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Structural improvement and experimental verification of a horizontal single tube heat transfer performance test bench

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Abstract
Based on the purpose of reducing testing time while ensuring the accuracy of measuring single tube heat transfer performance, an improved horizontal single tube heat transfer performance testing test bench using R134a as the refrigerant for conducting full liquid evaporation, external condensation, and falling film evaporation experiments is proposed, and its system principle and process are introduced. Through verification and repeatability tests of light tube evaporation and condensation, the error analysis between the measured values of heat transfer coefficients inside and outside the tube and the theoretical calculation values is carried out, and compared with the experimental data of the original experimental platform. The experimental results show that under the same working conditions, the accuracy of this experimental platform is improved by 3% compared to the original testing experimental platform, and the time is shortened by 5 hours. This experimental platform can significantly shorten the experimental time while ensuring the accuracy of the experiment. At the same time, the structure of the experimental platform is simplified and the experimental steps are reduced.
Keywords: *Falling film evaporation; horizontal single-tube;R134a;heat transfer coefficient.t*

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I. CONTRODUCTION

The horizontal single tube heat transfer performance test bench is an experimental equipment used to measure the heat transfer performance of liquids or gases in a single tube, which generates heat transfer effects by controlling the temperature difference between the heater and cooler. The single tube in the test bench is usually made of high thermal conductivity material to ensure that heat can be quickly transferred to the liquid or gas. The test bench is also equipped with sensors and a data acquisition system to monitor and record parameters such as temperature, pressure, and flow rate of the medium inside a single tube, in order to calculate parameters such as heat transfer coefficient and thermal resistance. Starting from theory and experiments, combined with the structure[1] and experimental principles of previous experimental benches, the author improved the experimental setup by changing the circulation path of refrigerant in full liquid evaporation and condensation experiments outside the tube. Under the same working conditions, light tube experiments were conducted and the experimental results were compared horizontally. The results showed that the experimental setup can significantly shorten the experimental time while ensuring the accuracy of the experimental results.

II. Testing System and Experimental Principles

2.1. Test system composition

The experimental device mainly includes an evaporator, a falling film evaporator, an auxiliary condenser, an ethylene glycol water tank, a constant temperature water tank, a refrigeration unit, a spray pipe, a flow meter, a water pump, a refrigerant storage tank, a constant temperature water tank electric heater, and system accessories. The schematic diagram of the experimental structure is shown in Figure 1. By controlling the pipelines and valves and changing the refrigerant circulation path, this device can perform three test conditions: full liquid evaporation, external condensation, and external falling film evaporation.

