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RESEARCH ON ENERGY SAVING OF 59990 T BULK CARRIER BASED ON FREQUENCY CONVERSION CONTROL WITH PULSATING ENHANCED HEAT EXCHANGE

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ИССЛЕДОВАНИЕ ЭНЕРГОСБЕРЕЖЕНИЯ НА БАЛКЕРЕ ДЕДВЕЙТОМ 59990 Т НА ОСНОВЕ УПРАВЛЕНИЯ ПРЕОБРАЗОВАНИЕМ ЧАСТОТЫ С ПУЛЬСИРУЮЩИМ УЛУЧШЕННЫМ ТЕПЛООБМЕНОМ

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Abstract. The ship's central cooling water system is one of the most important systems serving the main engine. With the progress of society, the design and construction of ships increasingly need to develop in the direction of environmental protection and energy-saving. Taking the 59,990 t bulk carrier as the *research object*, this paper proposes that based on the frequency conversion control of the seawater pump and supplemented by the energy-saving scheme of pulsation enhanced heat exchange, the frequency conversion control of the seawater pump is realized by adjusting the speed according to different working conditions. At this time, adding pulsation enhanced heat transfer technology can generate forced convection, increase the turbulence of the fluid in the tube, and introduce convection into the boundary layer, and at the same time produce cavitation, which can improve the heat transfer efficiency of the equipment. After using the seawater pump frequency conversion control and pulsation enhanced heat exchange program, the energy consumption is about 36% of that before the system was installed. The data shows that the program achieves the purpose of environmental protection and energy-saving and has a certain reference value for engineering research.

Аннотация. Центральная система водяного охлаждения судна — одна из самых важных систем, обслуживающих главный двигатель. По мере развития общества проектирование и строительство судов все чаще должно развиваться в направлении защиты окружающей среды и энергосбережения. В качестве *объекта исследования* предлагается балкер дедвейтом 59 990 т. На основе управления с преобразованием частоты насоса морской воды и дополненной энергосберегающей схемой теплообмена с усилением пульсации реализовано управление с преобразованием частоты насоса морской воды путем регулировки скорости в соответствии с различными условиями работы. В это время добавление технологии усиленной пульсации теплопередачи может вызвать принудительную конвекцию, увеличить турбулентность жидкости в трубе и ввести конвекцию в пограничный слой, и в то же время вызвать кавитацию, которая может повысить эффективность теплопередачи оборудования. После использования управления преобразованием частоты насоса забортной воды и программы теплообмена с усилением пульсации потребление энергии составляет около 36% от того, что было до установки системы. Данные показывают, что программа достигает цели защиты окружающей среды и энергосбережения и имеет определенную эталонную ценность для инженерных исследований.

Keywords: frequency conversion, pulsation, enhanced heat exchange, energy saving.

Ключевые слова: преобразование частоты, пульсация, усиленный теплообмен, энергосбережение.

Introduction

With the development of the times, due to environmental issues and energy shortages, energy efficiency has become more and more important. Ship transportation is the main mode of transportation in world trade. Energy consumption and carbon dioxide emissions are huge. So important, because it consumes nearly 20% of the total energy in onshore power installations. Compared with the above-mentioned land equipment, the energy consumed by pumps in marine equipment is much more than that. Studies have shown that the energy consumed by the ship's water pump system accounts for almost 50% of the total energy consumption. These pumps work at a constant speed. However, some systems work under variable loads. For example, the load of a seawater cooling system depends on certain parameters: seawater temperature and engine load. Therefore, the pump speed can be adjusted according to different working conditions to reduce energy consumption [1]. Variable speed pump is one of the solutions to save energy in this system, it will change the pump speed according to the seawater temperature; another method is to add pulsation enhanced heat transfer technology in the original system, which can not only improve the heat transfer performance of the equipment, but also and it also has the function of anti-scaling and descaling. And this technology has also attracted widespread attention from all walks of life at home and abroad and has been used in industrial production. It is believed that it will also have a wide range of application prospects in daily life in the future. This paper takes the 59990 t bulk carrier of Hyundai Shipbuilding Co. as the research object. Based on the frequency conversion control of the sea water pump, a design plan for improving the heat transfer with pulsation is proposed. By calculating the energy consumption under different working conditions after the addition of frequency conversion control and pulsation enhanced heat exchange, the energy saved in the system, and proved its energy saving effect.

