Study on Waste Heat Utilization Device of High-Temperature Freshwater in the Modern Marine Diesel Engine

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Abstract. Based on using the waste heat recycling from high temperature freshwater in marine diesel engine to heat fuel oil tank, lubrication oil tank and settling tank and so on to achieve energy saving, improve fuel efficiency as the goal, study on waste heat utilization device of high-temperature freshwater in the modern marine diesel engine to make the combustion chamber effectively cooled by high-temperature freshwater and the inner liner freshwater temperature heat is effectively utilized and so on to improve the overall efficiency of the power plant of the ship and the diesel optimum working condition.

1. Introduction
With the development of shipping industry, energy shortage, higher fuel cost, sustainable growth of the demand of fuel and International Maritime Organization (IMO)'s attention to energy saving make energy saving be viewed as an extreme significant problem by all shipping companies[1][2]. To achieve win-win benefits of economy and environmental protection, we should study on energy-saving technology and applying it into practice. Therefore, to recycle and utilize ship waste heat is an important and effective way.

Waste heat recovery mainly consists of recycling waste heat from exhaust gas and high temperature chilled freshwater. In recent years, experts and scholars devote themselves into the research of recovering energy of ship from exhaust gas. So far, they have obtained the certain achievement. But it’s far from adequate that only recycle waste heat from exhaust gas. It is of great significance to ship energy saving that make full use of the waste heat recycled from high temperature freshwater.

In the ship which takes diesel engine as the main propulsion, most of heat energy produced by burning fuel is dissipated through cooling water, exhaust and so on, only 40-50% can be converted to mechanical energy[3]. The general temperature of the high temperature freshwater in the inner liner of diesel engine is 70-85°C. Obviously, the freshwater contains a large amount of energy, but most of them will be wasted as the freshwater flows out of the ship. According to Heat Balance of the Diesel Engine, 25%-35% of total heat is dissipated by liner cooling water. Presently, reusing ship waste heat has become the inevitable trend of energy conservation and emission reduction[4][5].

2. The Status of High Temperature Freshwater Cooling System in Modern Marine Diesel Engine

2.1. High temperature Freshwater Cooling System
During the operation of marine diesel engine, a great deal of heat produced by fuel in the air cylinder makes the surface temperature of the combustion chamber increase which may affect the normal work of the unit. to ensure that the temperature is in a normal working range, some heat should be taken away by smoke and the rest part needs to be processed by cooling medium.
As shown in Figure 1, the high temperature freshwater enters the cooling water chamber of cylinder liner through the cooling water main pipe K. After cooling the cylinder liner, it enters the cooling jacket of the cylinder head by two cooling water joints. When the lower part of the cylinder head is cooled, it goes upward through water holes into cylinder head and exhaust valve seat to form the confined space to cool the exhaust valve seat. After that, a part of water cools the upper part of the exhaust valve, the rest of the water flows out of cylinder head and gathers at the outlet main pipe. Finally the first part will flow out into the main pipe.

![Figure 1: High temperature freshwater cooling system](image)

1-expansion tank; 2-dearation tank; 3-evaporator
4-high temperature freshwater cooler

When cooling water flows out from the outlet main pipe L, it will pass through the first temperature control triple valve A which is a bypass-valve of the evaporator, the temperature is generally set to about 70°C. The temperature of water which flows into the jacket water cooler can be regulated by the by-pass valve. When the evaporator is running, the triple valve makes a part of high temperature freshwater pass through the evaporator, but the freshwater will all pass by if it stops working.

After passing through the triple valve of evaporator, the cooling water will flow into the second triple temperature control valve and its temperature is set to about 80°C. Then the water will be divided into two parts, one bypasses the cooler while the other goes into the high temperature freshwater cooler. At last, they will flow into dearation tank together. In the system, the temperature of the water that flows out of the main engine can be detected by the sensor installed on the water outlet main pipe of cylinder liner. Afterwards, the temperature can be maintained between 80 and 85°C by controlling the flow of by-pass water and the water flowing into cooler with the help of regulator. When the temperature of the water that flows into cylinder liner is below normal value, the opening degree of valve will be regulated to reduce the flow of the water cooler. If the temperature is higher than normal value, it will do the opposite. Once air gets into the system, it will enter into the expansion tank
through the upper pipe of the dearation tank and be released into air. In addition, there’s a stream of water from expansion tank flowing directly into dearation tank to play the role of replenishing water and increasing the pressure head of water pump and flowing into two parallel running cylinder pump finally.

