MATEC Web of Conferences **213**, 04001 (2018) https://doi.org/10.1051/matecconf/201821304001
ACMME 2018

Simulation and Experimental Study on Flow and Heat Transfer of Ship Central Cooling System

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Abstract. The centralized cooling system of a certain type of oil ship is a large-scale complex fluid network system. Fluid system simulation software (FLOWMASTER) was used to establish simulation model for steady operating conditions. The design of central cooling system was validated reasonably by simulation in steady-state condition. In this paper, the flow and heat transfer experiment was carried out. The experimental results were in good agreement with the simulation results, which suggested that using FLOWMASTER to validate the heat transfer performance of fluid system is reliable.

1 Introduction

The marine centralized cooling system provides and distributes seawater and freshwater to multiple users, ensuring the onboard air compressor and inverter to operate in a safe temperature range. The design of ship cooling system has certain complexity. Reasonable choice and design of cooling system have important influence on ship`s economy and seaworthiness [1].In the traditional ship cooling system design and debugging, design is mainly based on empirical formula, and debug is usually relied on engineering experience[2]. If the test conditions are available, the rationality of the system design would be verified by experiment.

In this paper, according to the pipeline design of the centralized cooling system of a certain type of tanker, a simulation model was established by using the fluid system simulation software FLOWMASTER. On the basis of modeling, the steady flow and heat transfer calculation of the pipeline system were carried out. The temperatures and flow parameters at key positions of the system were compared with the designed values to verify the rationality of the design .At the same time, the flow heat transfer experiment of the central cooling system was carried out, and the experimental results are in good agreement with the simulation results.

2 Overview of marine centralized cooling system

As shown in Figure 1, the centralized cooling system of a certain type of tanker consists of two parts, a closed loop freshwater cooling circuit and an open loop seawater cooling circuit. The closed loop freshwater circuit cools the air compressor, inverter and other equipment. The open seawater cooling circuit uses low temperature seawater overboard to cool high temperature freshwater centrally through intercooler. The high temperature seawater was discharged overboard after the heat exchange.

The freshwater cooling circuit provides cooling water for several users, including 3 air compressors located in different compartments, and 4 inverters located in the same cabin. The total flow demand of freshwater is supplied by a single freshwater pump, and the chilled flow of each user is regulated by the outlet flow control valve of freshwater pump, the bypass flow control valve and the user branch flow control valve. In the seawater cooling circuit, a single seawater pump is used to supply seawater to 2 series central coolers. According to the temperature of the seawater and the heat load of the freshwater, the supply of low temperature seawater is regulated by the bypass flow regulating valve and outlet regulating valve of the seawater pump.

The design idea of the separation of freshwater circuit and seawater circuit in marine centralized cooling system can fundamentally reduce the corrosion of most pipelinescaused by seawater in ships. And it is the development trend of ship cooling system in the future. However, the centralized cooling system has become more complex, and the design, commissioning and checking work has changed considerably. In this paper, the rationality of system design is verified by simulation and analysis of flow heat transfer in centralized cooling system, which is of great significance for shortening design cycle and reducing design cost.