The maritime sector is one of the causes of global air pollution. According to statistics from relevant departments, carbon emissions in 2012 were 962 million tons, compared with 1.056 billion tons in 2018. In these six years, nearly 3% of global carbon dioxide emissions were emitted by ships. And because about 90% of world trade is transported by sea, there is no alternative transportation method for the time being. For this reason, the International Maritime Organization has proposed a new goal to reduce the industry's overall greenhouse gas emissions by 50% from

2008 levels by 2050. Therefore, the pressure on the shipping industry is increasing. In the past six years, the carbon dioxide emissions of the maritime transport industry have increased dramatically. It is difficult for the IMO to achieve the targets set, and there may even be more stringent regulations to establish a more complex regulatory framework. Shipping emissions will affect global air quality, people's health, marine ecology and global warming.

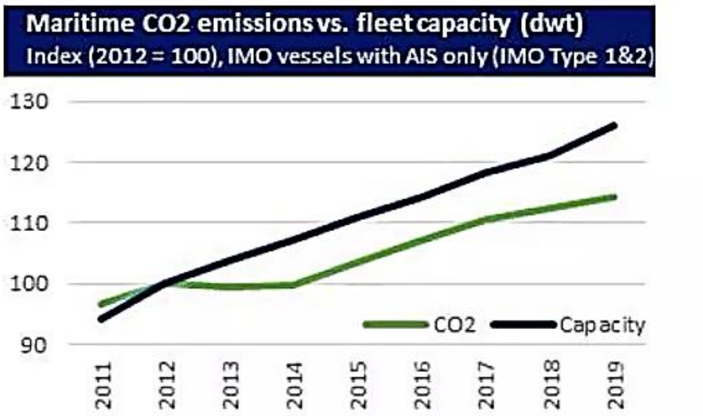

Figure 1. Maritime CO_2 emissions vs. Fleet capacity

Research background and methods

In addition to the study of control theory, there are also ways to improve the efficiency of centrifugal pumps through frequency conversion adjustment. In 2012, taking the 57000t bulk carrier as the research object, Chen Weizhi and others based on the EEDI formula, obtained the influence of the design scheme on EEDI, and also analyzed the corresponding investment income. The final result shows that the cost of investment in frequency conversion control can be offset by the saved fuel cost in half a year, so it has a broad market prospect [2].

