Investigation on Switchable Evaporation and Condensation Horizontal Single Tube Heat Exchange Experiment Platform

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Abstract. In this experiment, the switchable evaporation and condensation horizontal single-tube heat exchange experiment platform is designed. And the equipment selection and construction of the experiment platform is completed through the design calculation. The experimental results show that the thermal balance error of the test section of the experiment platform is less than 15%, especially the condensation and evaporation experiment of R22 in 12.7 mm copper tube, and the evaporation experiment of R410A in 9.52 mm copper tube, the thermal balance error of the experiment is less than 5%. The experiment platform can realize heat exchange experiments with different refrigerants, and the test section of the experiment platform can be standardized replacement of tube types according to research needs.

1. Introduction

In machineries, equipment and industrial processes, heat transfer is one of the key aspects to maintain their functions and obtain better product quality [1]. Among them, heat transfer in the tube is widely used in nuclear power and refrigeration and other fields. Especially in the refrigeration field, the demand for refrigeration equipment in all walks of life is increasing, and the rapidly growing demand for cooling has led to a sharp rise in energy consumption [2]. Facing the deteriorating natural environment and increasing energy shortage, as well as the ozone layer destruction and global warming that are currently concerned by countries all over the world [3], there is an urgent need for all walks of life to optimize and update heat transfer equipment, and to develop and utilize new refrigerants.

At present, in the field of refrigeration, as the result of improving the actual performance of heat exchangers and enhancing heat transfer have a profound impact on energy conservation and environmental protection [4], enhancing heat transfer in tubes has become one of the important means to improve energy efficiency. The heat exchange can be enhanced by optimizing the tube shape of the heat exchange tube. Aroonrat et al. [5] researched the heat transfer experiment of R134a in bellows and smooth tubes, and the results showed that the heat transfer of bellows was 70% higher than that of smooth tubes. Diani et al. [6] studied the heat transfer of R513A in smooth round tubes and micro-finned tubes, respectively, and the results showed that micro-finned tubes have a more significant effect on heat transfer enhancement. Wang et al. [7] studied the heat transfer of supercritical pressure R134a in a horizontal internally ribbed tube and a smooth tube. The results show that, under various working
conditions, compared with a smooth tube, the temperature change of the inner ribbed tube is small, and its heat transfer coefficient is higher than that of a smooth tube. Zakeralhoseini et al. [8] conducted experiments on R1234yf in a smooth horizontal spiral coil. The experiment showed that the average heat transfer coefficient of the spiral coil is 60-120% higher than that of the straight pipe. Azarhazin et al. [9] conducted a heat transfer experiment of R1234yf in a flat tube. The study showed that the use of a flat tube can not only increase the heat transfer coefficient but also significantly increase the pressure drop of the flat tube compared with the round tube.

It is also important to reduce the refrigerant charge by reducing the size of the equipment [10]. Copetti et al. [11] studied the boiling heat transfer of R600a in a circular tube with an inner diameter of 2.6 mm. The results showed that the heat flux has the most obvious effect on the heat transfer coefficient under the conditions of low mass flow rate and low vapor quality. Enoki et al. [12] studied the heat transfer of water in a circular microchannel tube with an inner diameter of 2.12 mm. The results showed that the highest heat transfer coefficient occurs at the highest mass flux, and the pressure loss increases when the mass flux is higher. Li et al. [13] experimented with R32 on a microchannel tube with a hydraulic diameter of 0.643 mm, while Gao et al. [14] used a 4 mm horizontal ordinary tube to experiment with ammonia, and their research showed that the heat transfer coefficient increased with the increase of heat flux. de Oliveira et al. [15] conducted the boiling heat transfer experiment of R290 in a horizontal tube with an inner diameter of 1.0 mm. The study found that both mass flux and heat flux have an important influence on the heat transfer coefficient of R290, and the heat transfer coefficient of R290 increases with the increase of steam quality.