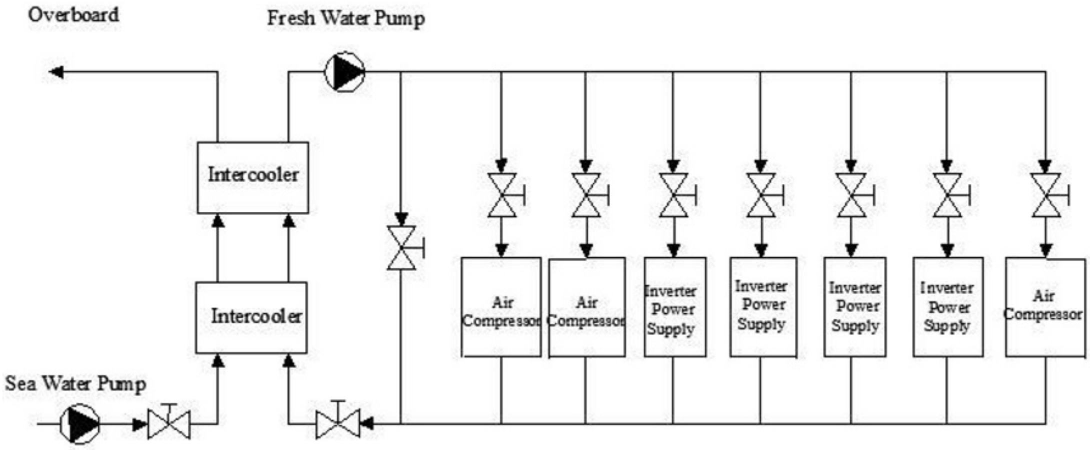

Figure 1. Schematic diagram of a certain type of ship centralized cooling system

3 Modeling of marine centralized cooling system

3.1 Fundamentals of fluid networks

FLOWMASTER is one-dimensional fluid system simulation software for engineering applications. For complex pipeline systems in various engineering, a system model can be established quickly and effectively to be analyzed completely in FLOWMASTER [3-7]. This software can analyze the fluid network system in steady state and transient state, and can also analyze the flow and heat transfer of the fluid network system and the coupling analysis between the two systems [8].
The numerical calculation of the software is based on fluid network analysis method. Fluid network analysis simplifies the fluid system by connecting a series of nodes and pipe sections. The following assumptions are made for the nodes:(1)The node has a certain volume and the fluid in the node is in a homogeneous state;(2)The storage of fluid mass can only occur in the interior of the node, and all flow resistance of the system is concentrated on each branch.

The pipe network is composed of C pipe sections and N+ 1 node, and the mathematical model of the pipe network is as follows:

$$B \cdot G = dM / dt \quad (1)$$

$$B^{'} \cdot P = S \cdot |G| \cdot G + \rho \cdot gZ - DH - L \cdot \frac{dL}{dt} \quad (2)$$

$$\overline{B} \cdot q - \underline{B} \cdot (q + r) = dH / dt \quad (3)$$

Among them, B is the $N \times C$ order correlation matrix of the pipe network; G represents branch traffic, C order vector; M represents node quality, N order vector; $B^{'}$ is the $C \times N$ order correlation matrix of the pipe network, the transpose matrix of B; S is the resistance coefficient of each other, $C \times C$ order diagonal matrix; Z is the height difference of the pipe section, C order vector; DH represents the boost of the power source on each branch, C order vector; L represents flow inductance, numerically equal to the amount of pressure caused by 1 units of flow change; P represents the pressure at the node; ρ represents the density at the node;g represents the acceleration of gravity; $\overline{B} \cdot q$ represents the sum of heat flow of each branch to the node; $\underline{B} \cdot (q + r)$ represents the sum of heat flow at the outflow node; H represents the enthalpy of each node.
Equation (1)、(2)and(3) are the concrete expressions of fluid dynamics, continuity equations ,momentum equations and energy equations in one-dimensional pipe networks. FLOWMASTER is a kind of software for simulation analysis of fluid system. The essence is to substitute the relevant parameters of the system components into the equation, obtaining the flow, pressure, temperature and other parameters.

3.2 Physical simulation model

According to the actual design of the centralized cooling system of the oil ship, a one-dimensional simulation model of the cooling system pipe network is established by using FLOWMASTER software. The pipe network includes pipes, pumps, tee coupling, valves, etc. The overall flow loss of centralized cooling system is large, so the influence of low flow resistance components such as elbow is not considered in the modeling process. At the same time, to reduce the number of pipes and tee couplings, discrete loss components are used to replace a large number of flow resistance components in the system, so as to improve the computational efficiency. The simplified simulation model is shown in Figure 2.

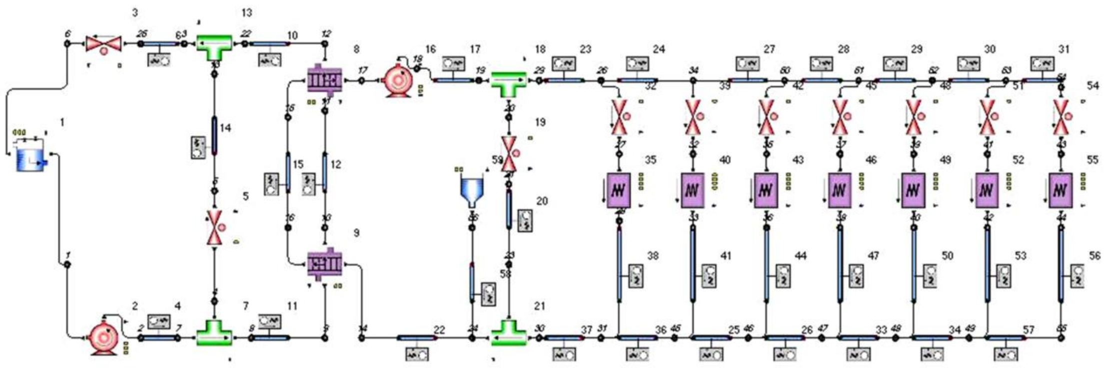

Figure2. Centralized cooling system piping model

4 Steady state simulation of flow heat transfer in concentrated cooling system

4.1 Simulation conditions and parameter settings

On the basis of flow simulation modeling of centralized cooling system,the steady state simulation of flow heat transfer in centralized cooling system was carried out by taking common navigational conditions as an example. Under this condition, 3 sets of air compressor in different compartments all are put into operation and 4 sets of inverter in the same cabin work at the same time. The cooling system adjusts the user traffic through the distributor valve, branch valve and bypass valve to meet the cooling demand. The flow demand and heat load of the fresh water cooling system under common navigation conditions are as follows.