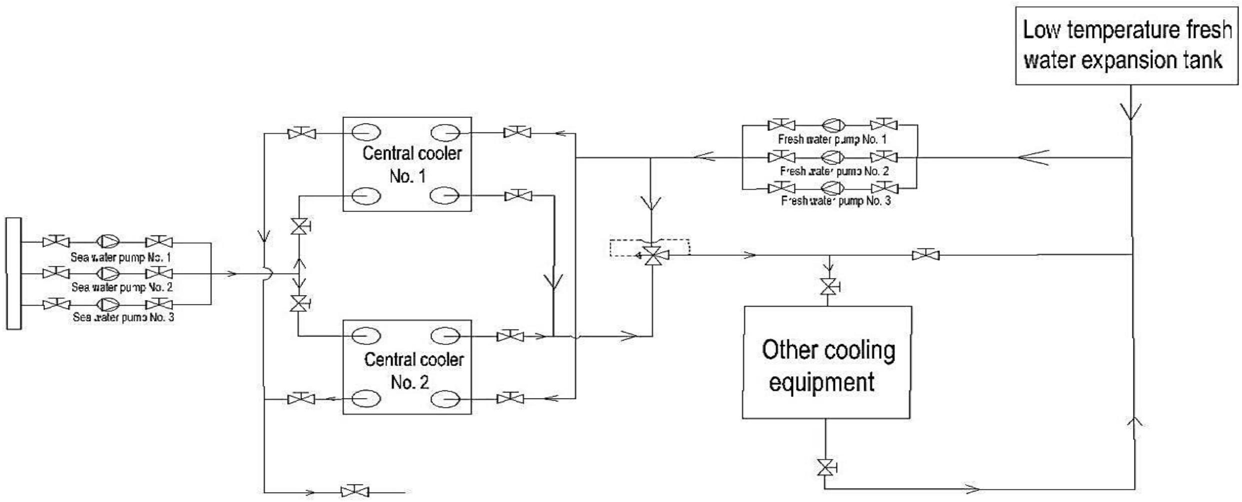

Figure 2. Frequency conversion sea water pump cooling system

Figure 2 shows the frequency conversion sea water pump cooling system on a 59990t bulk carrier. As can be seen from the figure, the system first detects different freshwater temperatures at the outlet of the cooler through the sensor, and then can change the frequency of motor rotation according to the calculation, and output the demand for seawater at this time, so as to achieve the purpose of energy saving. If it is detected that the freshwater outlet temperature exceeds the set temperature, it indicates that the amount of cooling water is insufficient at this time, and the frequency of the motor should be increased, so that the amount of cooling water will also increase; when the temperature is less than 32°C, it indicates excessive cooling. It will cause energy waste and cause certain damage to the equipment. So, reduce the frequency of the motor, thereby reducing the amount of cooling water. Another important point is that if the seawater temperature exceeds a certain value, salt precipitation will occur. Therefore, when the seawater outlet temperature reaches the set value, the speed of the seawater pump cannot be reduced. At this time, we can pass the automatic tee the temperature control valve regulates the temperature of the fresh water. This system first detects the freshwater temperature at each cooling device, and then calculates the required amount of cooling water to change the speed and flow rate of the sea water pump, so as to achieve the effect of energy saving [3].

The most important equipment in the cooling system is the heat exchanger, and the research on the heat exchanger has always been a hot spot. Research by Feng Lili and others many years ago showed that if the flow rate of the hot fluid is increased while the flow rate of the cooling fluid remains unchanged, the heat transfer coefficient and flow resistance of the hot side of the heat exchanger will also increase accordingly [4]. And Shu Tao et al. verified through experiments that the equal flow rate method can be used for heat transfer performance experiments of plate heat exchangers [5]. Gut et al. used two methods in 2004 to obtain simulation results of different heat exchanger structure parameters and different flow distribution patterns. They established a steady-state model during the research process. In the research, the corresponding thermodynamic model is first obtained according to the difference of the heat exchanger structure, and then the pure countercurrent conditions are used to compare and analyze the results calculated by the two methods to obtain a conclusion [6]. In 2009, Ren Hongli and others studied the heat transfer performance of fluids with higher viscosity, and finally concluded that the flow index value is related to the fluid viscosity, and the higher the viscosity, the greater the actual deviation, and the smaller the viscosity, the smaller the deviation [7].

The research object of this paper is the 59990dwt bulk carrier of Hyundai Shipbuilding Company. The main engine model of the ship is 6S50ME-C9.5, the power is 7500 kW, and there are 3 main central sea water cooling pumps and 3 freshwater cooling pumps. Each sea water pump has a flow rate of 250. The power is 37 kW, the flow rate of each freshwater pump is 200, the power is 30 kW, and the total heat exchange area of the central cooler is 245. The experiment set the highest temperature of seawater to 32 °C, and the highest temperature of the cooler seawater outlet to 45 °C.

The heat exchange formula is: (1)

In the formula: P is the heat to be exchanged, kW;

Q is the flow rate of the cooling sea water pump;

C is the specific volume of the cooling sea water;

It is the temperature difference between the inlet and outlet of the cooler, °C.

When sea water temperature is 32 °C, = (45–32); when sea water temperature is 25 °C, = (45–25). Assuming the same amount of heat exchange, when the seawater temperature is 25°C, the amount of cooling seawater required for each unit is about 165. At this time, the power of the seawater pump is 28 kW, which saves 9 kW of electricity per unit and saves about 24.3%. When the power of the main engine is 60%, the heat that needs to be cooled by seawater is about 67% of the rated state. If sailing in waters of 25 °C, the amount of cooling sea water required by each pump is only 100. At this time, the shaft power consumed by the sea water pump is 24 kW, and each pump can save about 13 kW of electricity and save about 35.1%. It can be seen that when the frequency

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conversion technology is added to the ship's central cooling water system, energy consumption can be effectively reduced. It can also greatly save operating costs while saving energy and reducing emissions. It is a technology worth promoting [8].

Experimental Research

Set a diversion at the cold-water end of the 59990 t bulk carrier's frequency conversion control system, so that the mainstream flow will be stable. The amplitude of the pulsation can be changed by adjusting the opening of the ball valves at the two branch ends, and the pulsation frequency can be changed by setting the opening and closing time of the solenoid valve through the time controller. The heat exchanger used in this experiment is a BRQ opposite-side brazed plate heat exchanger. Due to environmental constraints, a smart temperature-controlled water tank is selected. The temperature of the cold and hot fluid can be measured through a K-type thermocouple, and the pulsating pressure amplitude is It is measured by the SIN-P300 pressure sensor, and the flow of cooling water and hot water is measured by the volume method. The data during the experiment was collected by Advantech USB-4718 data acquisition card, and then used Microsoft Visual Studio as the platform to program independently to establish a data visualization platform and database [9].

