Research on Utilization of Ship Waste Heat

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Abstract: Since the oil crisis in 1973, world oil prices have continued to rise, and ship operating costs have risen year by year. In 2013, the ship energy efficiency design index formally took effect, setting a rigid indicator for ship CO2 emissions, bringing a new round of technical competition to ship construction, and the application of waste heat utilization technology has a significant effect on improving the efficiency of diesel engines.

1. The composition of waste heat

1.1. Exhaust heat
Marine diesel engine is the power source for ship operation and navigation. Its exhaust heat accounts for almost 40% of the total heat. The exhaust temperature is between 350°C and 420°C. If this part of heat enters the atmosphere directly, it not only causes energy waste but also harms the atmospheric environment. The total exhaust heat of diesel engine is:

\[ Q = C_p T_2 M T_2 - C_p T_1 M T_1 \]

1.2. Cooling water waste heat
In order to ensure the normal operation of diesel engines, cooling is an indispensible part, but cooling will take away part of the heat and reduce thermal efficiency. The main cooling components in diesel engines are cylinder liners and pistons. In order to improve efficiency, this part of cooling water is required. The heat taken away is recycled.

The heat taken away by the cooling water is:

\[ Q_2 = C_p m_1 \Delta T_1 + C_p m_2 \Delta T_2 \]

1.3. Other heat dissipation
In addition, the diesel engine itself, the air cooler, the lubricating oil cooler, the supercharged air, etc. will lose part of the heat during the working process of the diesel engine. This part of the heat is difficult to collect and is generally not considered.

2. Waste heat kinetic energy utilization technology

2.1. Exhaust turbocharger
The exhaust gas turbocharger uses the exhaust inertial impulse to drive the turbine in the turbine
chamber, and the turbine drives the coaxial impeller. The impeller compresses the fresh air passing through the air filter to increase the pressure of the air entering the cylinder. The air volume of the cylinder increases, which can support more fuel combustion. Therefore, by increasing the fuel injection volume and adjusting the speed, the output power of the diesel engine can be increased and fuel consumption can be reduced.

2.2. Power turbine
The power turbine is an impeller machine that converts the energy of the gas into mechanical energy to drive an external load. When the diesel engine is working under high load, it guides the excess exhaust gas to drive the power turbine to drive the generator to generate electricity and integrate it into the grid.

2.3. Power turbine
The application of pressurization technology on ships makes the exhaust temperature of marine diesel nearly 400°C, and high-temperature flue gas is introduced into the waste heat boiler through pipelines to produce water vapor or hot water. Among them, water vapor can be used to drive steam turbines to generate electricity or to drive steam auxiliary machinery to work, and can also be used for oil tank heating and daily water use by ship personnel.

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2.5. Waste heat boiler
The discovery of the Seebeck effect makes the direct conversion of thermal energy into electrical energy a reality. Connecting one end of two different semiconductors together and heating it to make it in a high temperature state, and leaving the other end in a low temperature state without treatment, will form an open circuit voltage $\Delta V$ at the low temperature end. This effect is called the Seebeck effect.

3. Waste heat heating

3.1. Direct heating
1) Pre-heating of food and domestic water for crew members and passengers, and fuel heating;
2) Warm up the engine to solve the cold start problem;
3) The waste heat can also heat the crew living area.

3.2. Fresh water from waste heat
In recent years, with the development of economic globalization, there has been more and more maritime transportation, and ships have sailed farther and farther. At this time, the demand for fresh water by ships is also increasing. Among them, seawater desalination devices usually use distillation to obtain fresh fresh water. The use of waste heat of exhaust gas for desalination has considerable economic benefits.

3.3. Waste heat power generation
During the working process of marine diesel engines, a large amount of high-temperature exhaust gas waste heat resources are discharged outward. The general waste heat recovery system converts this heat energy into hot water or steam for machine operation or life needs. However, this heat energy utilization method is often restricted by the working conditions of the ship, and in many cases the heat
energy cannot be fully utilized. The waste heat power generation technology can directly convert the waste heat into electrical energy that is convenient for use and transmission, which significantly improves the economic benefits of ship transportation.

3.4. Waste heat cooling
Although the medium and low temperature waste heat can be directly used for domestic heating, and the equipment is simple and economically feasible, the heating is seasonal, and the waste heat can only be discharged during the non-heating period. If the waste heat is used as a low-temperature heat source, the heat pump can increase the temperature level, which can expand the use range and increase the utilization value of low-temperature waste heat.

3.5. Power application of waste heat
Turbocharging technology has a history of more than 100 years. Large and medium-sized marine diesel engines basically use exhaust gas turbocharger technology, and small high-speed diesel engines with turbines are also developing rapidly. The exhaust gas turbine drives the compressor of the diesel air system to inject high-pressure gas into the cylinder. Because the turbocharger uses the exhaust energy of the diesel engine to drive, and does not consume the power of the diesel engine itself, it helps to improve the economy of the marine diesel engine, generally reducing fuel consumption by 3% to 10%.

4. New utilization and prospect of waste heat

4.1. New utilization of waste heat
The gas turbine is an ideal Carnot cycle. Due to its high exhaust temperature, the efficiency of the gas turbine is not much higher than that of the steam turbine. The exhaust temperature of modern high-temperature gas turbines has reached about 600°C, which is higher than the initial temperature of the steam turbine cycle. Such high-temperature exhaust gas is discharged into the atmosphere, causing a huge waste of energy. Therefore, the high-temperature exhaust gas is used to heat water to generate steam, which leads to the steam turbine to drive the motor to generate electricity. This constitutes a gas-steam combined cycle waste heat reuse system. The basis of thermoacoustic cooling technology is the thermoacoustic effect. It absorbs the waste heat energy of the marine diesel engine, converts the heat energy into sound energy, and then uses the thermal effect to consume the sound energy to achieve cooling. The thermoacoustic refrigeration system has no moving parts, high reliability, and will not cause negative effects on the environment.

4.2. Waste heat utilization outlook
1) With the increase of crew requirements for the comfort of ship's engine room, the application of waste heat utilization technology will be popularized in various ships, such as ship engine room heating and shipboard refrigerator cooling.
2) The waste heat technology is used in the heat preservation of the engine, which can solve the problem of cold start of diesel engines in high latitude areas and winter, and can improve the fuel economy of ships.

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