Report on the Test of Small Diameter Heat Exchanger for Refrigerated Cabinet

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Executive Summary

Based on the International Copper Association requirements, this project aims to introduce the technology of small diameter heat exchangers into the refrigerated display cabinet industry to improve the operation efficiency of refrigeration systems effectively, save the production cost of enterprises and reduce the damage to the natural environment. According to the preliminary theoretical research and simulation results, in the constant temperature and humidity laboratory, the performance of the newly designed condensing heat exchanger on the refrigerated display cabinet was studied, and the experimental results were compared and analyzed. The results show that the cooling effect and thermal efficiency of the small diameter condenser replacement unit are significantly improved compared with the prototype unit, and the newly designed C1 and C3 condenser have the best effect. In terms of display surface temperature, the counter display surface temperature of C1 and C3 unit system is the lowest, and the matching degree in the system is the highest, and the thermal efficiency of the refrigeration system is better improved.

Catalog

Chapter 1 The performance Testing of the Refrigerated Cabinet with small tube diameter condenser

Although through the 5mm small diameter heat exchanger structure design, small diameter flow path research, and new small diameter heat exchanger design. The simulation can not entirely reflect the actual operation of the condenser in the refrigerated display case. The simulation is based on a steady-state distribution parameter model to study the condenser's heat transfer and temperature distribution. In order to make the research more rigorous and convincing, it is necessary to test the performance of the whole machine to design and manufacture the small diameter heat exchanger. In order to evaluate the replacement effect of the small diameter heat exchanger, a comparative analysis of large diameter condenser and small diameter condenser is carried out. The required test environment was formulated according to the national standard GB/T 21001.2-2015 Refrigerated Display Cabinets part 2 Classification, Requirements and Tests, and the condenser performance was tested according to the requirements. A detailed test scheme was developed, the data were sorted out, and the results were analyzed.

1.1 Testing conditions

1.1.1 Testing environment

The laboratory is a parallel cube space. The air return mode in the laboratory is the top and side return mode. The top of the environmental chamber is the air supply hole plate and the air return port's side. The ceiling is the air outlet of the orifice plate, as shown in Figure 1-1.

Fig. 1-1 Laboratory air supply wall

Humidified steam is placed at the return air outlet on the side of the laboratory to adjust the temperature and humidity of the laboratory jointly. Figure 1-2 shows the air return vent of the laboratory.

Fig. 1-2 Laboratory air return wall

The remaining non-technical wall surfaces of the indoor environment are approximately insulated. The insulation material is a 60mm thick rigid polyurethane foam board (λ=0.03W/(m·K)), and all are installed on the inner metal surface. In addition, the floor is made of concrete, which provides sufficient insulation to prevent ambient weather conditions from affecting the temperature of the floor.

The laboratory is illuminated to ensure that the illumination measured at 1m above the ground is (600±100) lx. In addition, the wall and ceiling of the laboratory are coated with light gray coating. When the temperature is 25℃, the emissivity is between 0.9 and 1.

1.1.2 Testing operation conditions

According to the national standard, a small diameter condenser's refrigerated display cabinet test needs to be carried out in a constant temperature and humidity test chamber. Therefore, tests shall be conducted in one of the climate types specified in Table 1-1. The temperature and relative humidity deviations in the laboratory are within ±1℃ and ±5%, respectively. According to the test regulations of Highly Nakano, the working condition of the laboratory climate type is 3 (dry bulb temperature 25℃, relative humidity 60%). The test room is equipped with an ambient temperature and humidity measurement sensor.

Table 1-1 Laboratory test conditions

Laboratory climate type	Dry-bulb temperature /°C	Relative humidity /%	Dew-point temperature /°C	Moisture content /g/kg
0	20	50	9.3	7.3
1	16	80	12.6	7.1
8	23.9	55	14.3	10.2
2	22	65	15.2	10.8
3	25	60	16.7	12
4	30	55	20.0	14.8
6	27	70	21.1	15.8
5	40	40	23.9	18.8
7	35	75	30.0	27.3

In addition to the temperature and humidity measuring device in the environment room, additional temperature measuring points are arranged on the refrigerated display case to record real-time temperature fluctuations. The T-type thermocouple is used for temperature measuring points with an accuracy of 0.5℃. Figure 1-3 shows the layout of ambient temperature measurement points. The purpose is to record temperature data and avoid the influence of hot air discharged from the condenser on the temperature of the test point.

Figure 1-3 Layout of ambient temperature measurement points

1.1.3 Testing conditions

Apart from the above test lab environment conditions, the regular work of the refrigerated cabinets needs all parts. Under requirements of the standard and manufacturer instructions, it should conform to the actual conditions of use as much as possible to assembly, setup, and positioning. All permanent attachments needed for regular use shall be in their normal position. Figure 1-4 shows the installation position of the display cabinet.

When positioning the refrigerated display cabinet D12CY-N05 selected in this topic, according to the standard, the size of the layout position is X=2m, B⩾1m, Y⩾0.8m, and A ⩾0.8m. Figure 1-5 shows the actual positioning of a refrigerated display cabinet. Again, the positioning space meets the national test standards.