The pulsation frequency and pulsation amplitude increase the heat transfer by increasing a part of the longitudinal flow cycle and in turn reducing the tube inner film thickness [10], and then reverse the axial flow, causing the kinetic energy of the radial shunt. Pulsating flow is related to sudden changes in periodic pressure gradients that lead to increased radial and axial mixing. Each periodic movement of the fluid increases the degree of turbulence in the tube. Higher pulsation frequency and pulsation amplitude means more frequent and more severe interference to the fluid, which further improves the turbulence. However, at higher flow rates, the influence of pulsation on the heat transfer coefficient is weakened, because the pulsation will compete with the high degree of turbulence already formed in the fluid at this time [11].

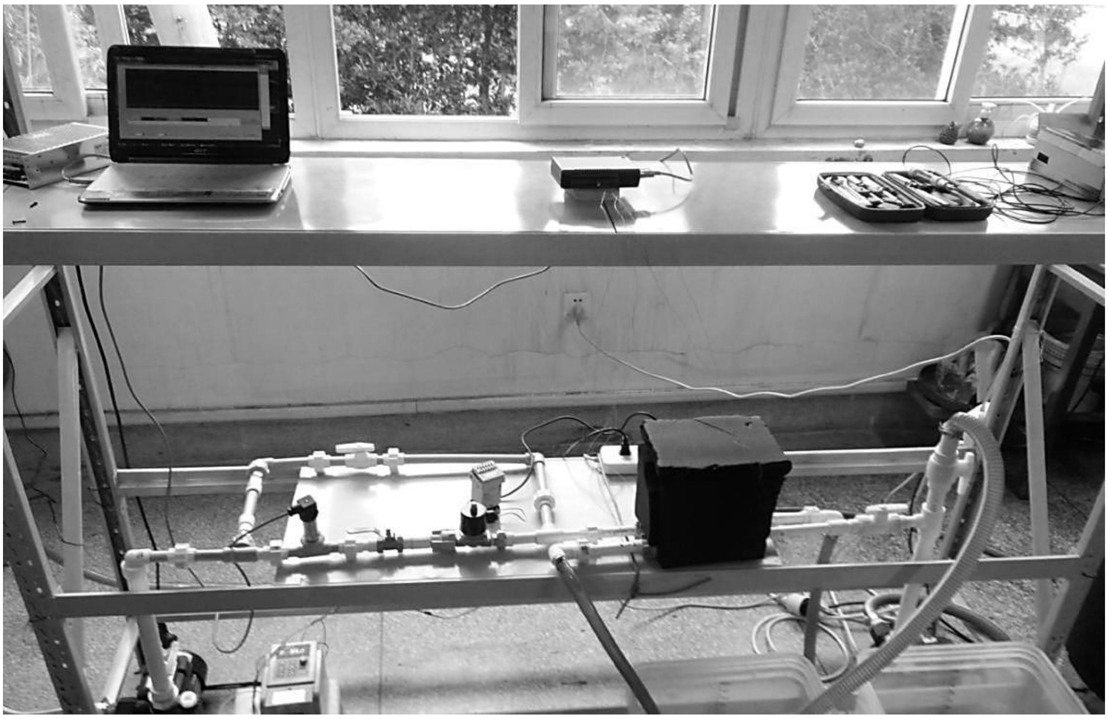

Figure 3. Physical picture of the pulsation enhanced heat transfer experimental system

Mohammad J et al. proved the existence of the optimal pulsation frequency through experiments [12]. They used the LBM (Lattice Boltzmann Method) method to study the effect of pulsating flow on forced convection in corrugated channels. The results show that: the heat transfer efficiency will change with the Strouhal number, and there is an extreme peak. When the extreme value is taken, the heat transfer rate is the highest, and then as the pulsation frequency increases, the heat transfer rate will decrease [13].

It can be known from the knowledge of heat transfer that in a stable flow, convection does not participate in the heat transfer of the inner boundary layer close to the wall, and the heat transfer in the laminar flow zone can only be through heat conduction. However, after adding pulsation, the periodic changes will cause the fluid to produce forced convection and increase the effective heat transfer by promoting the formation of vortices, thereby introducing convection into the boundary layer [14].

Table 1.

PULSATION FREQUENCY TABLE

Pulsation parameter	1	2	3	4	5	6
f/Hz	0	0.5	1	1.5	2	2.5

Table 2.