Table 1 User flow demand and heat load under common navigation condition

Order	Cooling user name	number	Single flow demand （m^3/h）	Single thermal load (kW)	Cooling medium	Use attributes
1	air compressor	3	7	51	Fresh water	Common
2	inverter power supply	4	2.5	25	Fresh water	Common

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4.2 System design check

According to the design parameters of the centralized cooling system, the centralized cooling system model was simulated in steady state by regulating the detour valves, branch valves and bypass valves. By comparing the simulation results with the design values, the rationality of the centralized cooling system design was checked. As shown in the following table:

Table Import and export parameters of fresh water and sea water of central cooler under common navigation conditions

Parameters	Fresh water inlet		Fresh water outlet		Sea water inlet		Sea water outlet	
	Design value	Simulati-on value	Design value	Simulati-on value	Design value	Simulati-on value	Design value	Simulati-on value
Temperature/℃	38	38.13	—	34.23	28	28.21	—	33.22
Pressure/bar	—	0.28	—	0	—	1.52	—	1.51
Flow speed/m·s^{-1}	—	1.74	—	1.74	—	0.40	—	0.40

The design specifications of the centralized cooling requires that the temperature difference between central cooler's freshwater outlet and heat exchanger's seawater inlet shall not be greater than 10 degrees centigrade. The simulation results show that the fresh water outlet temperature of the central cooler is 34.23℃ and the seawater inlet temperature of central cooler is 28.21℃。Therefore, the temperature difference between the freshwater outlet of central cooler and seawater inlet of heat exchanger is 6.02 ℃, which satisfies the requirement of the design instructions that the temperature difference between the two is not greater than 10 ℃。Therefore, the design of the centralized cooling system of the ship is reasonable.

4.3 Comparative analysis of experiment and simulation

In order to prove the rationality of the system design checked by using FLOWMASTER simulation, the heat transfer experiment of the centralized cooling system was carried out, and the critical position flow, pressure, temperature and other parameters were obtained.

The temperature of the sea system is 28.07℃ and the laboratory air temperature is 20 ℃。Heat transfer performance experiment was carried out on common sailing conditions. First, start the freshwater pump, and adjust each cooling branch flow of fresh water circuit to make the closed circuit of fresh water operate steadily. Then, start the seawater pump and adjust the flow of the system to make the seawater loop run stably. Finally, start the all heat source simulation devices,and adjust the 3 air compressors' heat power to 51kW and 4 inverters' heat power to 25kW respectively. The inlet temperature, the fresh water outlet temperature and the user flow of the centralized cooling system were measured. The results are shown in Table 3.

Table3 Experimental results of heat transfer in common navigation condition

Order number	T1	T2	H1	H2	H3	H4	H5	H6	H7
1	27.51	29.6	7.35	7.25	7.24	2.61	2.56	2.56	2.59
2	27.51	33.89	7.33	7.25	7.19	2.58	2.53	2.54	2.61
3	27.51	35.1	7.26	7.28	7.20	2.56	2.51	2.53	2.60
4	27.84	35.76	7.19	7.26	7.17	2.56	2.50	2.51	2.61
5	28.07	35.99	7.19	7.23	7.17	2.54	2.50	2.51	2.61
6	28.28	36.31	7.22	7.26	7.19	2.54	2.50	2.51	2.61
7	28.61	36.64	7.19	7.26	7.06	2.54	2.50	2.51	2.61
Mean value	27.90	34.76	7.25	7.26	7.17	2.56	2.51	2.52	2.61
Simulation value	28.21	34.23	6.92	7.11	6.98	2.48	2.43	2.44	2.49

Note:T1-Temperature of central cooler seawater inlet,T2-Temperature of central cooler fresh water outlet,H1～H3-Air compressor cooling flow,H4～H7-Inverter cooling flow.

The experiment results show that the difference between the temperature of fresh water outlet and the temperature of seawater inlet is 6.86 ℃,and it meets the design requirements as well. The simulation results of key position of temperature and flow rate are consistent with the experiment results, and the error is in the allowable range. So the simulation can reflect the heat transfer performance of the ship central cooling system. Therefore, the simulation analysis based on FLOWMASTER software to verify the rationality of the design is reliable, and the software can be applied to the design, commissioning and verification of the pipe network system.

5 Summary

In this paper, FLOWMASTER software was used to carry out steady state simulation calculation of a certain type of ship centralized cooling system, and the temperature, flux and other parameters of the critical position were obtained. According to the design specification, the rationality of system design was checked. The results show that the centralized cooling system meets the design requirements. In order to further prove the reliability of FLOWMASTER system simulation, the heat transfer experiment of the centralized cooling system of the ship was carried out. Comparing the experimental results and simulation results, the results show that the system simulation using FLOWMASTER can reflect the heat transfer performance of the system effectively and truly.

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