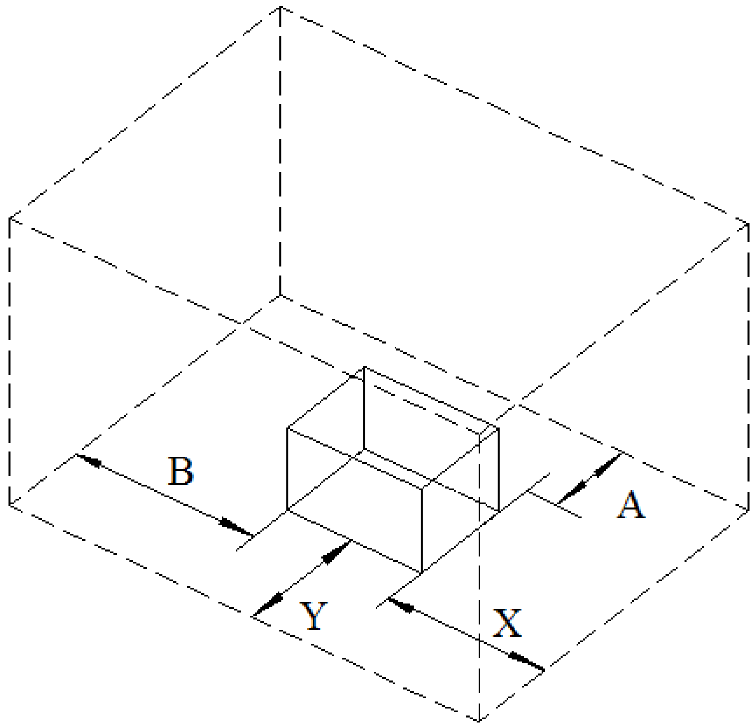

Figure 1-4 Schematic diagram of installation position of display cabinet

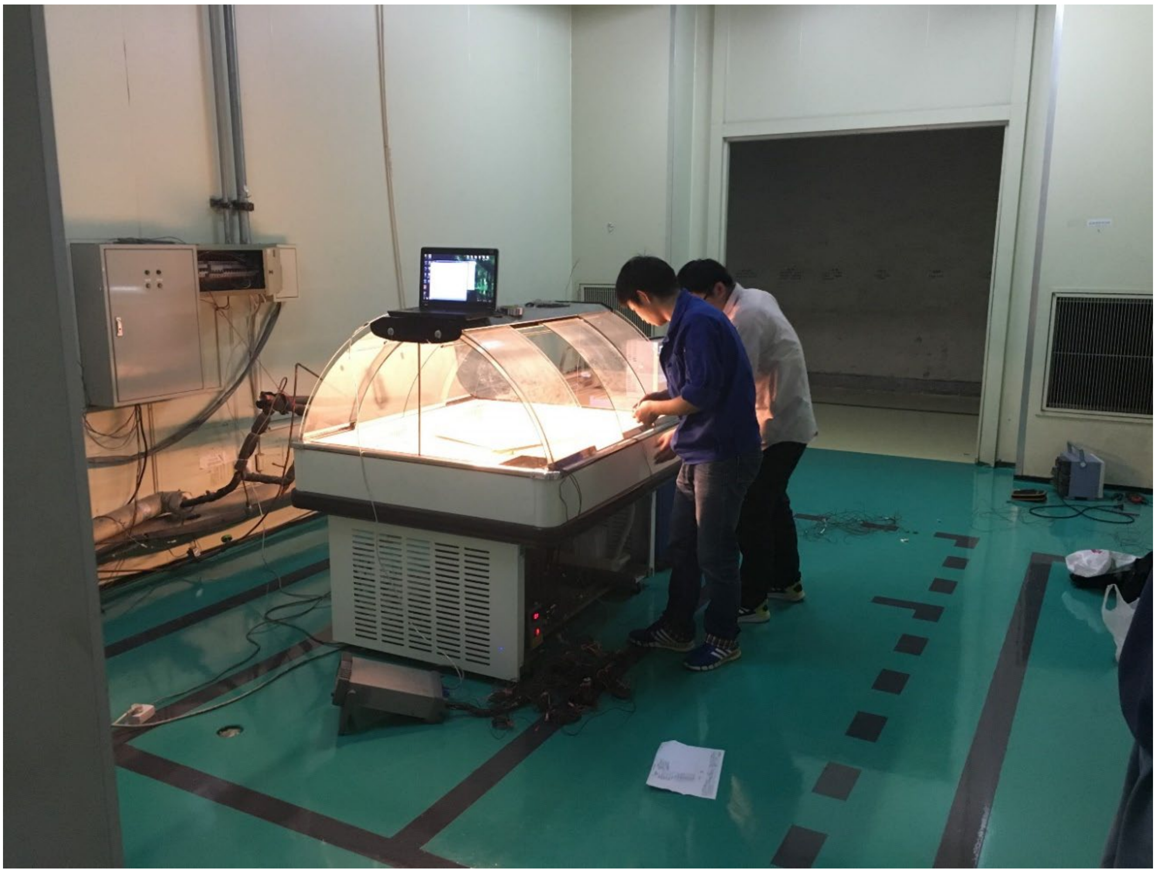

Figure 1-5 Refrigerated display case testing site

1.1.4 Testing period

The temperature in the display cabinet changes periodically, and the time cycle depends on the interval between two defrosting times. The defrosting program set by the manufacturer is defrosting once in 12h. When the temperature fluctuation range measured by the thermometer on the cabinet remains at ±0.5℃, the display cabinet is considered to have reached the temperature operation state. Subsequently, according to the national standard, the display cabinet was tested in a stable operation condition, and the total operation time of the refrigerated display cabinet was more than 24h.

1.2 Performance test system and method

1.2.1 Experimental system

The type of refrigerated display cabinet selected in this experiment is D12CY-N05, a horizontal closed display cabinet. Unlike the typically closed display cabinet, this display table is an island with curved glass closed doors on both sides. The average temperature of the cabinet is 0~5℃. Figure 1-6 shows the cabinet structure from the side view. The cabinet is divided into two layers, the lower layer for refrigeration system and electronic control device shelving layer, the upper layer for the cabinet surface display layer, below the cabinet surface for the evaporator and capillary placing layer, air outlet for the top of the bottom back points.

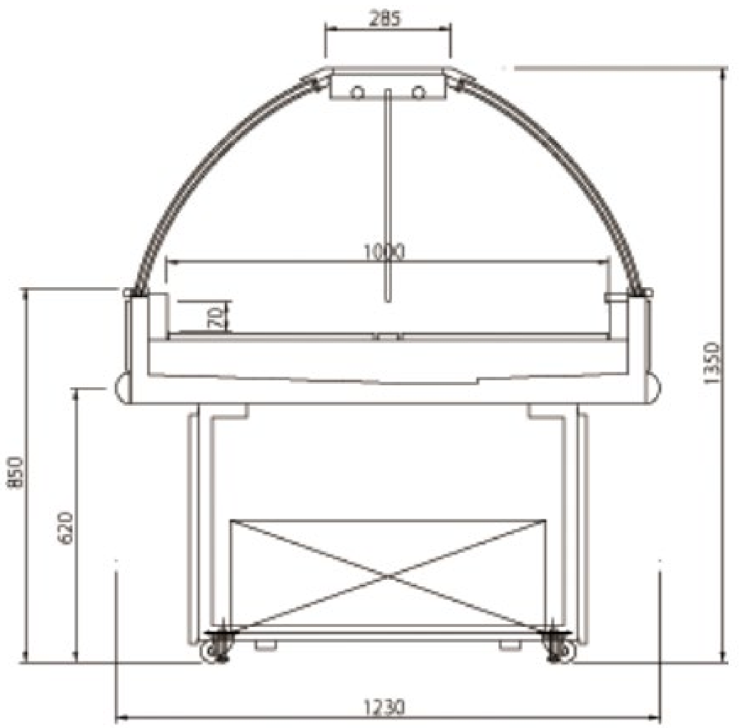

Figure 1-6 Display cabinet side view structure drawing

Test experimental system and schematic diagram are shown in Figure 1-7.

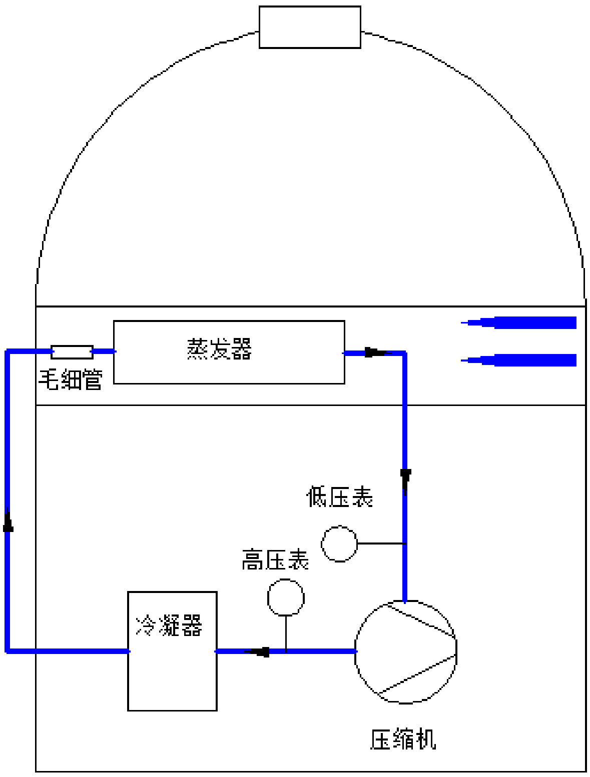

Figure 1-7 Schematic diagram of experimental system

1.2.2 Data acquisition system

Data acquisition equipment as shown in Figure 1-8, the data acquisition system can realize the collection, storage, monitoring, and processing of various physical parameters in the experimental process. The system consists of hardware and software, and the hardware mainly includes sensors, an Agilent acquisition instrument, and a computer. The system uses a T-type thermocouple and capacitive pressure sensor to measure temperature and pressure. The VB6.0 programming language programs the experimental acquisition software. The INPUT and output function of the I/O port is realized by the DLL file loaded by VB. Figure 1-9 shows the main window of the data collection system.

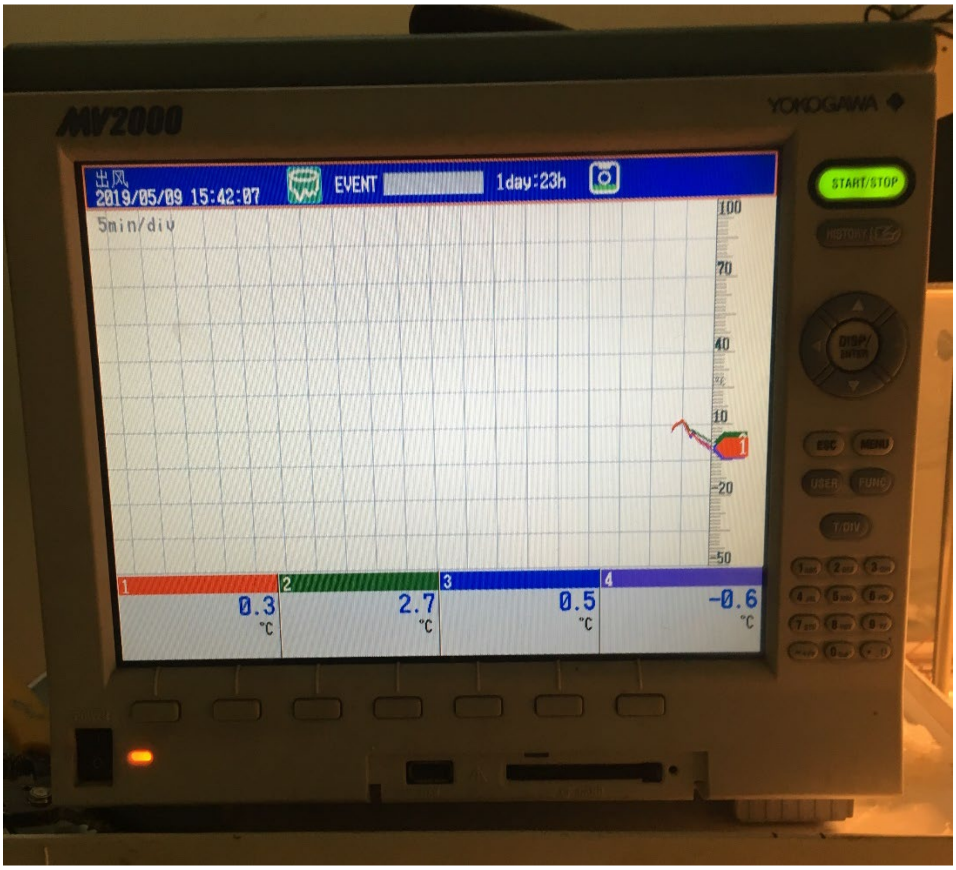

Figure 1-8 Data Acquisition Equipment

Figure 1-9 Main interface of data acquisition system

1.2.3 Testing method

In order to test the heat flow distribution and heat transfer of the small-diameter condenser in the operation of the refrigeration system, the project arranged temperature and pressure tests for this test experiment according to the manufacturer's test specifications and in combination with the national standards. The temperature measurement method is to arrange a thermocouple for temperature measurement at the temperature measuring point. In order to avoid a significant heat transfer error, the thermocouple is fixed with tin foil tape. When the whole system runs stably, the Agilent acquisition instrument collects the data in a long-running time. The collected information is filtered to avoid the error of temperature fluctuation. Finally, with the help of the experimental data set, transverse comparison (performance comparison between small pipe diameter refrigeration units and conventional pipe diameter refrigeration units) and longitudinal comparison (performance comparison between condenser refrigeration units with different small pipe diameters) can be made.