SOLENOID VALVE OPENING AND CLOSING SCHEDULE AT EACH PULSATING FREQUENCY

(f/Hz)	0.5	1	1.5	2	2.5
t_0(s)	1.0	0.5	0.33	0.25	0.2
t_c (s)	1.0	0.5	0.33	0.25	0.2

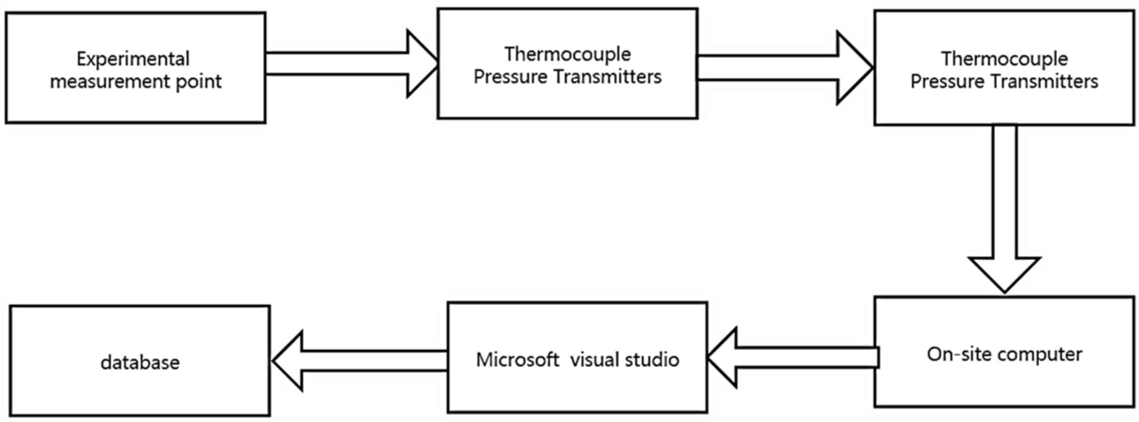

Figure 4. Data collection flowchart

Experimental calculation:

Plate heat exchanger cold water heat exchangeQc : $Q_c = c \cdot m_c \cdot \Delta T_c = c \cdot m_c \cdot (T_{co} - T_{cin})$

C: Specific heat capacity of water, $J/(kg \cdot ℃)$;

m_c: Average mass flow rate of cooling water;

T_{co}: Average outlet temperature of cooling water, °C;

T_{cin} : Average inlet temperature of cooling water, °C;

Heat exchange in hot water circuit of plate heat exchanger Q_h : $Q_h = c \cdot m_h \cdot \Delta T_h = c \cdot m_h \cdot (T_{hin} - T_{ho})$

m_h : Average mass flow rate of hot water, kg/s; T_{ho} :Average outlet water temperature of hot water, °C ; T_{hin} :Average inlet temperature of hot water, °C;

According to the total heat transfer coefficient of the plate heat exchanger $K = \frac{Q}{A\Delta t_m}$,

$$Q = \frac{Q_c + Q_h}{2} , \quad \Delta t_m = \frac{\Delta t_{\max} - \Delta t_{\min}}{\ln\left(\frac{\Delta t_{\max}}{\Delta t_{\min}}\right)} .$$

Q: Average heat exchange on the cold and hot water side, W;

A: Total heat transfer area, m^2 ; Δt_m : Log mean temperature difference $\Delta t_{\max}$: Cold water inlet temperature difference: $\Delta t_{\min}$:Temperature difference between hot and cold-water outlets.

Definition of enhanced heat transfer ratio $E_m = \frac{K_p}{K_s}$;

K_p : Total heat transfer coefficient under pulsating flow K_s :The total heat transfer coefficient under steady-state flow. Results and discussion

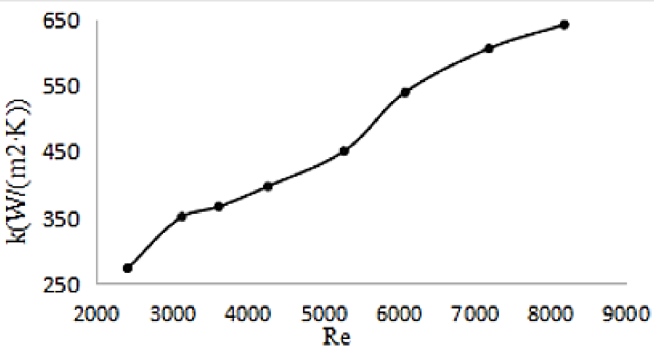

Figure 5. Under steady-state flow conditions, the total heat transfer coefficient of the plate heat exchanger at different flow rates