2.2. Defects and Influences of Existing Systems

When the marine diesel engine is running, heat loss in the engine is one of the most important aspects among numerous defects. In the central cooling system, the temperature of sea water will gradually rise because of interchanging heat with low temperature water. However, the heat can’t be recycled for that most of sea water is expelled from the ship, which may reduce the thermal efficiency of the marine diesel engine.

Once the seawater pump is plugged, it cannot reach the cooling effect. What’s more, seawater is so corrosive that the cooler and pipeline may be corroded, which may arouse freshwater pollution, increase the maintenance cost of central cooling system of marine diesel engine and shorten the lifespan of equipment and pipelines[6].

3. Waste Heat Utilization Device of High-Temperature Freshwater in the Modern Marine Diesel Engine

3.1. Working Principle

A large amount of heat is wasted in the central cooling water system. To solve this problem effectively, based on heat transfer theory and the character that water’s temperature is higher than fuel oil tank, lubrication oil tank and settling tank, we come up with an idea to improve the cooling water system of the main engine and design a waste heat utilization device of high-temperature freshwater which can replace the traditional low temperature freshwater cooling system and sea water cooling system. It will cool the combustion chamber while applying the waste heat into heating fuel oil tank, lubrication oil tank and settling tank, etc.

![Figure 2 Block diagram of high temperature freshwater cooling water system for marine main engine](image)

1-water replenishing valve; 2-water replenishing pipe; 3-outlet valve; 4-outlet pipe(high temperature freshwater inlet pipe of main engine); 5-triple temperature control valve; 6-inlet pipe(high temperature freshwater outlet pipe of main engine); 7-heat exchange tube; 8-heat exchange tank; 9-overflow pipe; 10-return pipe; 11-return valve; 12-outlet pipe; 13-outlet valve; 14-return junction box; 15- hot water distributor; 16-non-return valve; 17-inspection glasses; 18-centrifugal pump; 19-inlet pipe; 20-outlet pipe;
As shown in Figure 2, the system consists of high temperature freshwater system, heat exchange tank, residual heat utilization terminal cooler and heat exchange tube. The temperature of freshwater rises for taking away the excess heat of the main engine. To achieve the double effect of cooling high temperature freshwater and heating the water in the tank, bring the outlet water into the heat exchange tank when it flows to the triple valve which can adjust the opening degree automatically maintain the temperature between 60-70°C. The hot water flows out from the water outlet pipe and then flows to heating terminal tube through the main valve, hot water distributor, non-return valve and so on. That means the hot water will heat fuel oil tank, lubrication oil tank and settling tank, etc. At last, it flows back to the tank and cycles again and again.

3.2. The Function of Components
Waste heat utilization device of high-temperature freshwater in the marine main engine is composed of many independent components. The functions of these components are as follow:

3.2.1. Heat Exchange Tank. The open-designed tank is used to store the water. The opening at the top of the tank is beneficial to the expansion of the hot water and convenient for the marine engineer to observe. The lower part is equipped with an outlet pipe to export the heated water and the upper part is equipped with a replenish pipe with a water replenishing valve. Once the water is not enough, the sensor installed at the lowest water-level sends out water shortage signal to replenish water. To avoid the overflow, the overflow pipe is installed above the water replenishing valve. There are return pipe and valve letting the water flow back to tank.