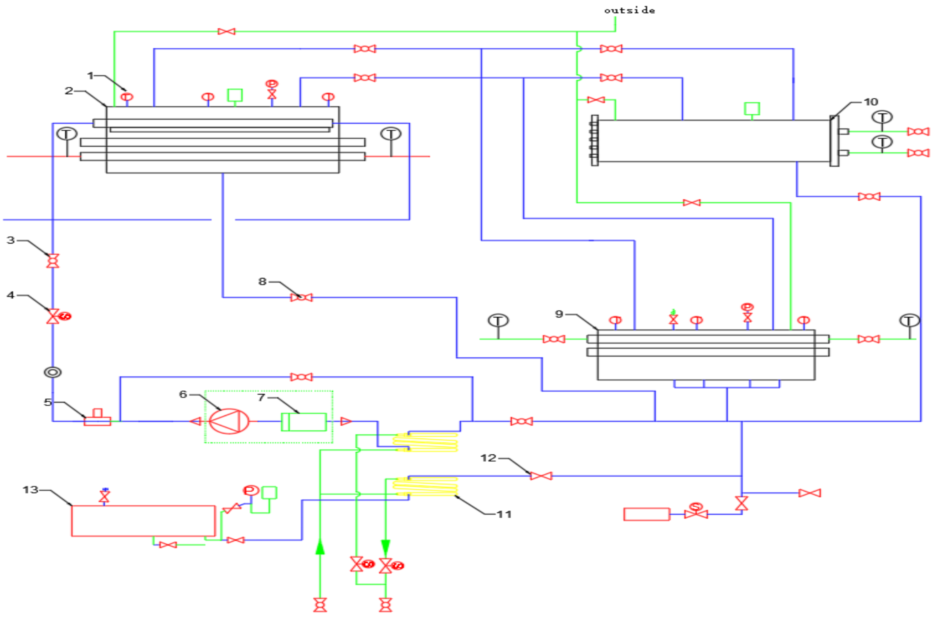

Figure 2.1 Testing System Schematic - Refrigerant Section

1.Platinum resistance thermometer 2.Falling film evaporation/external condensation test bucket 3.ball valve 4.solenoid valve 5.Refrigerant flow meter 6.Refrigerant circulation pump 7.Subcooling controller 8.Bypass valve 9.Full liquid evaporation test bucket 10.Auxiliary condenser drum 11.Subcooling coil 12.Refrigeration system shut-off valve 13.Refrigerant storage tank

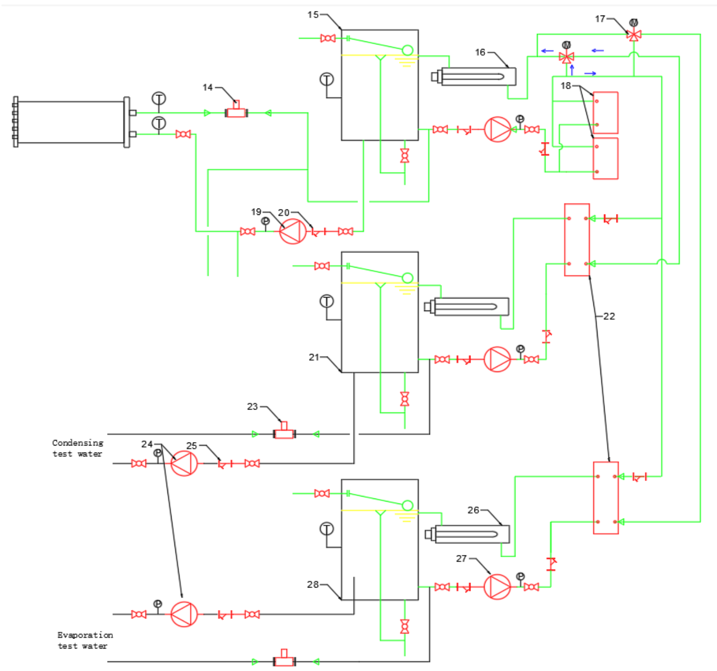

Figure 2.2 Testing System Schematic - Water Section

14.Ethylene glycol flow meter 15.Ethylene glycol water tank 16.Ethylene glycol electric heating 17.Three way regulating valve 18.Refrigeration unit 19.Ethylene glycol testing pump 20.Ethylene Glycol Impurity Filter 21.Condensation test constant temperature water tank 22.Plate heat exchanger 23.Condensation test water flow meter 24.Test water pump 25.Test water filter 26.Testing water electricity heating 27.Circulating water pump 28.Evaporation test constant temperature water tank