In terms of refrigerant research, the research of Copetti et al. [11] on R600a and the research of Solanki et al. [16] on R600a in a smooth spiral corrugated tube show that R600a can provide a higher heat transfer coefficient than R134a. Liu et al. [17] studied the condensation heat transfer process of R245fa. The test results show that under the condition of small mass flow, the heat transfer coefficient of R245fa increases with the increase of mass, and under the condition of large mass flow, the heat transfer coefficient has a peak value. The experimental of Li et al. [13] results show that under the same conditions, the pressure of R32 is lower than that of R134a, and when the mass increases, the heat transfer coefficient of R32 will increase before R134a. Wang et al. [18] conducted a heat transfer experiment of supercritical carbon dioxide in a smooth circular tube. The experimental results show that other parameters are fixed, and under the conditions of high mass flux, low inlet temperature and small diameter, the supercritical carbon dioxide heat exchange system has high heat transfer performance.

The above-mentioned scholars’ heat exchange experimental research is realized by building a completed heat exchange experimental platform, but the introduction to the design principles of the experimental platform and the process of construction are not comprehensive. Therefore, this paper has carried out a detailed discussion of the switchable evaporation and condensation horizontal single-tube heat exchange experiment platform. This test bench is mainly used to study the heat transfer performance of a horizontal single tube. It uses five refrigerants of R22, R32, R134a, R245fa, and R401A as test working fluids, and uses Φ3 mm, Φ4 mm, Φ5 mm, Φ6 mm, Φ7 mm 8 kinds of copper tubes are designed and calculated as the inner tube of the test section, and the equipment selection of the experimental bench is completed according to the calculation results. The heat transfer experiment was conducted through the completed experimental platform, and the experimental results showed that the experimental platform had excellent heat transfer performance.

2. Design principle of switchable evaporation and condensation horizontal single-tube heat exchange experiment platform

The principle design diagram of the switchable evaporation and condensation single-tube heat exchange experiment platform is shown in figure 1, including a refrigerant cycle system and a water cycle system. The water cycle system includes a preheating cycle, a test section water cycle and a chilled water cycle. The refrigerant circulation system consists of a reservoir, a filter drier, a subcooler, a refrigerant pump, a front-end heat exchanger HE2, a test section, and a condensing heat exchanger HE3. Among them, the subcooler is located in front of the refrigerant pump to ensure that the refrigerant entering the refrigerant
pump is kept supercooled, and to prevent flash steam when the refrigerant passes through the inlet and outlet valve groups of the refrigerant pump. The test section is a sleeve structure, the inner tube is a copper tube to be tested with a length of 1800 mm, and the outer tube is a stainless steel tube. Between the inner tube and the outer tube is a sleeve, the refrigerant flows in the inner tube, the glycol aqueous solution flows in the sleeve and exchanges heat with the refrigerant in the inner tube, and the flow direction of the refrigerant is opposite to the flow direction of the glycol aqueous solution. Besides, there are multiple needle valve reserved holes on the refrigerant circulation loop, which can measure pressure, leak detection and charge refrigerant to the experimental device, to ensure the normal operation of the experimental bench and the accuracy and rationality of the experiment.

![Figure 1](image_url)

**Figure 1.** Principle design diagram of the switchable evaporation and condensation single-tube heat exchange experiment platform

The chilled water cycle includes pre-cooling treatment cycle, condensation treatment cycle and subcooling treatment cycle, which is composed of front-end heat exchanger, heat exchanger HE1, condensing heat exchanger HE3, supercooler, glycol low-temperature water tank, Y-type filter, and low temperature circulating water pump. When the evaporation experiment was performed, the heat exchanger HE1 was not working, and the front-end heat exchanger HE2 and the condensing heat exchanger HE3 were running. When conducting the condensation experiment, the heat exchanger HE1 is running, and the front-end heat exchanger HE2 and the condensing heat exchanger HE3 are not working. Besides, there is an electric heater with a power regulator in the glycol low-temperature water tank, which can be used as a precision heater to control and fine-tune the water temperature, making it easy to adjust the temperature.