Temperature test includes three parts: refrigeration system temperature test, condenser temperature test, display case surface temperature test.

1) refrigeration system temperature test

The temperature test of the refrigeration system is critical, which can analyze the system's performance change after the replacement of the condenser and help judge the defects of the system. Therefore, measuring points are arranged in the following positions: compressor inlet and outlet, compressor housing, capillary outlet, and evaporator outlet.

Compressor housing temperature: The temperature of the compressor housing and the temperature of the exhaust port directly affect the long-term stable operation of the compressor. The high temperature of the compressor shell will bring a series of adverse effects, the cooling of lubricating oil is directly affected, which affects the lubrication of the compressor moving parts such as the suction and exhaust valve, accelerating wear, light lead to the reduction of refrigeration capacity of the refrigeration unit, heavy cause the bearing bite compressor cannot work correctly.

Compressor suction port: The temperature of the suction and exhaust ports of the compressor is closely related to the temperature of the chassis. Suppose the suction temperature of the compressor is too high. In that case, superheated steam enters the compressor, which directly increases the temperature of the chassis, and then causes the exhaust temperature to be too high. At the same time, if the suction temperature is too low, it is beneficial to the cooling of the refrigerant oil and the motor winding, but the cooling capacity decreases. When the suction temperature is too low, the suction superheat is not enough, which may cause condensation of the casing and liquid strike, seriously affecting the service life of the compressor. At the same time, a large amount of refrigerant will be dissolved in the frozen oil, which is not conducive to the lubrication of moving parts.

Compressor exhaust port: The high exhaust temperature will reduce the cooling capacity and refrigeration efficiency. When the exhaust temperature is too low, the compressor may be in a wet stroke operation, or the system's operating state is relatively small. Compressor wet stroke easily damages the valve structure; The lack of refrigerant operation will affect the heat dissipation of the motor winding and accelerate the aging of insulation materials.

Capillary outlet: if the temperature at the capillary outlet is too low, ice blockage may occur at the interface between capillary and evaporator. Because the isentropic expansion process occurs in the capillary tube, capillary and evaporator are joint diameter expanding suddenly, refrigerant leaving the capillary, instantaneous volume increase, evaporating pressure dropping lead to evaporation temperature drop, if contain a small amount of water, even if rare, also easy to freeze into ice, the nozzle block, the refrigerant evaporating heat could not enter the evaporator arise.

2) condenser temperature test

In addition to the temperature test of the refrigeration system, the research focus of this topic is the performance of small tubular condensers in the whole refrigerated display cabinet, so the condenser is the crucial object of the temperature test. After replacing the small diameter condenser, whether the refrigerant charging amount is appropriate, and the system is matched can be reflected by the heat exchange effect of the condenser. Therefore, multiple measuring points are arranged on the condenser to study the flow distribution and temperature distribution of refrigeration working medium in the process of condensation heat transfer, which can assist in exploring the influence of small diameter condensers on the refrigeration effect and the rationality of the design of small diameter condensers with different structures. Therefore, temperature measuring points were arranged in the inlet and outlet of the condenser, the outlet and middle section of various processes of the condenser before the experiment. Condenser inlet and outlet: If the refrigeration system is improperly matched after the replacement of the condenser, it has a significant impact on the whole refrigeration system. Insufficient condenser heat transfer area, scaling, insufficient cooling air volume, and too high cooling air temperature can lead to poor heat transfer effect. By comparing the temperature changes of the inlet and outlet of the small diameter condenser and the conventional condenser, it can be judged whether the heat exchange effect is optimized after replacing the condenser.

The middle part of the condenser: for each branch of the air-cooled condenser, the usual situation is that the temperature of the heat exchange tube in the first half is high, and the temperature has a slow and gradual trend of decline. Compared with the first half, the heat sensitivity of the latter half of the heat dissipation tube is greatly reduced because the last half's refrigerant has been gradually liquefied and has reached the condensation temperature and undercooling temperature. When abnormal conditions occur, the first half is not too hot, and the second half is close to the ambient temperature. The reason is that the compressor absorbs wet vapor refrigerant, or the refrigeration dose is insufficient. The other is that the whole condensing tube is boiling. Its reason is the refrigeration dose is too much, or ventilation volume is small, or the ambient temperature is high. The heat transfer and undercooling of the refrigerant in different branches can be detected by measuring the temperature in all paths of the condenser and observing the temperature variation trend. Whether the refrigerant temperature at the outlet of each branch is similar can reflect whether the refrigerant flow distribution of different paths is even and whether the design of a small diameter flow path is reasonable.

3) display case surface temperature test

At the same time, the air temperature distribution around the display surface of the display cabinet has a decisive influence on the preservation degree of the products, the information of the working state of the products, and the utilization degree of the display surface. Therefore, the arrangement of temperature measuring points on the display surface is also essential for temperature measurement. Thus, an extensive range thermometer is arranged on the cabinet surface, and a plastic bracket is used to raise the head of the thermometer so that it can directly feel the air temperature on the cabinet surface.

The layout of the thermometer on the display surface is shown in Figure 1-10. In order to ensure the accuracy of data measurement, three thermometers are arranged on each of the four panels of a single cabinet face, a total of 12 mercury thermometers. After the defrosting is completed and the system runs statically for 1 hour, the surface temperature is recorded by real-time data. The final cabinet surface temperature is averaged from 12 results.

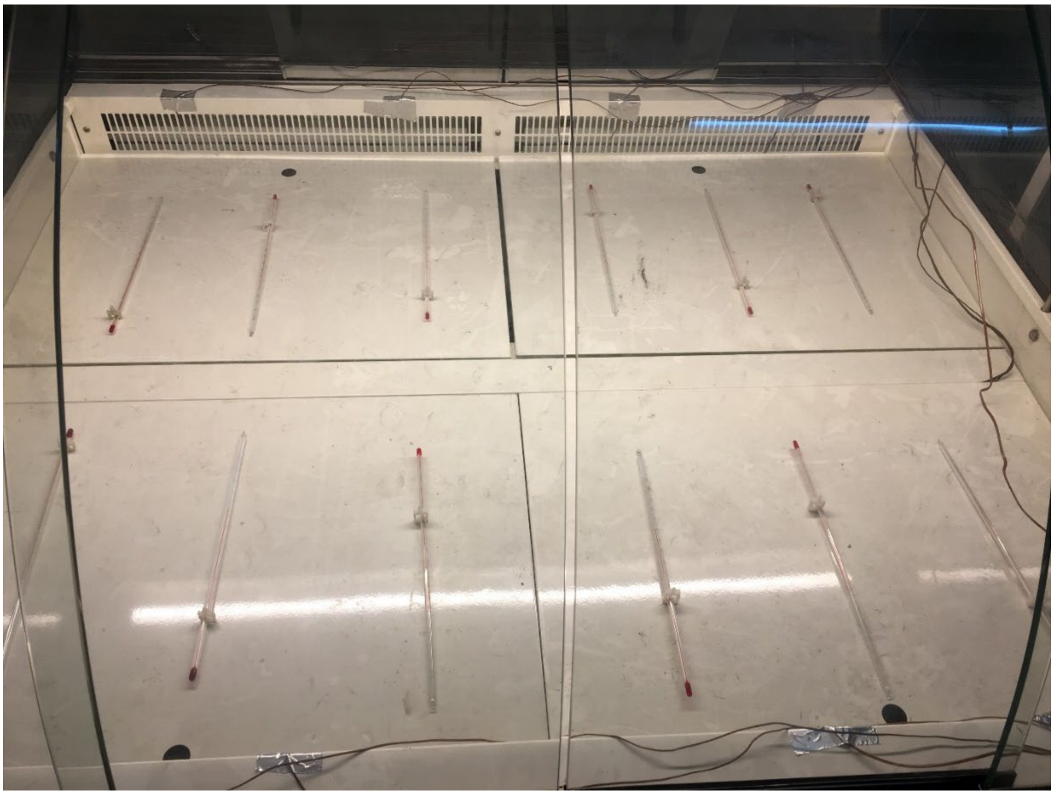

Figure 1-10 Display surface thermometer arrangement

The pressure test is also an essential part of the experiment. There are two pressure measuring points for the refrigeration system of the refrigerated display cabinet. One is the high-pressure measuring point, which is connected to the exhaust pipe of the compressor. The other is the low-pressure measuring point, which is located on the return pipe of the compressor, and the high and low-pressure meter (see Figure 1-11) is used for measurement. The pressure test is essential to judge the performance of the refrigeration system. By comparing the pressure value of a conventional condenser, the advantages and disadvantages of a small diameter condenser can be compared in the same direction. The pressure data collection method is different from the display surface temperature collection method. After the system temperature runs for one hour, the timing of photographing and recording is when the air outlet temperature in the cabinet approaches the set temperature. At this time, the pressure value is considered to reach the temperature state within one cycle, with the highest accuracy.