2.2. Exprimental Principles

2.2.1. Full liquid evaporation

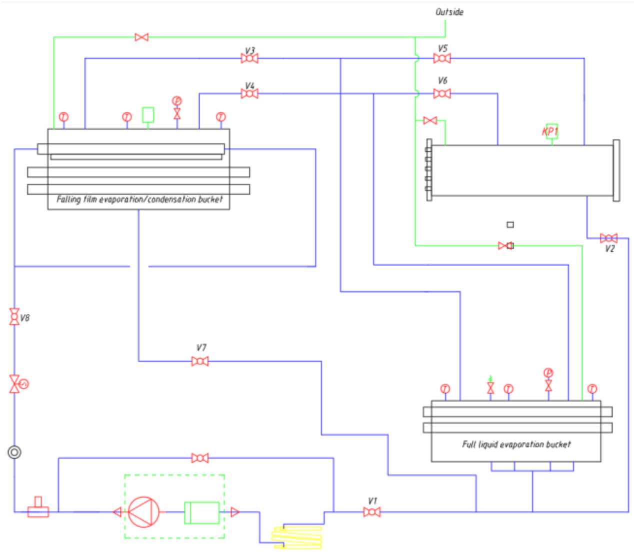

Figure 2.3 Testing System Schematic - Water Section

In the full-liquid evaporation condition, the principle of the refrigerant circulation system is shown in Figure 1.3. Close the gas valves V3 and V4, and the liquid valves V1 and V7. The level of the refrigerant liquid is 2-3 cm higher than the height of the test copper tube inside the full-liquid evaporation drum, ensuring that the refrigerant completely submerges the test copper tube. The liquid refrigerant in the full-liquid evaporation drum absorbs heat from the hot water inside the test copper tube, evaporates into gaseous refrigerant, and enters the auxiliary condensation drum through gas valves V5 and V6. The gaseous refrigerant releases heat to a 60% ethylene glycol solution in the auxiliary condensation drum, transforms from gas to liquid, and continues through liquid valve V2 back to the full-liquid evaporation drum, completing the refrigerant cycle.

2.2.2. Falling film evaporation

In the working condition of falling film evaporation, the liquid refrigerant is evenly sprayed on the test copper tube inside the falling film barrel through the spraying device, absorbing the heat of hot water in the copper tube and converting it into gaseous refrigerant. The unexpired liquid refrigerant returns to the full liquid evaporation barrel through the liquid valve V7, and the evaporated gaseous refrigerant enters the auxiliary condensing barrel through V5 and V6. After releasing heat to the ethylene glycol solution, it is converted into liquid refrigerant. It returns to the full liquid evaporation barrel through the liquid valve V2, and is pushed into the spray pipe by the refrigerant circulation pump through the liquid valve V1, completing a refrigerant cycle

2.2.3. External condensation

In the condensation condition outside the pipe, close liquid valves V1 and V2, air valves V5 and V6, open air valves V3, V4, and liquid valves V7. The liquid refrigerant absorbs heat from hot water in the full liquid evaporation bucket and converts it into a gaseous refrigerant. It enters the falling film evaporation/external condensation bucket through gas valves V3 and V4, releases heat to the cold water inside the test copper tube, condenses from the gaseous refrigerant into liquid refrigerant, and returns to the full liquid evaporation bucket through liquid valve V7, completing a refrigerant cycle.

III. Calculation and Analysis

The target quantity for experimental testing is the total heat transfer coefficient of the heat exchange tube, the heat transfer coefficient inside the tube, and the heat transfer coefficient outside the tube.

1) Overall Heat Transfer Coefficient

Due to the varying inlet and outlet water temperatures of the test tube, the logarithmic average temperature difference is used, and the calculation formula for the total heat transfer coefficient is as follows:

$$U_0 = \frac{Q}{A_0 \Delta t}$$

Q - Heat Transfer

A_0 - External Surface Area of Heat Transfer Tube

Δt - Logarithmic Mean Temperature Difference

2) Heat Transfer Coefficient Inside the Tube

The author uses the Sieder-Tate equation[2] to calculate the heat transfer coefficient inside the tube:

$$\mathrm{h}_i = St_i \frac{\lambda}{D_{in}} \mathrm{Re}^{0.8} \mathrm{Pr}^{1/3} \left(\frac{\mu}{\mu_W} \right)^{0.14}$$

St_i - Stanton Number, St

λ - Thermal Conductivity of Fluid Inside Tube

D_{in} - Nominal Diameter of Inside Tube

Re - Reynolds Number for Fluid Inside Tube

Pr - Prandtl Number for Fluid Inside Tube

μ - Dynamic Viscosity of Fluid at Mean Temperature

μ_W - Dynamic Viscosity of Fluid at Wall Temperature

Establishing equations based on Wilson's graphical method[3]：

$$\frac{1}{U_0} = \frac{1}{\mathrm{h}_0} + r_s + r_W + \frac{1}{\mathrm{h}_i}$$

Because the state of the refrigerant is constant, the heat transfer coefficient h_0 outside the tube is also constant, and the change in the total heat transfer coefficient comes from the change in the heat transfer coefficient inside the tube. Considering that the test tube is a new copper tube, its fouling thermal resistance $\mathrm{r_W}$ can be ignored. From the above formula, it can be concluded that:

$$\frac{1}{U_0} = \frac{1}{St} \bullet \frac{1}{\frac{\lambda}{D_{\mathrm{in}}} \mathrm{Re}^{0.8} \mathrm{Pr}^{1/3} \left(\frac{\mu}{\mu_W} \right)^{0.14}} + Cons$$

By fitting with the least squares method, the slope of the line is obtained, which is the reciprocal of $\mathrm{S_t}$.