3. **Design calculation and selection of experimental platform**

In the experiment of the single-tube heat transfer test bench, factors such as the mass flow rate, saturation temperature, and heat flux density of the refrigerant will affect the data of each measurement point on the test bench. Therefore, by considering the influence of various factors, according to the requirements of different test working fluids and tube types of the test section, the test bench design and verification calculations are carried out to select reasonable equipment to build the test bench. The specific
The experimental conditions of the experimental platform are shown in Table 1.

| Project                          | Experimental design parameters                                      |
|----------------------------------|---------------------------------------------------------------------|
| Copper tube specifications        | Φ3 mm, Φ4 mm, Φ5 mm, Φ6 mm, Φ7 mm, Φ9.52 mm, Φ11.43 mm, Φ12.7 mm   |
| Refrigerant                      | R22, R32, R134a, R245fa, R401A                                      |
| Evaporation temperature          | -20~20 °C                                                           |
| Condensation temperature         | 30~60 °C                                                           |
| Flow velocity in evaporation test tube | Φ3 mm, Φ4 mm, Φ5 mm, Φ6 mm, Φ7 mm, Φ9.52 mm: 50~600 kg/(m²·s)     |
|                                  | Φ11.43 mm, Φ12.7 mm: 50~300 kg/(m²·s)                              |
| Flow velocity in condensing test tube | refigerating medium                                 |
|                                  | Ethylene glycol aqueous solution                                  |
| Thermal balance error            | ≤5% (The thermal balance error is 15% under the condition of small temperature difference (<2 °C) on the refrigerant side.) |

3.1. System pressure of the test bench

Due to environmental issues such as ozone depletion and global warming, R22 needs to be phased out urgently [19], so it is necessary to study new refrigerants that can be used to replace R22. R32 has a higher specific heat capacity and thermal conductivity, thereby enhancing heat conduction, and has good safety [20] and a lower global warming potential (GWP) [21]. R134a is one of the HFCs with the lowest GWP, and it has no ozone depleting potential (ODP) and is not flammable [22]. R245fa is a high-temperature refrigerant with an ODP of 0, which can provide a high coefficient of performance for systems that use it as a working fluid [23]. R401A has a relatively low boiling point and high latent heat, and its ODP is also 0 [24]. Therefore, R22 is used as a reference refrigerant to analyze the heat transfer characteristics and pressure drop performance of other different refrigerants in the test section. Within the test temperature range, the saturation pressures of the refrigerants R22, R32, R134a, R245fa, and R401A to be tested are shown in Figure 2.

![Figure 2](image_url)

**Figure 2.** The saturation pressure of the refrigerant to be tested in the test temperature range

It can be seen from Figure 2 that when the test temperature is 50 °C, the saturation pressure of R32 is the largest, that is, the maximum operating pressure of the pipeline is 3.141 MPa. The design pressure of the pipeline should be greater than the maximum operating pressure. Take 1.15 times the maximum operating pressure of the pipeline to know that the design pressure of the pipeline should be greater than
or equal to 3.612 MPa.

3.2. Calculation of refrigerant flow rate and test section heat transfer in the experimental platform

According to the test conditions and requirements listed in Table 1, the refrigerant flow rate and the heat exchange amount of the test section under the required conditions are calculated. The refrigerant flow rate, the minimum heat exchange rate and the maximum heat exchange rate are from equation (1) to equation (3) calculated and shown in Table 2.

\[ m_R = G_R \cdot A \]  
\[ Q_{R_{\text{min}}} = m_{R_{\text{min}}} \cdot r \]  
\[ Q_{R_{\text{max}}} = m_{R_{\text{max}}} \cdot r \]

Where \( m_R \) — Refrigerant flow; \( G_R \) — Refrigerant flow rate; \( A \) — Heat transfer area; \( Q_R \) — Refrigerant heat exchange amount; \( r \) — Latent heat of vaporization.

