EXPERIMENTAL STUDY ON THE INFLUENCE OF FLUID FLOW PRESSURE ON THE WORKING EFFICIENCY OF COOLING TANKS

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DOI: http://doi.org/10.57001/huih5804.2024.179

ABSTRACT

Cooling is a crucial step in the operation of devices ranging from micro to macro structures. This process involves dissipating the heat created by the equipment in order to enhance the performance of the system. The cooling plate structure is a fundamental, prototypical, and widely used design in engineering applications. This article describes the findings of an experimental study that examined how changes in refrigerant flow pressure affect the performance of cooling plates. The requirements, technical specifications, as well as equipment layout diagrams are described in detail in the article. The study findings were obtained to validate the validity and precision of the studies conducted using Ansys-Fluent finite element simulation software.

Keywords: *Cooling tank; cooling plate; medium flow; experiment; Ansys-Fluent.*

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Received: 20/3/2024
Revised: 04/5/2024
Accepted: 25/5/2024

1. INTRODUCTION

The authors of prior works have provided theoretical principles for calculating and developing a model to simulate heat exchange processes in cooling plates, as well as the aspects that impact the system's performance [1]. Ansys-Fluent is the program used for simulating the impact of flow regimes in the water layer between the plates on heat exchange efficiency [2]. However, to validate the calculation findings and assess the suitability of the model constructed by the authors. Simultaneously, there is an instruction to adjust the computational model and the physical model [3]. Conducting experiments is necessary to verify the accuracy of the computation and simulation outcomes. To validate the findings of the study team, the authors performed experimental research on the impact of refrigerant flow pressure on the performance of cooling plates, stemming from the aforementioned issues [4].

The experimental study described in this article investigates the effect of refrigerant flow pressure on the operational efficacy of cooling plates, among other objectives. Developing equipment and methodologies for conducting tests. Confirm the results obtained from calculations and blueprints. This functions as a fundamental basis for evaluating the suitability of the simulation model and implementing any necessary adjustments to enhance the precision of the experimental methodology and calculation model.

Essential criteria for doing experimental research: Utilize a detachable plate-type cooler, which is a piece of equipment composed of a collection of heat exchanger plates firmly sealed together with gaskets and secured with two flanges and pressing bolts. Select a Z-shaped coolant flow diagram, ensuring that the seawater pipe remains in a straight line, in accordance with the pipe system of the M500 Engine Power Test Bench at X50 Factory. The small cooling tank is designed to fit perfectly inside the area of the Test Bench and provides a cooling capacity that is appropriate for the engine chosen for testing. The experimental diagram is developed to align with the characteristics of the experimental item and the equipment system of the Laboratory (Capacity test bench). Measuring equipment and sensors possess measurement ranges and errors that align with the values to be measured and remain within the designated inspection time. The input parameters may be modified to guarantee the execution of experimental modes. It is important to ensure that pipelines and equipment are correctly placed, adhere to safety rules, and are free from leaks in order to guarantee the precision of experimental findings [5].

2. SUBJECTS AND TESTING MODES

2.1. Requirements set

In order to conduct the experiment and meet the intended objectives and specifications, as well as maintain safety during the process, it is necessary to adhere to the following requirements: Prior to mounting the device on the test bench, it is necessary to conduct a pressure test to ensure its integrity. The bolts must be securely fastened, ensuring that no liquid escapes from the tank. Additionally, the cooling tank and its components must remain structurally intact when exposed to heat or pressure. The test method must adhere to the specifications and procedures outlined in the X50 Factory Engine Test Procedure [6]. The cooling tanks have been appropriately fitted in accordance with the designated schematic, so assuring compliance with the laboratory's safety protocols. If any of the parameters above the permissible threshold or if there is any anomalous occurrence, the experiment should be terminated. Throughout the testing procedure, it is essential that both the overall testing system and the cooling tank function consistently and reliably. Additionally, there should be no occurrences of oil or water leakage in the engine, test system, or cooling tank. It is essential to avoid any abrupt rise in pressure inside the liquid channels throughout the test. The processes for increasing the pressure must adhere to the testing protocols of the Factory and the specified testing protocols. Evaluate all the treatment plans produced by the study team. During each test mode, it is necessary to wait for the parameters to achieve a state of stability. Once the value has reached a stable state for a duration of 5 minutes, proceed to document the outcomes.