After the refrigerated cabinet's power supply is turned on, the refrigeration unit runs. The air outlet constantly blows out the cold air cooled by the evaporator, and the temperature in the cabinet continues to drop. The air outlet in the cabinet is provided with a temperature sensing package. As a result of heat leakage and other factors in the refrigerated cabinet, the temperature began to rise. When the temperature rose to return to the temperature of 9℃, the refrigeration unit opened so continuous circulation. Defrost the refrigerated display cabinet once for 12h. Within one hour after defrosting, the system is in a stable state, and the data is recorded. The refrigerated display cabinet was operated for more than 24h in a single experiment, and a set of data was recorded. Each type of condenser was tested three times, and three sets of data were recorded, respectively.

Figure 1-11 High- pressure and low-pressure gauge

Due to the enormous amount of data collected by the Agilent acquisition instrument, and the working state of refrigerated display cabinet refrigeration unit is a dynamic balance process of continuous start and stop, part of the temperature test results cannot be accurately expressed by the average value. So, it is necessary to select more representative data from each data group for later comparative analysis. The method of data selection is as follows. First, the compressor exhaust port temperature is taken as the standard to select a set of data with the highest compressor exhaust temperature in a certain period from the database collected by Agilent. The values of this set's other measurement points are also adopted.

As shown in Figure 1-12, the thermocouple used to measure the temperature is fixed to the required measuring point using tin foil tape, and the high and low-pressure meter is connected to the cooling system tubes.

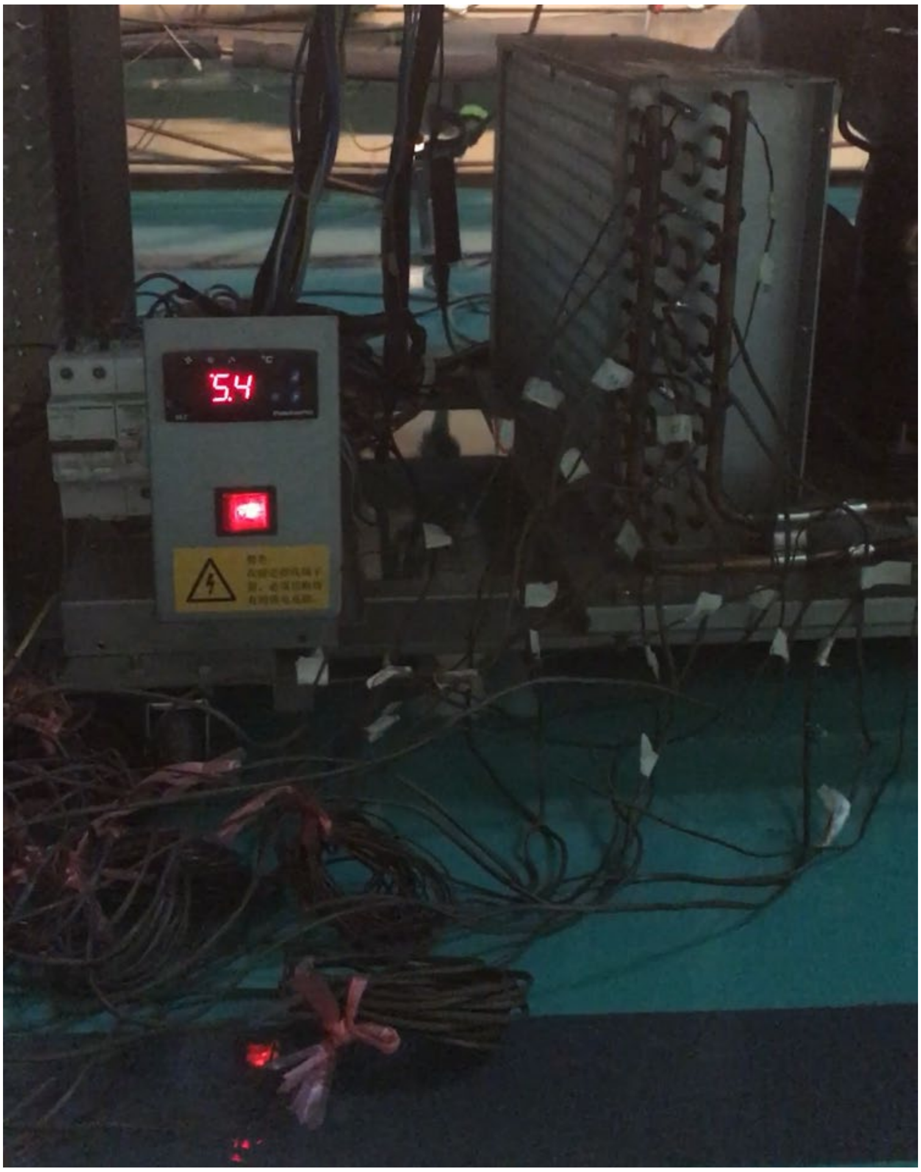

Figure 1-12 Refrigerated display cabinet experiment

Chapter 2 Experimental test results and analysis

Because of the comparison of the actual machine performance test results of small diameter tube condensers in refrigerated display cases, the analysis is carried out from two aspects. The first is transverse comparison. By measuring the temperature and pressure of the system, the performance difference between a small diameter condenser and a conventional tubular condenser in the refrigerator is compared. The second is circumferential comparison. By comparing the temperature of the measuring point and the temperature and pressure of the system of the four types of small-tube diameter condensers, the heat transfer capacity of different kinds of small-tube diameter condensers is analyzed to judge the rationality of their design and flow path optimization.

2.1 Temperature analysis of system measuring point

For refrigeration units, under constant capillary length and ambient temperature, the condensing heat transfer area increases after using the small diameter condenser. So the condensing temperature difference of the refrigeration cycle condenser will decrease, the condensing temperature will fall, and the corresponding condensing pressure will also drop. Because the throttling device has not changed, the evaporation pressure will decrease after throttling, the heat transfer temperature difference of the evaporator increases, and the superheat of the working medium at the outlet of the evaporator increases. In addition, the decrease of evaporation pressure will decrease a series of subsequent parameters, such as the compressor suction pressure and exhaust pressure. The above changes will lead to a slight decrease in the subcooling degree of the working medium at the outlet of the condenser in the next cycle so that the evaporation pressure will rise slightly and the superheat will decrease.

When the heat transfer area of the condenser increases, the refrigeration cycle will fluctuate dynamically until it is stable. After stabilization, the condensing pressure decreases, the subcooling degree increases, the evaporation pressure decreases, and the cooling capacity increases.

2.1.1 Compressor temperature measurement point

The maximum value of the compressor exhaust temperature in a period after the refrigeration system runs stably was selected three times. Table 2-1 to Table 2-3 compares the data of compressor shell temperature and suction and exhaust temperature for different compressor units.

Table 2-1 Compressor housing temperature (℃) comparison

Test No.	*Φ*9.52mm	*Φ*5 mm			
		B1	B2	C1	C3
1	55.80	40.51	43.62	37.68	42.37
2	49.24	39.60	43.98	37.60	42.76
3	51.90	37.52	42.07	36.24	42.00
Mean value	52.31	39.21	43.22	37.17	42.38
Increment	/	-13.10	-9.09	-15.14	-9.93

The experimental results show that the compressor housing temperature of the small-diameter condenser unit is significantly lower than that of the prototype unit, and the drop ranges of the four condenser replacement units range from −9.09 ℃ to −15.14℃. The change of the casing temperature is consistent with the theoretical analysis, and its decline makes the operation of the compressor more stable and safer, indicating that the refrigeration system of the refrigerated display cabinet is better matched after the small-diameter condenser replaces the original prototype.

The suction temperature decreased slightly, and the suction temperature of the four condenser replacement models dropped by 0.67~2.99℃. The main reason for the decrease was related to the refrigeration system's decrease in evaporation pressure. The reduction of the suction temperature is beneficial to reducing the compressor shell temperature and exhaust temperature. The drop is reasonable, and the compressor runs stably without abnormal noise.