### Table 2. Calculation of heat transfer in the test section under experimental requirements

| Project | Parameters of different pipe diameters |
|---------|----------------------------------------|
|         | 3 mm | 4 mm | 5 mm | 6 mm | 7 mm | 9.52 mm | 9.52 mm | 11.43 mm | 12.7 mm |
| \( \delta \) (mm) | 0.5 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 |
| \( \varphi \) (mm) | 2 | 3 | 4 | 5 | 6 | 8.32 | 8.32 | 10.83 | 11.5 |
| A (mm²) | 3.14 | 7.07 | 12.57 | 19.63 | 28.27 | 54.37 | 54.37 | 92.12 | 103.87 |
| \( G_{R_{\text{min}}}(\text{kg}/(\text{m}^2 \cdot \text{s})) \) | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| \( G_{R_{\text{max}}}(\text{kg}/(\text{m}^2 \cdot \text{s})) \) | 750 | 750 | 750 | 750 | 750 | 750 | 300 | 300 | 300 |
| \( m_{R_{\text{max}}} \) (kg/s) | 0.0001 | 0.0003 | 0.0006 | 0.0009 | 0.0014 | 0.0027 | 0.0027 | 0.0046 | 0.0051 |
| \( m_{R_{\text{min}}} \) (kg/s) | 0.0024 | 0.0053 | 0.0094 | 0.0147 | 0.0212 | 0.0408 | 0.0163 | 0.0276 | 0.0312 |
| \( r \) (KJ/kg) | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 | 200 |
| \( Q_{R_{\text{min}}}(\text{kW}) \) | 0.031 | 0.071 | 0.126 | 0.196 | 0.283 | 0.544 | 0.544 | 0.921 | 1.039 |
| \( Q_{R_{\text{max}}}(\text{kW}) \) | 0.471 | 1.061 | 1.886 | 2.945 | 4.242 | 8.156 | 3.262 | 5.527 | 6.232 |

It can be seen from Table 2 that the flow range of the refrigerant is 0.000157 ~ 0.0312 kg/s, that is, 0.565 ~ 112.32 kg/h. The range of the amount of heat exchange of the refrigerant is 0.031 ~ 6.232 kW.

When the heat preservation effect of the test section is significant, the test section reaches thermal equilibrium, and the heat exchange on the waterside and the refrigerant side is equal, as a result, the range of the heat exchange on the waterside of the test section is 0.031 ~ 6.232 kW.

3.3. Calculation of water flow in the test section of experimental platform

The flow rate of different pipes corresponding to the waterway is calculated by equation (4), and the temperature difference \( \Delta t \) is taken as 2 °C and 5 °C respectively for calculation, as shown in Table 3.

\[ V_{s,W} = Q_W / C_{p,W} \rho \Delta t \] (4)

Where \( V_{s,W} \) — Water flow; \( Q_W \) — Water heat exchange amount; \( C_{p,W} \) — Specific heat capacity of water.
Table 3. Calculation of the flow rate of the test section of different pipe diameters when the temperature difference $\Delta t$ is 2 °C and 5 °C respectively

| Project | Parameters of different pipe diameters |
|---------|----------------------------------------|
|         | 3 mm | 4 mm | 5 mm | 6 mm | 7 mm | 9.52 mm |
| $C_{p,W}$ (KJ/(kg·K)) | 3.56 | 3.56 | 3.56 | 3.56 | 3.56 | 3.56 |
| $\Delta t_1$ (°C) | 2 | 2 | 2 | 2 | 2 | 2 |
| $\Delta t_2$ (°C) | 5 | 5 | 5 | 5 | 5 | 5 |
| $Q_{W_{min}}$ (kW) | 0.031 | 0.071 | 0.126 | 0.196 | 0.283 | 0.544 |
| $Q_{W_{max}}$ (kW) | 0.471 | 1.061 | 1.886 | 2.945 | 4.242 | 8.156 |
| $V_{s,W_{min1}}$ (m³/h) | 0.015 | 0.0341 | 0.060 | 0.094 | 0.136 | 0.261 |
| $V_{s,W_{max1}}$ (m³/h) | 0.226 | 0.509 | 0.904 | 1.412 | 2.034 | 3.911 |
| $V_{s,W_{min2}}$ (m³/h) | 0.006 | 0.014 | 0.024 | 0.038 | 0.054 | 0.104 |
| $V_{s,W_{max2}}$ (m³/h) | 0.090 | 0.203 | 0.362 | 0.565 | 0.814 | 1.565 |