2.2. Experiment objects

From the requirements for the experimental process and the calculation results to determine the heat exchange area for the oil cooler and water cooler for the M503B engine. The authors manufactured two coolers (oil cooler and water cooler) for experimentation on the AVL Zöllner Marine engine power test bench (Germany) equipped at Factory X50/General Department of Defense Industry. The structure of the cooling tank is shown in Fig. 1. The oil cooler and water cooler have the same structure, and the number of heat exchanger plates in the tanks is also the same. The parameters of the two cooling plates are given in Table 1 [7].

a)

b)

Fig. 1. Cooling plate used in experiments

a) Structure of the cooling plate; b) Oil cooler and water cooler

Technical specifications of two cooling plates used in the experiment are as Table 1.

Table 1. Technical specifications of oil cooler and water cooler

Order	Parameter	Unit	Value
1	Length × Width × Height	mm	850 x 510 x 610
2	Dry mass	kg	255
3	Number of heat exchanger plates: + Cooling plate + Isolation plate	 plate plate	 70 02
4	Size of heat exchanger plate, Length × Width	mm	775 x 345
5	Thickness of heat exchanger plate	mm	0,5
6	Number of pipes carrying fluid in and out	item	4
7	Nominal diameter of inlet and outlet fluid pipes	mm	90
8	Number of covered rubber gaskets: + Rubber gaskets cover the heat exchanger plates + Rubber gaskets cover the isolation plates	 item item	 70 02

Basically, the two cooling tanks have the same structure, but it must be clearly noted to avoid mixing the positions of the tanks to avoid mixing water into the lubrication system as well as mixing oil into the engine water jacket.

2.3. Experiment modes

Table 2. Technical specifications of oil cooler and water cooler during testing

Order	Specifications	Unite	Value
1	Number of heat exchanger plates	item	70
2	Width of the heat exchanger on the cooling plate	m	0,3
3	Length of the heat exchanger on the heat exchanger plate	m	0,4
4	Distance between 2 heat exchanger plates	m	0,005
5	Thickness of heat exchanger plate	m	0,0005
7	Air temperature	^0C	30
8	Fuel temperature	^0C	35
9	Atmospheric pressure	mmHg	860
10	Air moisture	%	75

During the experiment, the engine was operated at load and speed modes by the acceptance experiment procedure of the M503Б engine after major repair at the X50 Factory. The engine was operated under load and the speed gradually increased from 750rpm up to 1800rpm. After that, the engine is reduced and the speed gradually returns to idle mode. The retention time in each test mode is at least 15 minutes to ensure that the parameters to be measured reach stable values.

- Sampling rate milestones: 780rpm, 1020rpm; 1200rpm; 1500rpm; 1800rpm.

- Change the pressure of the inlet and outlet seawater flow by changing the flow rate of the seawater flow into the tanks.

- Parameters determined during experimental research include Engine crankshaft rotation speed n rpm; useful power of the engine N_e (kW); the temperature of freshwater flow into T_{nv} (°C) and out T_{nr} (°C) from the water cooler; oil flow temperature T_{dv} (°C) and outlet T_{dr} (°C) from the lubricating oil cooler; the flow rate of seawater through plate coolers V_b (m^3/h); the temperature of seawater inlet T_{bv1} (°C) and outlet T_{br1} (°C) from the lubricating oil cooler; inlet seawater temperature T_{bv2} (°C) and outlet T_{br2} (°C) from the freshwater cooler [8].

3. LAYOUT DIAGRAM OF EQUIPMENT EQUIPMENT

3.1. Equipment for experimentation

Two cooling tanks used in the experiment were installed on the M500 engine power test bench of the X50 Factory. The cooling seawater line is taken from seawater near the test bench, through the cooling pump system for the oil cooler and water cooler. At the inlet seawater line, a CX-EMFM flow sensor is installed. Inlet and outlet seawater temperatures, inlet and outlet hot water temperatures, and oil temperatures in and out of cooling tanks are measured by a TEMPSENS RTD PT100 temperature sensor. Pressure in and out of the coolant tank is measured using KKgauges pressure sensors.