Table 2-2 Compressor suction temperature (℃)) comparison

Test No.	*Φ*9.52mm	*Φ*5 mm			
		B1	B2	C1	C3
1	1.1	-0.9	-1.86	-0.7	-1.3
2	-1.34	-0.97	-1.72	-0.64	-1.26
3	0.75	-0.91	-1.89	-0.15	-1.22
Mean value	0.17	-0.93	-1.82	-0.5	-1.26
Increment	/	-1.10	-1.99	-0.67	-1.43

Table 2-3 Compressor exhaust temperature (° C) comparison

Test No.	*Φ*9.52mm	*Φ*5 mm			
		B1	B2	C1	dC3
1	56.6	41.73	43.83	40.7	42.97
2	50.1	41.15	44.1	40.71	42.53
3	52.4	40.60	43.27	39.38	42.41
Mean value	53.03	40.16	43.73	40.60	42.64
Increment	/	-12.87	-9.30	-12.43	-10.39

Compressor exhaust temperature is an important index to measure refrigeration systems' stability and heat transfer capacity, so the selection of experimental data is also based on the most representative exhaust temperature from the database. As can be seen from Table 2-3, the exhaust temperature of the new unit decreased significantly, with the decrease range ranging from −9.30 ℃ to −12.87℃, and the decrease range was ideal. The compressor ran in a stable state, and no abnormal operation was caused by damage. The experiment measured the exhaust temperature under equilibrium, and its reasonable decrease accords with the theoretical analysis.

The data set selected in the experiment is determined according to the maximum temperature point under the stable operation of the unit because the actual operation status of the cabinet refrigeration unit is not steady but dynamic as far as the unit is concerned. The unit is constantly starting and stopping, so the temperature of the various components of the refrigeration unit is also rising and falling, cycle after cycle. The specific content is elaborated in detail when analyzing the temperature of the condenser measuring point below.

2.1.2 Capillary temperature measuring point

Table 2-4 shows the temperature comparison at the capillary outlet. Compared with the capillary outlet temperature of the prototype unit, the capillary outlet temperature of the new unit decreased slightly from -1.83 ℃ to -3.89℃. Again, unit B2 has the most significant decrease, and unit C1 has the minor decline.

When the heat transfer area of the condenser increases and the refrigeration cycle changes to a stable state, the condensation pressure drops. Still, the throttling device does not change, so the pressure of the working medium at the outlet of the capillary decreases compared with the original, and the temperature also decreases. The more significant the drop in the outlet temperature of capillary means that the more significant the decline in the condensing pressure. It limits the refrigerant's mass flow rate after throttling. However, under constant throttle capillaries, the condensation pressure does not drop the bigger, the better. In the environment of low-temperature season, the condensing pressure on the low side leads to refrigeration system regular work necessary for the fluid drive pressure is too low, eventually leading to decreased feed liquid. The refrigeration and heat exchange ability play not to come out at the end. Compressor suction pressure is low, the refrigeration capacity of the whole system can't play. The cooling capacity of the refrigeration system can be greatly increased if the capillary length is changed, and the condensation pressure is reduced.

Table 2-4 Capillary outlet temperature (℃) comparison

Test No.	*Φ*9.52mm	*Φ*5 mm			
		B1	B2	C1	C3
1	-5.8	-7.9	-9.66	-7.7	-8.3
2	-5.8	-7.97	-9.52	-7.64	-8.26
3	-5.4	-7.91	-9.49	-7.15	-8.22
Mean value	-5.67	-7.93	-9.56	-7.50	-8.26
Increment		-2.26	-3.89	-1.83	-2.59

2.1.3 Evaporator temperature measurement point

Table 2-5 compares the temperature of the evaporator outlet measurement point. The experimental results show that the outlet temperature of the evaporator of small diameter condenser unit is slightly lower than that of a conventional condenser unit, with a decrease of only -1.23~-3.05℃, and the temperature of the B2 unit has the most significant decline. As the condensation pressure decreases, less refrigerant flows out of the capillary, so the evaporation pressure and temperature are lower.

Table 2-5 Evaporator outlet temperature (℃) comparison

Test No.	*Φ*9.52mm	*Φ*5 mm			
		B1	B2	C1	C3
1	-6.68	-9.12	-10.32	-8.05	-8.39
2	-7.32	-9.3	-10.05	-8.38	-8.93
3	-6.86	-8.66	-9.65	-8.13	-8.9
Mean value	-6.95	-9.03	-10.01	-8.19	-8.74
Increment		-2.07	-3.05	-1.23	-1.79

2.2 Temperature analysis of condenser measuring point

Table 2-6, 2-7 shows the comparison of inlet and outlet temperatures of the condenser in three experiments:

The data results show that the inlet temperature of small diameter condenser is significantly lower than that of small diameter condenser, which mainly comes from the increase of the area of small diameter condenser and the reduction of the compressor exhaust temperature of the unit. The outlet temperature of the condenser also decreased slightly because the increase of the heat exchange area reduced the condensation pressure and condensation temperature. The outlet temperatures of the four small-diameter condensers are relatively close. The designed small-diameter condenser has a sufficient heat exchange area, and the refrigerant can achieve complete condensation and supercooling in the heat exchanger.

Table 2-6 Condenser inlet temperature (℃) comparison

Test No.	Φ9.52mm	Φ5 mm			
		B1	B2	C1	C3
1	53.1	37.65	39.89	36.67	39.1
2	47.09	37.32	39.6	35.82	38.89
3	49.64	38.67	39.7	36.09	38.73
Mean value	49.94	37.88	39.73	36.19	38.91
Increment	/	-12.06	-10.21	-13.75	-11.04

Table 2-7 Condenser outlet temperature (℃) comparison

Test No.	Φ9.52mm	Φ5 mm			
		B1	B2	C1	C3
1	33.3	31.8	31.4	31.63	30.83
2	31.4	31.6	31.36	30.9	30.86
3	32.8	32.25	31.43	31.2	30.92
Mean value	32.50	31.88	31.4	31.24	30.87
Increment	/	-0.62	-1.10	-1.26	-1.73

Because the operation state of the refrigerated display cabinet refrigeration unit is a dynamic process, after the refrigerated display cabinet is turned on, the refrigeration unit starts to run and then repeatedly starts and stops the cycle. A complete start-stop cycle is divided into start-up, stable, and shutdown. Figure 2-1 shows the temperature change of the condenser inlet in two operating cycles. Because the operation state of the refrigerated display cabinet refrigeration unit is a dynamic process, after the refrigerated display cabinet is turned on, the refrigeration unit starts to run and then repeatedly starts and stops the cycle. A complete start-stop cycle is divided into start-up, stable, and shutdown. Figure 2-1 shows the temperature change of the condenser inlet in two operating processes.

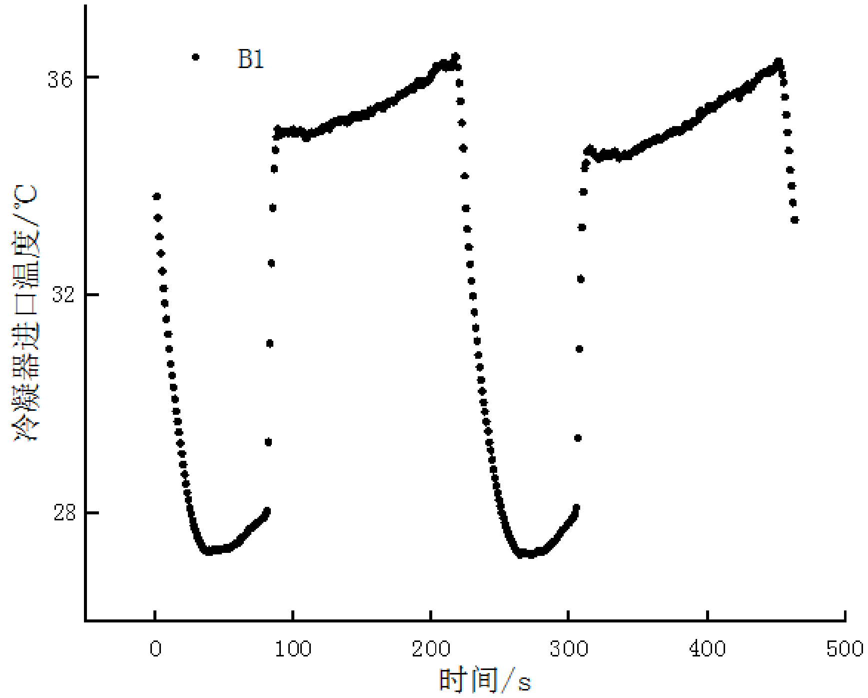

Fig. 2-1 B1 Condenser inlet temperature change

After the unit is started, the compressor begins to work. In a short time, the exhaust temperature rises rapidly, and the inlet temperature of the condenser increases quickly. With the continuous operation of the compressor, the process of the components makes the exhaust temperature rise slowly, and the inlet temperature of the condenser continues to increase. When the temperature in the cabinet reaches the set temperature, the temperature sensor is fed back to the unit control system, the compressor stops, and the temperature drops gradually. When the system is stable, the exhaust temperature of the compressor and the inlet temperature of the condenser is gradually cooled to the ambient temperature. And the working medium in the condenser is restored to the superheated gas, and the inlet temperature will rise slightly; When the temperature in the cabinet reaches the return temperature, the compressor of the temperature packet feedback control unit will start up again and start a new operation cycle.