When the copper tube to be tested is Φ11.43 mm and Φ12.7 mm, the experiment requires that the water velocity outside the copper tube to be tested is 0.5 ~ 1.5 m/s, and the water flow rate is calculated by equation (5). The water flow calculation in the test section is shown in table 4.

$$m_w = V_w \cdot A \tag{5}$$

Table 4. Water flow calculation in the test section

| Project | Parameters of different pipe diameters |
|---------|----------------------------------------|
|         | 11.37 mm | 12.7 mm |
| A (mm²) | 83.96 | 92.32 |
| $V_{W_{min}}$ (m/s) | 0.5 | 0.5 |
| $V_{W_{max}}$ (m/s) | 1.5 | 1.5 |
| $V_{s,W_{min1}}$ (m³/h) | 0.151 | 0.166 |
| $V_{s,W_{max1}}$ (m³/h) | 0.453 | 0.499 |

According to table 3 and table 4, the flow range of the waterway in the test section is 0.006 ~ 3.911 m³/h, which provides a reference for the selection of electromagnetic flowmeters in the waterway in the test section.

3.4. The overall structure design of the experimental platform and the selection of equipment and measuring instruments

The overall structure design of the switchable evaporation and condensation horizontal single-tube heat exchange experimental platform is shown in figure 3. The outer frame of the test bench is welded with channel steel into a structure of 2700L×1150W×1000H. A Φ100mm rubber universal wheel is welded to the bottom of the overall outer frame. Therefore, the overall height of the outer frame of the test bench is 1150 mm, which is convenient for the manipulation and installation of equipment on the test bench. The entire experimental platform can be divided into upper and lower parts. In the upper part, there are main equipment such as glycol cryogenic water tank, pulsation damper, heat exchanger and test section, and in the lower part, there are water pumps, a refrigerant pump, electric heating water tanks and a reservoir. And stainless steel water receiving plate is laid at the bottom of the experimental platform to collect the liquid flowing out of the experimental platform and uniformly discharge the accumulated water through the drainage port at the corner of the water receiving plate.
The equipment used in the experimental platform is shown in Table 5. In the refrigerant cycle system, electronic expansion valves are installed at the front and rear ends of the test section to adjust the pressure of the experimental system. According to the experimental conditions and requirements in Table 1, Danfoss electronic expansion valve model EKD316 is selected. The electronic expansion valve has the advantages of ensuring system energy efficiency, precise flow control, and high reliability. A filter drier is installed between the reservoir and the refrigerant pump to reduce impurities in the refrigerant entering the refrigerant pump, thereby ensuring the normal operation of the refrigerant pump. The refrigerant pump uses a hydraulic diaphragm metering pump to provide power for the entire refrigerant cycle. It can adapt to a variety of working fluids and high-pressure conditions and has the characteristics of high adjustment accuracy, flow adjustment in shutdown or running status, simple maintenance, low noise, and strong sealing [25]. A pulsation damper is connected to the outlet of the diaphragm metering pump to eliminate the pulsation of the refrigerant liquid. In the water circulation system, the front-end water pump in the preheating cycle and the test water pump in the test section water cycle use the horizontal circulating water pump, and the low-temperature circulating water pump in the chilled water cycle uses light horizontal multistage centrifugal pumps.