The main equipment for experimentation is as follows:

- AVL Zöllner Marine GmbH engine power test bench:

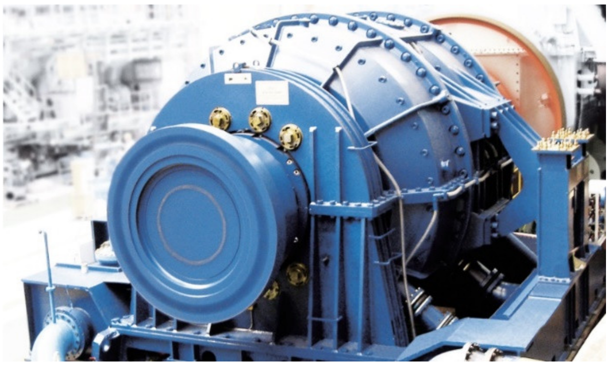

Fig. 2. AVL Zöllner Marine GmbH engine power test bench

This is the engine capacity test bench equipped at the X50 Factory. This system was first installed in 1996 and has been repaired and upgraded several times, most recently in 2019. The test bench has been upgraded with oil pipelines, water pipes, and sensor systems as well as recalibrated the entire test system [9].

- Flow sensor CX-EMFM - Germany (Fig. 3).

Fig. 3. Flow sensor

- Temperature sensor TEMPSENS RTD PT100 - Taiwan (Fig. 4).

Fig. 4. TEMPSENS RTD PT100 temperature sensor

- KK gauges pressure sensor МТП-60С1-М1 - Russian (Fig. 5).

Fig. 5. KK gauges pressure sensor МТП-60С1-М1

In addition, the testing process also uses the available equipment and sensors system of the M500 Engine Power Testing Room of the X50 Factory to measure engine parameters such as crankshaft speed and engine power.

3.2. Installation diagram of experimental equipment

The experimental process was conducted with the M503Б engine installed on the M500 AVL Zöllner Marine GmbH engine power test bench. Two cooling plates were designed and manufactured by the research team and were installed to replace the original oil and water coolers of the test bench. The cooling water pipeline system, seawater pipeline, and oil pipeline were renovated to suit the installation of 02 new cooling tanks. The layout diagram of the experimental equipment is shown in Fig. 6 [7-9].

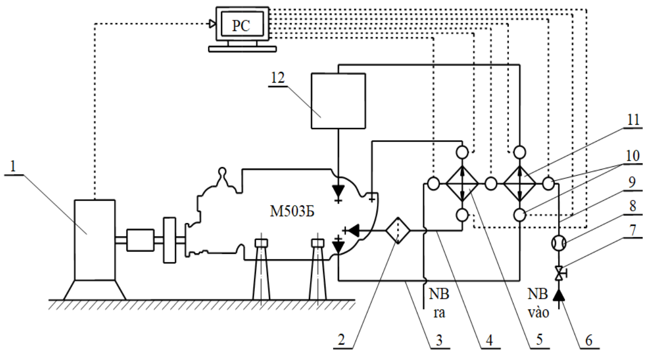

Fig. 6. Experimental equipment layout of the cooling plate on the M500 AVL engine testbed Zöllner Marine GmbH

1. M500 engine hydraulic test brake; 2. Filter; 3. Lubricating oil path; 4. Fresh water pipeline; 5. Fresh water cooling equipment; 6. Pump; 7. Flow control valve; 8. Flow meter; 9. Sea water pipeline; 10. Temperature sensor; 11. Lubricating oil cooling device; 12. Lubricating oil tank.

Figures of the installation location of the plate and motor cooling devices on the M500 test bench are shown in Figs. 7 and 8. Testing figures and experimental results are shown in Figs. 9 to 11.

Fig. 7. Original cooling fluid and lubricating oil piping system on the M500 engine test bench

Fig. 8. Installation and testing of a cooling plate on the M500 engine test bench

4. RESULTS AND DISCUSSION

4.1. Experiment results

The authors tested the upper cooling plate using the M500 engine power test. Environmental conditions, test contents and test results are as follows:

a) Environmental parameters at the time of testing

- Ambient temperature: 30^{0}C.
- Fuel temperature: 32^{0}C.
- Atmospheric pressure: 860mmHg.
- Air humidity: 75%.