3) External heat transfer coefficient

Due to the complex external geometric structure of surface enhanced heat transfer tubes, there is currently no widely applicable and high-precision criterion equation. The author adopts the following relationship equation:

$$\ln h_0 = \ln F + D \ln q$$

q - Heat Flux

h_0 - External Heat Transfer Coefficient

F、D - Coefficient

IV. CONCLUTIONS

The heat exchange tube selected for the experiment is a universal specification light tube, which is convenient for horizontal comparison of data. The parameters are shown in the table：

Tube Type	Outer Diameter/mm	Inner Diameter/mm	Length/mm	External Surface Area Coefficient	Internal Surface Area Coefficient
Optical Tube	25.4	23.0	2500		

Select a 25mm light tube for full liquid evaporation and external condensation experiments, and compare the calculated results with the theoretical formula. The expected deviation of the heat transfer coefficient inside the light tube from Gnielinski[4] is ± 20% , and from the theoretical values of Blasius or McAdams[5] is ± 10%, The deviation between the external film condensation heat transfer coefficient of the light tube and the Nusselt theoretical value is ±10%.

Compare the heat transfer coefficient obtained from the full liquid evaporation test with the theoretical values calculated by the Gnielinski formula and McAdams formula, As shown in Figure 3.1. From the results, it can be seen that the maximum deviation between the heat transfer coefficient test data in the full liquid evaporation experiment and the theoretical calculation value of the Gnielinski formula is 3.1%, and the minimum deviation is 9.2%, which is very close to the theoretical calculation value of the McAdams formula. From Figures 3.2 and 3.3, it can be seen that under the condensation condition outside the tube, the deviation between the heat transfer coefficient inside the light tube and the Gnielinski theoretical calculation value is very small, and the deviation from the McAdams theoretical calculation value is within 10% to 15%. The deviation between the heat transfer coefficient outside the light tube and the theoretical calculation value of the Nusselt1 formula under high heat flux conditions is 2%~7%, and the maximum deviation of the theoretical calculation value of the Nusselt2 formula under low heat flux conditions is 7%.

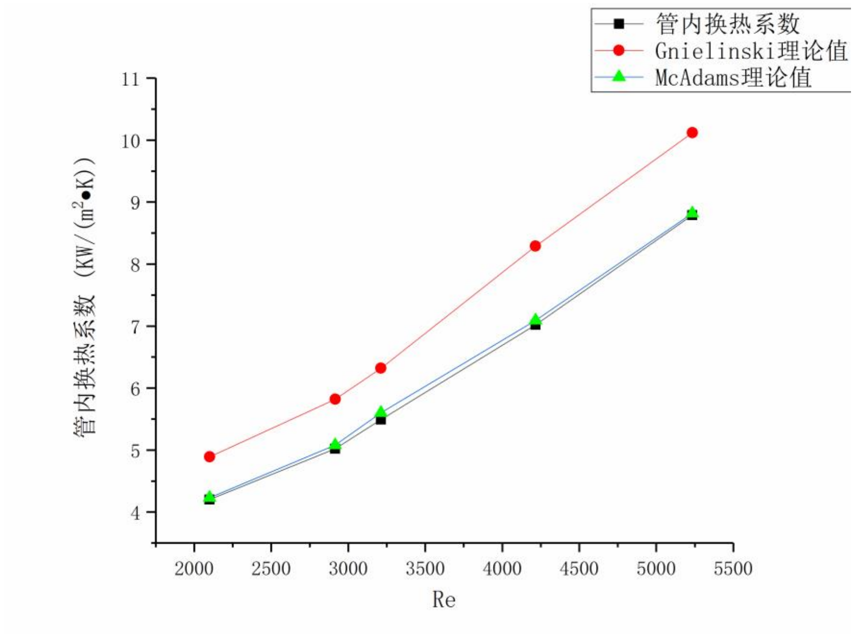

Figure 3.1 Comparison between the Heat Transfer Coefficient and Theoretical Values inside a Full Liquid Vaporized Light Emitting Tube