**Table 5. Equipment used in the experimental platform**

| Name                                | Type                     |
|-------------------------------------|--------------------------|
| Light horizontal multistage centrifugal pump | CHL2-40LSWSC            |
| Horizontal circulating water pump   | MHI204-380V              |
| Hydraulic diaphragm metering pump   | YSJ90LB4-1HS             |
| Pulsation damper                    | HLMZ-MS0.6/5.0           |
| Heat Exchanger                      | CB30-22H-F               |
| Front end heat exchanger            | ACH-30EQ-50HF            |
| Condensing heat exchanger           | AC-30EQ-44HF             |
| Filter drier                        | EMERSON EK-164S          |
| Subcooler                           | SS-0075GT-U              |
| Frequency converter                 | 6SE6440-2UD15-5AA1       |
| Regulator                           | PAC35C-B160-90A-11       |
| Electric heating                    | PAC35C-90A               |
| Electronic expansion valve          | EKD 316                  |

In the refrigerant cycle system, parameters such as temperature, pressure and flow have an important influence on the analysis of experimental data. The test bench adopts differential pressure sensors, pressure sensors, PT100 platinum resistances, electromagnetic flow meters and mass flow meters to...
collect temperature, pressure and flow signals. The measuring instruments used in the test bench are shown in Table 6. Each measuring instrument communicates with the PLC hardware in the large control cabinet through the RS-485 communication line. The conversion program that has been downloaded to the PLC hardware can convert the collected signals into easy-to-read values and display them in real-time based on the EB Pro configuration software development on the man-machine interface.

| Name               | Symbol   | Type                              | Precision | Range   |
|--------------------|----------|-----------------------------------|-----------|---------|
| Temperature Sensor | T1-T14   | Pt100                             | ±0.1 °C   | -10 ~ 60 °C |
| Pressure Sensor    | P1, P2   | PTX5072-TC-A1-CA-H0-PA: 0-4Mpa G  | 0.2%FS    | 0 ~ 4 MPa  |
| Differential pressure sensor | ΔP1 | PTX5072-TC-A1-CA-H0-PA: 1bar D | 0.2%FS    | 0 ~ 1 bar    |
| Differential pressure sensor | ΔP2 | PTX5072-TC-A1-CA-H0-PA: 0.5bar D | 0.2%FS    | 0 ~ 0.5 bar |
| Refrigerant flow meter | GR1 | RHM015T1P1PM0MOG1N               | 2.0%      | 0 ~ 0.6 kg/min |
| Refrigerant flow meter | GR2 | RHM03T1P2PM0MOG1N               | 2.0%      | 0 ~ 5 kg/min  |
| Electromagnetic Flowmeter | GW1 | AFX015G-D1AL1S-AD41-01B/CH         | 5.0%      | 0 ~ 6.3 m³/h  |
| Electromagnetic Flowmeter | GW2 | LDY-15S-21CC-12-01-0-(3)-6-10-00 | 5.0%      | 0 ~ 6.3 m³/h  |

After the completion of the experimental platform construction, the whole experimental platform is heat preservation. As shown in Figure 4, all piping and equipment are equipped with rubber-plastic pipe insulation cotton, so that the influence of convective heat exchange between the fluid and the outside air on the accuracy of the experimental parameters can be reduced when the test bench is working.

Figure 4. Insulation treatment of experimental platform

4. Data acquisition and monitoring interface of the experimental platform
The experimental platform adopts Siemens S7-300 PLC and WEINVIEW MT6103iP touch screen to
design the acquisition and monitoring system and system interface. PLC and touch screen communicate through the RS-485 communication line. The design of the experimental platform acquisition and monitoring system is shown in figure 5, including the operation section, the control section, the data acquisition section and the executable section. The PLC in the control section is responsible for processing the data signals of each measuring point of the experimental platform in the data acquisition section and controlling the various equipment of the executable section, transmitting data and equipment status to the operation section through the communication line, and accepting the instructions input by the researcher in the operation section. The system centralizes the field data of the entire experimental platform for display on the touch screen, the operation section can monitor the data of each measurement point of the experimental platform in real-time, and can directly adjust the temperature, frequency, power and other parameters.

![Figure 5. Design of the experimental platform acquisition and monitoring system](image)

The design of the interface of the experimental platform acquisition and monitoring system includes a start-up interface, a temperature data acquisition interface, a flow data acquisition interface, a pressure data acquisition interface, a control interface and an alarm history data interface.