b) Test content

Experimental parameters: crankshaft rotation speed, n (rpm); useful power of the engine, N_e (kW); seawater flow through cooling equipment, $V_{seawater}$ (m^3/h); inlet and outlet temperatures of the seawater stream, freshwater stream, and lubricating oil stream through the cooling device, T (^{0}C); the pressure difference between the inlet and outlet of the seawater stream, freshwater stream, and lubricating oil stream through the cooling device, Δp (kG/cm^2). During testing of the M503A engine on the test bench, when using cooling plate devices, the original cooling devices are replaced.

c) Test results in the following modes

Table 3. Measurement results at the oil cooler

Order	n (rpm)	N_e (kW)	$V_{seawater}$ (m^3/h)	Plate lubricating oil cooler					
				Lubricating oil flow			Seawater flow		
				T_{inlet} (°C)	T_{outlet} (°C)	Δp (kG/cm^2)	T_{inlet} (°C)	T_{outlet} (°C)	Δp (kG/cm^2)
1	780	92	46.88	48.3	39.9	0.00	31.6	32.5	0.15
2	1020	338	30.82	65.2	50.3	0.05	31.5	34.7	0.05
3	1200	735	46.93	71.9	54.9	0.05	31.4	34.3	0.15
4	1500	1034	30.86	79.0	62.4	0.05	31.3	36.7	0.05
5	1800	1608	46.52	84.5	67.0	0.10	31.2	35.8	0.15

Table 4. Measurement results at the water cooler

Order	n (rpm)	N_e (kW)	$V_{seawater}$ (m^3/h)	Plate lubricating oil cooler					
				Lubricating oil flow			Lubricating oil flow		
				T_{inlet} (°C)	T_{outlet} (°C)	Δp (kG/cm^2)	T_{inlet} (°C)	T_{outlet} (°C)	Δp (kG/cm^2)
1	780	92	46.88	40.9	35.8	0.25	32.5	36.2	0.15
2	1020	338	30.82	48.6	42.7	0.35	34.7	43.3	0.05
3	1200	735	46.93	54.0	45.7	0.45	34.3	43.6	0.15
4	1500	1034	30.86	62.5	54.7	0.50	36.7	53.3	0.05
5	1800	1608	46.52	65.9	55.3	0.60	35.8	53.8	0.15

4.2. Discussions

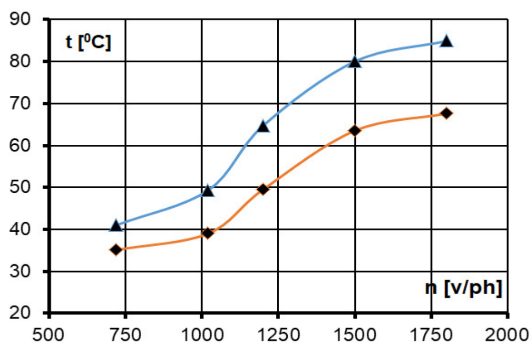

Fig. 9. Change in lubricating oil temperature at the inlet (▲) and outlet (♦) of the plate lubricating oil cooler at different speed modes

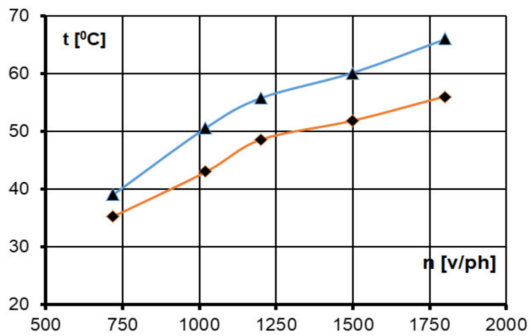

Fig. 10. Change in freshwater oil temperature at inlet (▲) and outlet (♦) of plate freshwater cooler at different speed modes

The evolution of temperature parameters in the engine's working modes when using a cooling plate device during testing on the M500 engine test bench is shown in Figs. 9 and 10.

Test experiment results show that:

- With a plate-type freshwater cooler, the temperature difference between the inlet and outlet of the freshwater stream ($\Delta t = t_{nv} - t_{nr}$) ranges from 5.1 ÷ 10.6^{0}C. These results have small deviations from the theoretical calculation results. From there, it can be concluded that the degree of agreement between the theoretical model and experimental data is good.