The refrigerated display case's refrigeration system's dynamic response is different from that of the general refrigeration and air conditioning unit. For the available refrigeration and air conditioning system, after the operation of the device reaches a specific stable state, the refrigeration system starts to run continuously and stably, and the state of the research object will not change significantly. The start-stop dynamic characteristics are different. As described, significant changes will take place in the start-stop process. The condenser changes from single-phase superheated gas to the dynamic equilibrium state of the superheated gas and gas-liquid two-phase supercooled liquid coexistence during the startup process. It returns to a single-phase superheated gas state in the shutdown process.

The inlet temperature changes of the four types of small diameter condensers in two cycles are shown in Figure 2-2. The operation status of different units can be analyzed from the figure.

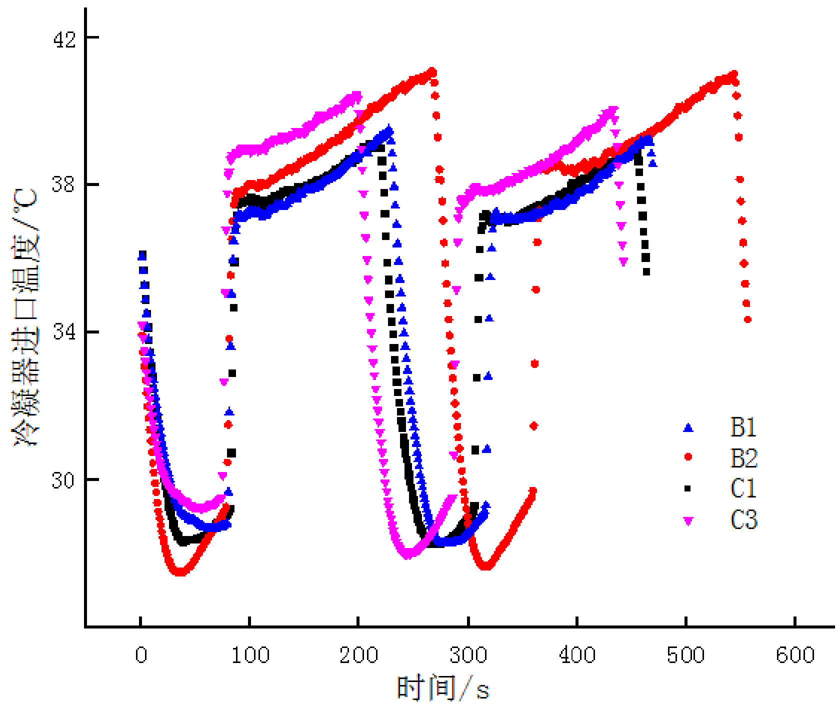

Fig. 2-2 The inlet temperature of the condenser changes in two cycles

The performance of condenser with different small diameters is analyzed from the periodic change of inlet temperature of condenser. Under the starting state, the compressor can quickly rise to the temperature operation's required temperature and enter the stable operation state. However, the stable running time should not be too long because a long time will cause the compressor exhaust temperature and shell temperature to rise. And a long time means that it takes a long time for the compressor to lower the temperature in the cabinet to the set temperature, which consumes a lot of power.

The B2 condenser has the longest stable operation time, resulting in the highest temperature and large power consumption from the above perspective. Meanwhile, the shutdown temperature amplitude is the largest, and poor performance. On the other hand, the C1 condenser has the best performance, the shortest stable running time, and the fastest temperature rise rate when starting up.

2.3 System pressure

It is crucial to measure the high and low pressure of the refrigeration system. Abnormal reading on the high and low-pressure meter can reflect the defects of the refrigeration system, such as too little refrigerant charging, incomplete vacuumization in the pipeline, and severe faults of the compressor and condenser. After replacing the condenser in the refrigeration system of the refrigerated display cabinet, the change of the system's internal pressure and refrigerant charge can be diagnosed according to the high and low pressure. At the same time, high and low-pressure difference refrigeration unit performance is a critical reference. Table 2-8 shows the comparison of high and low pressure of different condenser units.

Table 2-8 System high and low pressure (kfg) comparison

Test No.	Φ9.52mm		Φ5mm							
			B1		B2		C1		C3	
	High	Low	High	Low	High	Low	High	Low	High	Low
1	20	4.5	14.5	3.05	15.4	3.15	13.9	3.0	14.9	3.1
2	16.4	3.4	14.5	3.08	15.4	3.22	14.2	3.10	14.7	3.05
3	16.0	3.4	14.4	3.1	15.2	3.21	14.1	3.13	14.9	3.15

The results show that the difference between the high and low pressure of the small-diameter condenser unit is lower than that of the prototype unit. The high and low pressure of the four new small-diameter units decreased compared with that of the prototype unit. The decrease was that the increase of the condenser heat exchange area led to the decline of condensing pressure and suction and exhaust pressure. The drop of high pressure can protect the stable operation of the system.

It can also be seen from Table 2-8 that the difference between the high and low pressure of the small-diameter condenser unit is lower than that of the prototype unit. The decrease of the difference between high and low pressure reflects the better refrigeration effect of the system and the better condensation effect of the condenser. Meanwhile, from the high-pressure section of the compressor exhaust port, condenser, and capillary inlet to the low-pressure section of the capillary outlet, evaporator, and compressor inlet, the friction pressure loss of the refrigerant flow in this part of the pipe decreases. However, in summary, since the throttle device in the experimental system was not replaced, the evaporation pressure decreased. If the length of the capillary can be changed and the pressure difference between the two ends of the capillary can be adjusted, the refrigeration system can have higher efficiency. On this basis, it is considered that the heat exchange area of small diameter condenser is surplus, and further research can be done to reduce further the heat exchange area, and the amount of copper used.

2.4 Refrigerant Charge

According to the results shown on Table 2-9, the refrigerant charge of the prototype unit with small diameter copper tube heat exchanger can be reduce to 0.6 kg, which is almost 14.3% lower than that of original unit with 9.52mm diameter copper tube heat exchanger.

Table 2-9 Refrigerant Charge (kg) comparison

Test No.	Φ9.52mm	Φ5mm			
		B1	B2	C1	C3
1	0.7	0.6	0.6	0.6	0.6
2	0.7	0.6	0.6	0.6	0.6
3	0.7	0.6	0.6	0.6	0.6

2.5 Average surface temperature of display cabinet

From the temperature statistics of the above measuring points, it can be roughly analyzed that the performance of small diameter condenser unit is better than that of a conventional condenser unit. However, the refrigeration effect of the refrigerated display cabinet is mainly reflected in the average temperature of the first display surface. Because the air temperature on the surface of the display surface guarantees food freshness, the average temperature of the display surface must be stable after starting up for a while. Furthermore, the cooling capacity of the pressure cooling unit determines the air temperature on the display surface. Therefore, it is necessary to compare the air temperature near the display surface.

The average temperature of the display surface is measured by running the refrigerated display cabinet stably for six hours after starting up, running stably for one hour after completing a defrosting, and then recording. Multiple temperature measuring points are used to take the average value when recording.

In order to ensure that the object of temperature measurement is the air on the surface of the display surface, the measuring tool uses a large-range thermometer to measure, and the head of the thermometer is raised with a bracket to avoid the impact of the contact between the head and the metal plate on the cabinet. The thermometer layout is shown in Figure 2-3. The location of the thermometer layout has been described above.

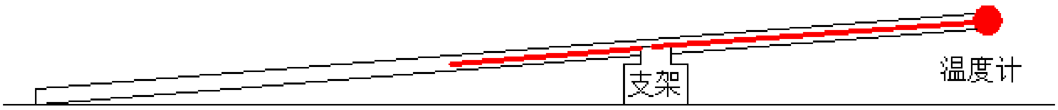

Fig. 2-3 Display surface thermometer arrangement

In order to simulate the actual use, a random sampling method was used to collect the measurement data, and the influence of the air outlet blowing on the surface air temperature of the cabinet was spread evenly. After the unit is stable for one hour after defrosting, random photo inspection is adopted, and then data statistics are carried out through reading.

Table 2-10 shows the comparison of the average temperature of the air on the surface of the display surface.

Table 2-10 Average temperature of display surface (˚C)

Test No.	*Φ*9.52mm	*Φ*5 mm			
		B1	B2	C1	C3
1	7.5	5.12	5.92	3.3	4.85
2	8.75	5.23	5.58	3.24	5.01
3	8.34	5.1	5.49	3.31	4.9
Mean value	8.20	5.15	5.66	3.28	4.92
Increment		-3.05	-2.53	-4.91	-3.28

The experimental results show that the surface temperature of the display surface of the small-diameter condenser unit decreases significantly, among which the temperature of C1 decreases the most, reaching 4.91 degrees Celsius. However, the change of Unit B2 is the smallest, only falling by 2.53℃. The performance improvement degree of unit B1 and unit C3 is similar. B2 condenser sets have the lowest performance improvement among the four small-diameter condenser sets. The main reasons are as follows:

Flow path design:

1. The number of branches of the B2 condenser is only 4, less than that of the C series condenser. The small number of paths directly leads to the improvement of the condenser's friction pressure drop and reduces the system's heat transfer performance.