The start-up interface of the experimental platform acquisition and monitoring system is shown in figure 6, which is used to complete the start-up of the experimental system. There are user logins in this interface, which can be used by researchers with different permissions. Authorized researchers can use the menu to enter different operation interfaces by entering the number and password. If there is no authorized person or the password is incorrect, the "Password Protected! Access Denied!" window will pop up to prevent misoperation of the touch screen.
The data acquisition of the experimental platform acquisition and monitoring system includes three interfaces of temperature, flow and pressure data acquisition. The temperature data acquisition interface is shown in Figure 7. On the left side of each collection interface, data changes can be displayed in real-time, and historical data can be stored on the right side. By clicking on the "Graph" at the bottom of the interface, researchers can observe the changes in the collected data over time within a specified time range. Researchers can also click "Backups" at the bottom of the interface to save the data for further data processing and analysis.

The control interface of the experimental platform acquisition and monitoring system is shown in
figure 8. The open and stop of each device are controlled by the switch of this interface, and the signal light is on when the device is turned on. The refrigerant pump, test water pump, and front water pump are controlled by adjusting the inverter parameters so that each water pump works according to the load required by the experiment. The combination of the frequency converter and the touch screen gives full play to the frequency converter's advantages of convenient speed regulation and energy-saving and reduces unnecessary energy waste.

![Control Interface](image)

**Figure 8.** Control interface

The alarm history data interface of the experimental platform acquisition and monitoring system stores the alarms that have occurred, and distinguishes whether they return to normal by different colors. The alarm function of the touch screen plays a key role in the safe operation of the test bench. Researchers can quickly obtain system hardware fault information through this function and then make corresponding operations.

5. **Thermal balance error analysis of the test bench**

The temperature in the test section of the experiment is at a certain difference from the ambient temperature, and the heat loss in the test section affects the measurement accuracy of the test bench. Therefore, thermal balance analysis is required. This experimental platform has studied the evaporation and condensation heat exchange experiments of R22 in Φ12.7mm copper tube. And under the condition of an evaporation temperature of 5 °C, the evaporation experiments of R410A in Φ7 mm and Φ9.52 mm copper tubes were carried out. The heat exchange obtained from the experiment is shown in figure 9. The thermal balance error is shown in figure 10.
It can be seen from figure 10 that when the R22 is used in the Φ12.7 mm copper tube for the evaporation experiment and the condensation experiment, the thermal balance error is less than 5%.
During the evaporation experiment of R410A in a Φ7 mm copper tube, due to the small diameter of the copper tube, the fluid flow rate in it is small, and there will be fluctuations in the fluid flow in the evaporation tube, and the fluctuation of the refrigerant pump will also affect the error. Consequently, the thermal balance error of the evaporation experiment is relatively large. In the evaporation experiment of R410A in a Φ9.52 mm, the thermal balance error is less than 5%. In summary, it can be proved that the selected insulation layer and package form in the experimental platform design stage have a good insulation effect. The accuracy of the experimental data can be guaranteed.

6. Conclusions
In this paper, based on the principle of evaporation and condensation heat transfer in the tube, a set of multi-functional single-tube heat transfer experimental rigs that can be used for variable refrigerants and tube types are designed. The main conclusions are as follows:

1. The switchable evaporation and condensation horizontal single-tube heat exchange experimental device was designed and built, and the design calculation and selection of the single-tube evaporation and condensation heat exchange system were completed. The overall design of the experimental system platform, the selection and design calculation of the main components of the system, and the data acquisition and control scheme of experimental parameters are all included.

2. The hydraulic diaphragm pump is used to replace the traditional compressor as the main power of the experimental device, to realize the system running without lubricating oil. The equipment selected according to the design calculation can meet the requirements of most refrigerants, which is beneficial to the research on the heat transfer characteristics of new refrigerants and tube types. By designing an experimental platform acquisition and monitoring system, the automatic control of the experimental platform is realized, the labor cost is reduced, and the automation and reliability of the experimental platform are improved.

3. According to experimental data, the thermal balance error of large pipe diameters (12.7mm and 9.52mm) is less than 5% and the repeatability is good, indicating that the experimental device meets the requirements of design calculations and the experimental results are reliable.

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