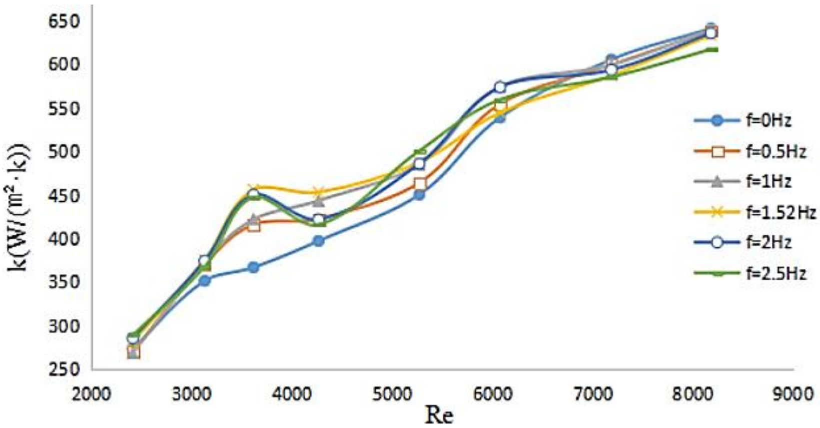

Figure 6. In the case of pulsating flow, the total heat transfer coefficient of the plate heat exchanger at different flow rates

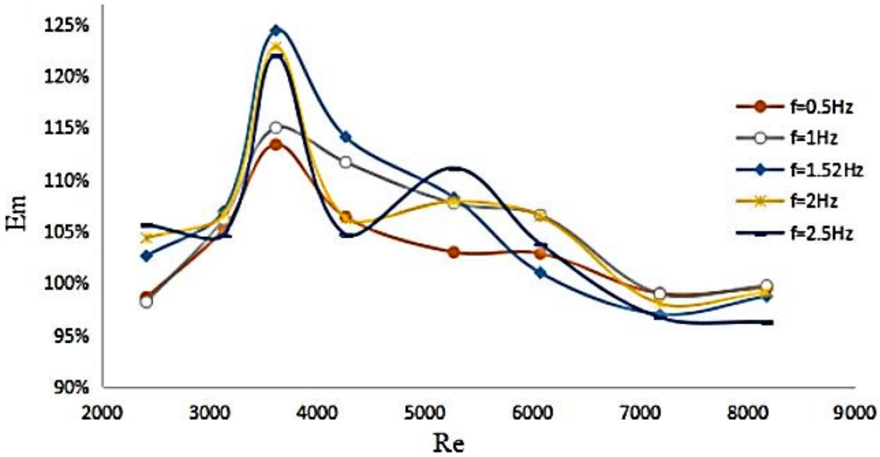

Figure 7. In the case of pulsating flow, the enhanced heat transfer efficiency of the plate heat exchanger at different flow rates

It can be seen that in the case of steady-state flow and pulsating flow, as the flow velocity increases, the total heat transfer coefficient of the plate heat exchanger also increases, which proves that the pulsating flow has a certain heat transfer enhancement effect. The maximum enhanced heat transfer efficiency obtained in the experiment reached 125.17% at various flow rates. After the sea water pump frequency conversion control and pulsation enhancement heat exchange system was successfully installed and used on the 59990 dwt bulk carrier, the calculation results after simulated sailing showed that the energy consumption after the installation of the system was about 36% of that before the installation, which fully reflects the frequency conversion. Control and pulsation enhance the energy saving effect of heat exchange technology.

Conclusion

The ship's central cooling water system is a very complex system. The model established in this article has simplified it to a certain extent. Some parameters are replaced by average values, and there is room for improvement in the accuracy of the model. In addition, due to the system errors of float flow meters, thermocouples, pressure transmitters and other instruments in this pulsation enhanced heat exchange experimental platform, the heat loss of plate heat exchangers and temperature-controlled hot water tanks will lead to deviations in experimental data. You can start to improve the accuracy of this data.

With the progress and development of the times, we must move closer to the direction of green shipbuilding. The International Maritime Organization has also put forward higher requirements for the energy efficiency of ships and carbon dioxide emissions. We need to consider research from many aspects in order to find ways to save energy and reduce emissions. The frequency conversion control and pulsation enhanced heat transfer technology of sea water pumps is a technology that is worthy of promotion. It cannot only reduce the loss of electricity, thereby saving energy, but also reduce the cost of shipping.

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