2. As the number of paths of small diameter B2 condenser decreases, the single path is too long, which may cause the waste of heat exchange area;

3. In the design of the B2 condenser, the split-total structure is adopted. The refrigerant finally converges into two paths from the beginning of the four paths to flow out of the condenser.

Processing technology:

As the length of a single path of the B2 condenser is long, the thickness of the condenser becomes more significant, which is reflected in Figure 2-5. As the thickness increases, the heat transfer effect of the tube bundle in the latter half becomes worse, which is affected by the reverse heat conduction of the front tube bundle, so the performance deteriorates.

All the above reasons eventually lead to the highest temperature on the display surface of the B2 condenser unit, and its performance is inferior to that of other condenser units.

2.6 Path temperature of small diameter condenser

2.5.1 Temperature result analysis

In addition to the above temperature and pressure tests, this paper measured the temperature of the small diameter condenser's path and tube side during the operation of the refrigerated display cabinet. The purpose of measurement is to measure the temperature distribution along the pipeline of different types of small diameter condensers and explore whether the refrigerant distribution in the condenser is uniform and whether the refrigerant in different paths is an entirely different condenser. That is, whether the heat exchange area is sufficient or there is waste from the temperature distribution of each branch. Therefore, it is necessary to measure the path temperature of small diameter condenser.

The measurement method is to arrange temperature measuring points on each path of the small diameter condenser according to the central nodes. Because the outer wall of the copper tube of the condenser has a layer of evenly arranged aluminum fins, it is challenging to put measuring points on the front wall of the condenser, so the measuring points are set at the side bend of the condenser. The specific arrangement of measuring points is shown in Figure 2-4. The red points in the figure are the temperature measuring thermocouple arrangement points.

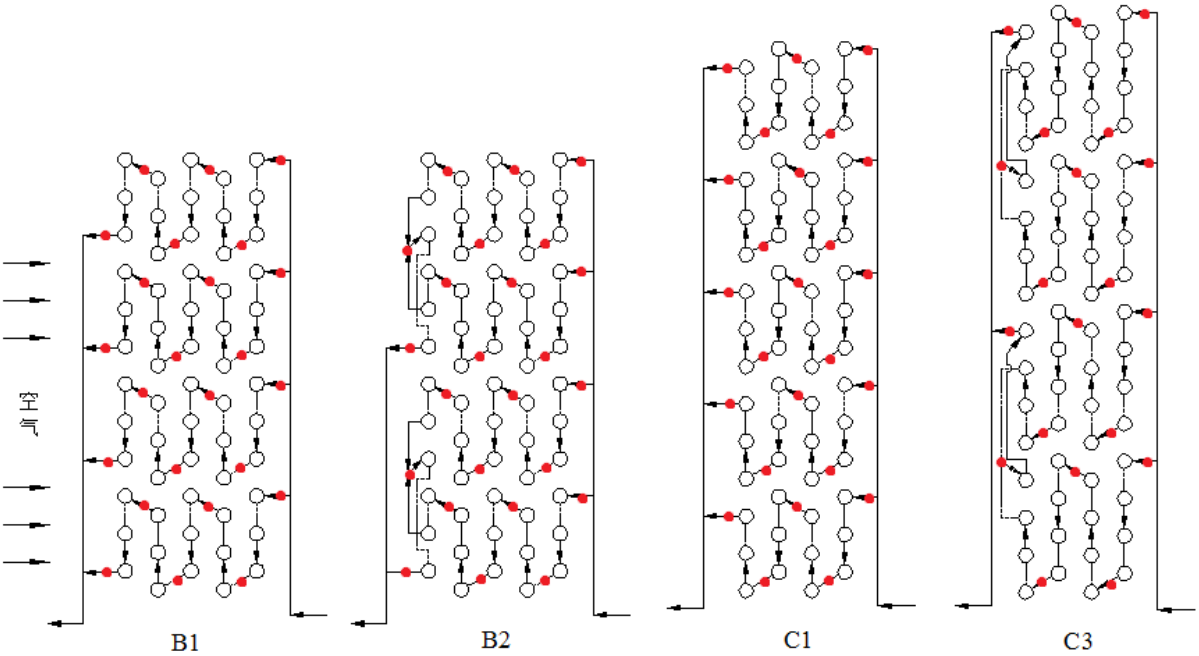

Fig. 2-4 Temperature measuring point of condenser tube side

As mentioned above, because the operation state of the refrigerated display cabinet unit belongs to dynamic balance, the refrigeration effect of the unit is achieved in the continuous start and stop. Therefore, the collection time of tube side temperature data should be selected in the stable operation stage of the refrigeration unit. When the compressor starts up, the exhaust temperature and condenser inlet temperature rise rapidly and continue to run in the stable stage. The data collection method uses the Agilent acquisition instrument to record continuously, so the final data amount is miscellaneous. In this paper, the co-direction data set is selected according to the inlet temperature of the condenser. The data selection stage is shown in Figure 2-5, the red part is the data selection area, and the black part is the inlet temperature of the condenser.

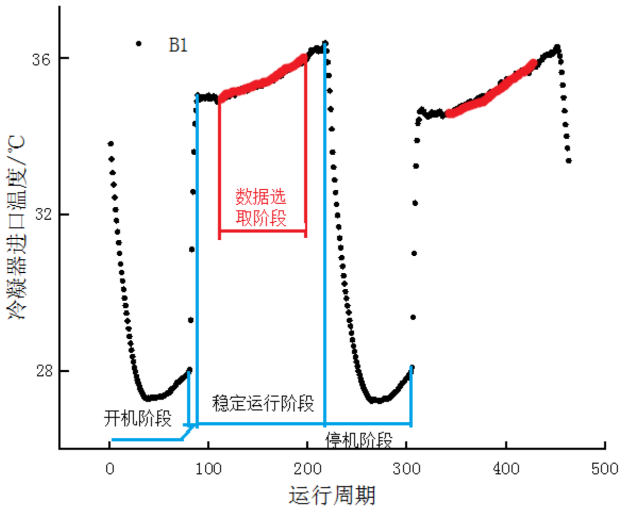

Fig. 2-5 Phase diagram of tube side temperature selection

Figure 2-6 shows the temperature of each branch pipe of the B1 condenser. The four curves on the scatter diagram are 1-4 paths from top to bottom of the condenser, and the temperature is recorded from the path inlet to the path outlet. As can be seen from the figure:

1) With the condensation process, the refrigerant temperature inside the path gradually decreases, and the temperature change of the measurement point near the outlet is minimal, indicating that the outlet refrigerant is in the state of supercooling;

2) The inlet temperature of different paths gradually decreases from top to bottom, which is not the same as the inlet temperature of the condenser. Still, the temperature difference is not around 1℃. The reasons for this phenomenon are as follows: The dynamic pressure of the fluid decreases gradually along the tube, resulting in different static pressure at each path junction. The static pressure at the path junction nearest to the condenser entrance is the lowest. Therefore, the refrigerant flow at the top path of the condenser is large, and the difference in pressure leads to the difference in flow rate and temperature.

3) Temperature difference exists at measuring points with the same pipe path due to different branches, and the temperature difference increases first and then decreases with the change of pipe path. This is because the phase transformation degree of the refrigerant in different paths is different after entering the path process. However, with the progress of the condensation process, the pressure of the refrigerant in different paths gradually approaches the saturation pressure at the condensation temperature. Hence, the final outlet temperature is close to the same. As a result, the maximum temperature difference between the fourth and first roads is close to 3℃.

4) Observing the fifth measuring point, the temperature difference seen in different paths is minimal, and the exit temperature is close to the same. It indicates that the total heat transfer area of the condenser pipe is enough, and the saturated vapor in the gas phase can be condensed into a saturated liquid phase with consistent pressure.

5) Abnormal data may occur at a measurement point of some branches in the figure, which is interpreted as reverse heat conduction between different columns and rows of condenser, and the heat conduction from the first half of the pipeline to the second half leads to abnormal data.

Figure 2-7 shows the temperature distribution of each path of the B2 condenser. As its structure is the same as B1's, the temperature distribution characteristics at the tube side are similar to that B1's. The difference between the B2 condenser and B1 condenser structure is that the second half of the path is confluent, and the flow path is divided into the total form.

As can be seen from the measurement results of pipe temperature in Figure 2-7, the convergence alleviates the temperature difference between different paths and significantly reduces the temperature difference at the junction point.