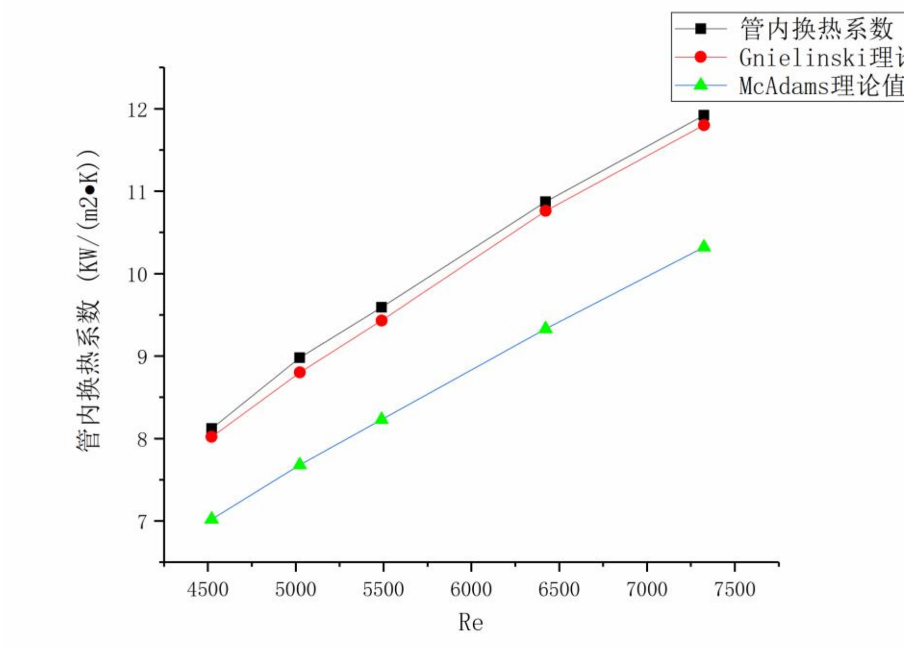

Figure 3.2 Comparison between the heat transfer coefficient and theoretical values inside the condensing light tube outside the tube

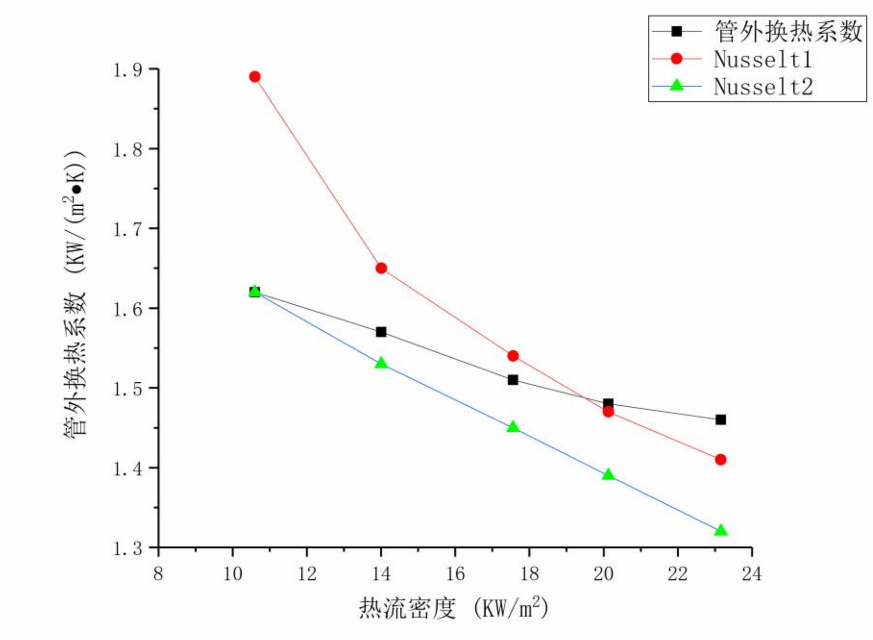

Figure 3.3 Comparison between the External Heat Transfer Coefficient and Theoretical Values of the Condensing Light Tube Outside the Tube

From the experimental results, it can be seen that by changing the structure of the experimental bench and changing the source of heat during condensation outside the tube from electric heating inside the evaporator bucket to hot water in the evaporator tube, it can ensure the accuracy of full liquid evaporation and condensation outside the tube, shorten the experimental process, and reduce time consumption.

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