant, and establishes the steady-state thermodynamic model of the basic ORC power plant. The effects of condensing temperature and evaporating temperature on the power of the basic ORC power plant were analyzed. For ORC power plants using scavenging air as a heat source, the optimum evaporation temperature is found. An increase in the condensing temperature will lead to a decrease in all performance indicators of the ORC power plant. The optimization results showed that the net power output is 83.74 kW and the efficiency is 12.23%.

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