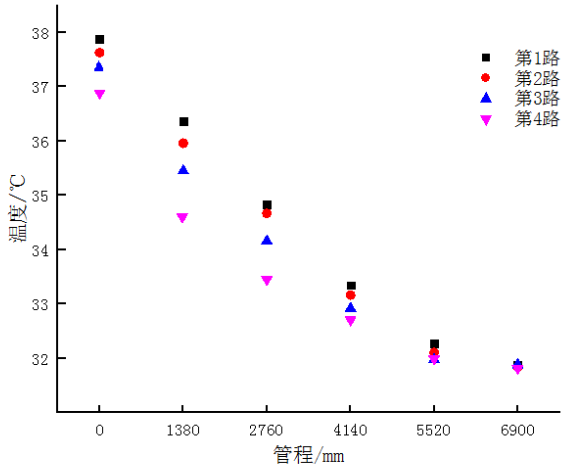

Fig. 2-6 B1 Condenser temperature distribution along the tube side

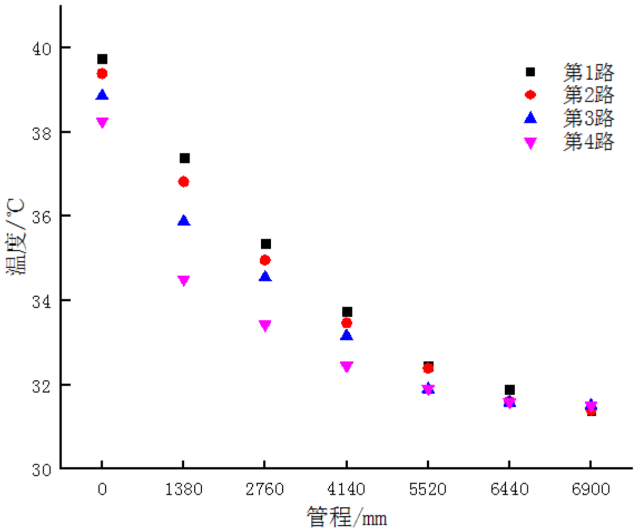

Fig. 2-7 B2 Condenser temperature distribution along the tube side

To sum up, the length of a single heat exchange tube is 460mm, and the number of rows is 4*15 small diameter condenser. Therefore, the temperature difference between different paths of the same tube is significant, and the refrigerant distribution of other paths is uneven.

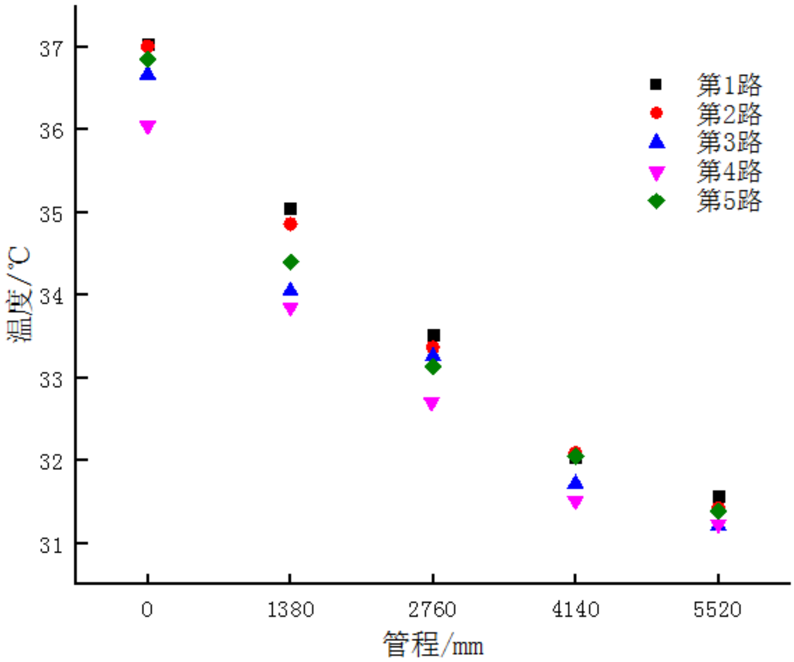

Fig. 2-8 C1 Condenser temperature distribution along the tube side

Figure 2-8 shows the temperature distribution of each path tube of the C1 condenser. The results show that:

1) There is still a temperature difference between different paths of the same tube. Still, the value of the temperature difference is small, the maximum temperature difference is less than 1.5℃, and the temperature difference gradually decreases with the continuation of the tube, indicating that the design of the tube is reasonable. The distribution of refrigerant flow is uniform.

2) The inlet temperature of the C1 condenser is lower than that of the B series, which is interpreted as the overall improvement of the refrigeration system after replacing the C1 small-diameter condenser, which lowers the compressor exhaust temperature and improves the system performance.

3) The temperature of two adjacent measuring points under a single path shows that the temperature change of the C1 condenser is smaller than that of the B series, indicating that the condensation process in the tube progresses more slowly than that of the first two models. This is because the number of paths of the C1 condenser is 5, and the number of paths is more than that of the B series, so the flow rate of path refrigerant is lower, and the condensation process is slow.

4) The outlet temperature of the four paths of the C1 condenser is the same. Still, the outlet temperature difference of different paths is slightly more significant than that of the first two models. It can be seen from the outlet temperature of the measurement point before

the outlet temperature that although the condensation process can be completed, the undercooling is not sufficient.

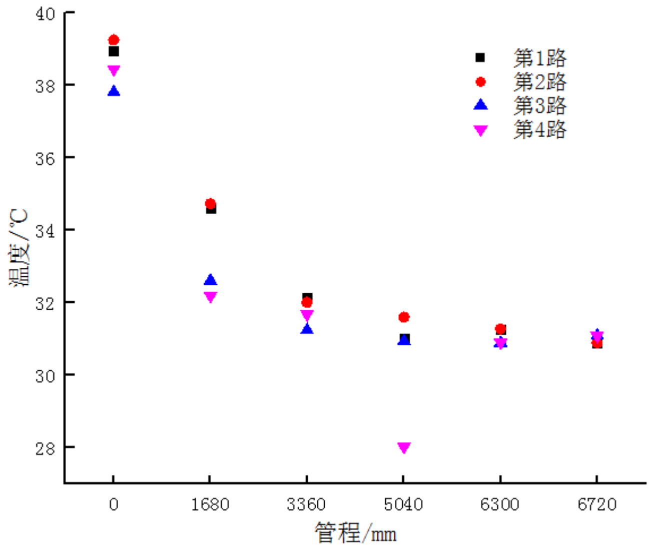

Fig. 2-9 Temperature distribution diagram of C3 condenser along the tube side

Figure 2-9 shows the temperature distribution of each path of the C3 condenser. For example, it can be seen from the figure:

1) The condensation temperature variation characteristic of refrigerant in the condenser is similar to that of other small diameter condensers.

2) There is still a temperature difference between different paths of the same path. Still, the temperature difference is controlled within 3 ℃ and gradually decreases with the continuation of the path. The conclusion is that the refrigerant flow is uniform to the B series condenser but less than the C1 condenser.

3) Observe temperature measuring points 3 and 4 in the figure, and judge that the working medium in the tube has realized condensation at this time, and the temperature change in the latter half of the tube is very low supercooling section is long. Therefore, it is concluded that the heat exchange area of the C3 condenser is wasted because the tube is too long.

2.5.2 Conclusion and prospect

Because of the above experimental process and results, the application of small diameter condenser in the refrigerated display cabinet refrigeration system is summarized as follows:

1. On the refrigerated display cabinet refrigeration unit, the refrigeration effect of the small diameter condenser unit is better than that of the conventional condenser unit. From the temperature parameters of the display surface, the suction and exhaust temperature of the compressor, as well as the high and low-pressure measurement results of the system, it can

be concluded that the performance and refrigeration efficiency of the refrigeration unit are significantly improved.

2. In terms of the flow pattern design of small diameter condensers, combining the test results of four small diameter condensers, it can be concluded that:

1) As the increase of condensing heat transfer area will lead to the decrease of the condensing evaporation pressure. In order to ensure the heat transfer performance, the heat transfer area of small diameter condenser can be slightly reduced and continue to study in the direction of saving copper quantity;

2) It is necessary to reduce the length of a single heat exchange tube to reduce the total length of each path and effectively use the heat exchange area;

3) In order to reduce the friction pressure drop of refrigerant in the condenser, the number of paths can be appropriately increased, but the total length of paths should not be too long. The measure can also make the distribution of refrigerant between different paths of condenser more uniform;

4) The confluence operation of the second half of different branches of the condenser can make the working medium of the condenser have better supercooling and strengthen the heat exchange effect;

5) From the analysis of the temperature measurement results of the refrigeration system and the condenser, it can be concluded that C1 and C3 small diameter condensers have better heat exchange effect, the highest matching degree in the system, and the thermal efficiency of the refrigeration system is more elevated. Therefore, it can be produced and used in the refrigerated display cabinet industry.

3. Outlook:

1) Combined with the temperature test results of the condenser and the heat exchange effect of the refrigerated display cabinet, it is found that the small diameter condenser unit has been greatly improved. Therefore, it can be tried to appropriately reduce the heat exchange area, continue to compress the volume of the small-diameter condenser, and conduct in-depth research in the direction of more energy-saving and material saving.

2)The system device can be changed to better match the small tube diameter condenser to improve the performance, such as replacing the capillary and improving the refrigeration system's efficiency.

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