- With a plate oil cooler, the temperature difference between the oil inlet and outlet ($\Delta t = t_{dv} - t_{dr}$) ranges from 5.1 ÷ 10.6^{0}C. These values are within the recommended range, however, there is a larger difference between the calculated results and the experimental results in the case of freshwater coolers. This is because the shape of the ribs on the heat exchanger plate changes the Re coefficient of the lubricating oil flow, increasing the convective heat exchange coefficient with the cooling plate. The lubricating oil used when testing is old oil, so the physical properties are different from new oil when calculating.

- When the pressure of the seawater flow is increased by raising the flow rate, the pressure differential between the inflow and outflow of the cooling tank remains relatively constant. Nevertheless, the cooling efficiency is enhanced, as seen by the increased temperature differential between the oil (or fresh water) before entering the tank and after exiting the tank, resulting in superior cooling of both the oil and fresh water. However, due to the limitations of the experimental settings, it is not possible to significantly decrease the saltwater flow. Therefore, the impact of seawater flow pressure on the heat exchange efficiency of the cooling tank can only be examined within a limited range.

- The experimental findings consistently demonstrate that the constructed calculation model and its corresponding results align with the experimental data. Additional investigation is required to examine the impact of rib profile on the Reynolds coefficient of lubricating fluid. The cooling plate device functions reliably and has operational characteristics that are comparable to those of the original engine cooling system.

Some figures of the equipment installation process and testing of plate coolers:

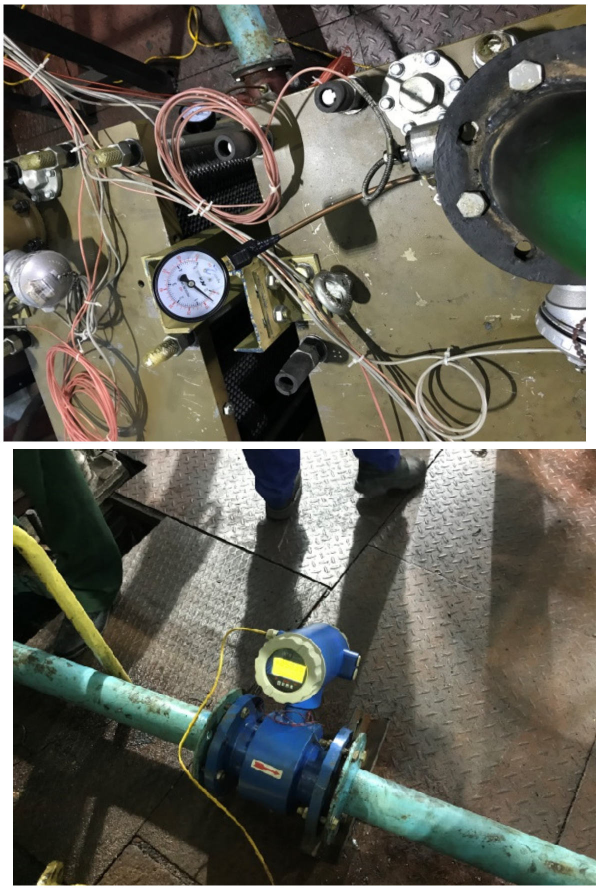

Fig. 11. Testing a plate cooler on the M500 test bench

5. CONCLUSION

The paper has outlined the prerequisites, testing methodologies, and schematic diagrams for the installation and execution of tests to verify the operational parameters of a plate cooler on the M500 engine power test bench. Tests were carried out using the M503B engine. The following findings were derived from the experimental process:

1. The experimental method was conducted in strict adherence to the X50 Factory's testing processes and specified testing protocols.

2. The temperature differential ($\Delta t = t_{dv} - t_{dr}$) between the intake and outflow of the oil cooler for the lubricating oil varies from 8.4 ÷ 17.5^{0}C. The temperature differential between the input and exit of the water cooler ($\Delta t = t_{nv} - t_{nr}$) varies from 5.1 ÷ 10.6^{0}C. The parameters align with the calculated findings and are within the required range for producing cooling tanks for internal combustion engines.

The experimental findings are deemed valid and exhibit resemblances with the calculated and simulated outcomes. The cooling plate device functions reliably and has operational characteristics that are comparable to those of the original engine cooling system. Therefore, it can be inferred that the model constructed by the authors accurately replicated the heat transfer mechanisms in the cooling plate. This simulation model may be used to simulate and compute the cooling tanks with plate-type design on M500 diesel engines.

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