3.2.2. Heat Exchange Tube. Heat exchange tube plays the role of supplying the freshwater into the tank and exchanging heat with inner water. The inlet pipe is equipped with a triple temperature control valve and connected to outlet of the main engine. The outlet of heat exchange tube is connected with the high temperature water pump by outlet pipe. The triple valve can regulate the flow according to the change of temperature in the tank. The triple temperature control valve is respectively connected with main engine cylinder liner, heat exchange tank and high temperature freshwater cooler in the main engine cylinder liner. There is an outlet valve installed between the outlet of heat exchange tube and the inlet of high temperature freshwater pump.

3.2.3. Hot Water Distributor. The main function of hot water distributor is to distribute the hot water to different water pipes. The inlet of hot water distributor is connected with outlet pipe of the tank and the outlet is connected with outlet pipe. Each outlet pipe has a centrifugal pump, of which non-return valve is installed on both sides, and is connected to the heating terminal tube to heat different equipment.

3.2.4. Heated Terminal. The heated terminal includes fuel oil tank, lubrication oil tank and settling tank. At the bottom of the fuel oil tank, heating coils is installed to maintain its liquidity and make it easy to be transferred. To accelerate the separation of precipitation in oil, engineers can regulate the flow and heat the fuel to the proper temperature. Lubricating oil which is pumped from the lubricating oil circulating tank and settling tank flows to lubrication oil purifier after heated by heating coils. Afterwards, sludge will be sent to the sludge tank. In the end, the lubricating oil return to the lubricating oil circulating tank.

Settling tank is used for storing the oil from fuel oil tank and heating the fuel oil to make the sludge settle into bottom and remove most of the water. The treated fuel oil will be transferred to daily service tank.

4. Maintenance of the Utilization Device

4.1. Adjustment of Fresh Water Temperature
It is forbidden to make the temperature of freshwater outlet too low or too high, the instructions should be followed strictly. For medium-speed diesel engine, the outlet temperature can be controlled at
70-80°C and 60-70°C for the low speed engine. In addition, the temperature between inlet and outlet is controlled within 12°C \(^7\). Once found that the individual cylinder temperature is abnormal, the marine engineer must evaluate whether thermal load is abnormal. If fuel injection quantity and fuel delivery are normal, engineer can adjust the cylinder outlet valve to make the water temperature return to normal. Engineer should remove some part of load and make the cooling water temperature gradually decreased if the diesel engine were overheated. It’s forbidden to stop diesel engine immediately or replace the high temperature water with cooling water.

4.2. Inspection of Cooling Water Flow in Each Cylinder
The high temperature freshwater should be cooled to make sure the water is in the normal range when the main engine is working. So an automatic temperature control device at the outlet of the system is needed. If the temperature reaches the limit value, the sea water cooling system can start automatically to keep the freshwater cooling system from high temperature. The more heated terminals are, the higher the heat exchange efficiency is, but the temperature should range from 60°C to 70°C. To utilize the waste heat effectively and protect high temperature freshwater cooling system from damage, the quantities of fuel oil tanks, lubrication oil tanks and settling tanks should be appropriate.

4.3. Inspection of Components and Parameters of Waste Heat Utilization Device of High-Temperature Freshwater
Need-to-check components include the triple valve, heat exchange tank, heat exchange tube, water supply device, overflow device, outlet pipe, hot water distributor, centrifugal pump, return main pipe, observation glasses and each valve. The parameters of tank level, liquid level of hot water distributor and return manifold should be checked and estimated whether meet the requirements. In the process of operation, tank level, temperature and pipeline circulation should be checked regularly. In addition, engineers should observe if each devices is working properly, replace water and clean the tank regularly according to the quality of water.

5. Conclusions
In this paper, based on the performance of heat-exchange device and water, the marine diesel engine cooling system will be replaced by waste heat utilization device of high-temperature freshwater. Some conclusions are as follow:

1) The device can cool the combustion chamber effectively, for which the main engine can work properly.
2) The device can recycle a large amount of heat, improve the efficiency of marine diesel engine and the power of propulsion plant.
3) It can reduce maintenance cost in circumstance of protecting flange and valve from the damage caused by high temperature steam that heat fuel oil tank, lubrication oil tank and settling tank with the heat from high temperature freshwater. Meanwhile, it can improve the utilization of energy.

6. References
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