

Temperature Characteristics of Cascade Refrigeration System by Adjusting Compressor Inlet Pressure

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Abstract: This paper present the development and testing of cascade refrigerator system for achieving super-low temperature condition. This experiment study effect of pressure in the second stage compressors inlet to the temperature distribution characteristics of the cascade refrigeration system. Compressor inlet pressure of low-pressure stage was tested in the vacuum condition and over-atmospheric pressure. Two different types of refrigerants are utilized for this system, R-22 is applied for the high stage, and R-23 for the low-pressure stage. The lowest temperature in the low-pressure evaporator, which can be achieved by this cascade refrigeration system, is down to -85°C .

Keywords: Cascade Refrigeration System, High Pressure Stage, Low Pressure Stage, Variable Expansion Valve.

1. INTRODUCTION

Refrigerator is a device that is used to freeze materials. The basic idea behind refrigerator operation is very simple: it uses evaporation of a liquid to absorb heat. The liquid, or refrigerant, used in refrigerator evaporates at an extremely low temperature so it can create freezing temperature inside the refrigerator.

There are four stages in the refrigeration process, the first process is evaporating process, when refrigerant at lower pressure evaporates and absorbs the heat from the system, the second process is compressing process, refrigerant is compressed to the higher temperature. The third stage is condensation, the refrigerant turn into fluid state, and release the heat into the environment, and the final stage is expansion, when the pressure of refrigerant is reduced.

General refrigerant has only had a single cycle. This conventional refrigerator can only reach low temperature down to -40°C . If the lower temperature is required, multi-stage refrigeration system must be utilized.

This lower temperature also called super low temperature. Super low temperature has many applications nowadays, from the chemical processing, automotives manufacturing, plastic recycling, etc. Considering of its wide application in the present and the future, study of the super-low temperature refrigeration system should be continuously carried out.

Cascade or two-stage refrigerator is one of type of multi-stage refrigeration system to reach super low

temperature condition. A cascade-condensing unit consists of two refrigeration systems; both of them are separate unit. The heat exchange process between two refrigerants occurs in cascade heat exchanger. It consists of a high-pressure evaporator in the higher stage, and low-pressure condenser in the low-pressure stage.

The high-pressure stage refrigerator, which is called or high-temperature stage, is utilized for cooling condenser of the low-pressure stage, which also called low-temperature stage. Thus, the low-pressure stage can reach the super-low temperature down to -85°C .

This refrigeration system consists of two cycles:

1. High pressure cycle: Compressor → condenser → expansion valve → cascade evaporator
2. Low pressure cycle: Compressor → cascade condenser → expansion valve → super low temperature cooling unit (low-pressure evaporator)

High-pressure evaporator and cascade low-pressure condenser are installed coaxially in the cascade heat exchanger. High-pressure evaporator pipe is located inside the low-pressure condenser. Heat exchange occurs between two systems in counter flow direction.

Figure 1 illustrates basic scheme of cascade refrigeration cycle. High-pressure evaporator can obtain temperature down to -40°C in the expansion valve outlet. At this temperature, low-pressure refrigerant is condensed in low-pressure condenser.

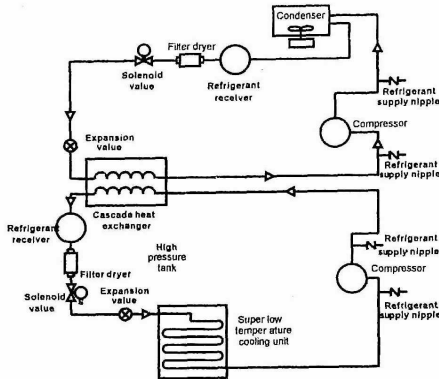


Fig. 1 Schematic Diagram of Cascade Refrigeration System.

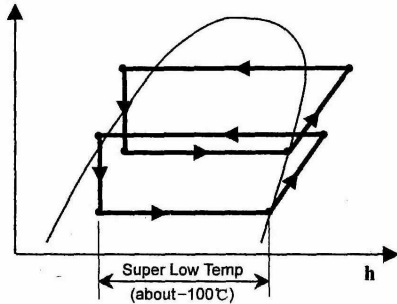


Fig.2 Ideal Cycle of Cascade Refrigeration system.

Super low temperature area in this system is located from low-pressure expansion valve outlet (T14) until low-pressure compressor inlet (T9) as shown in figure 2.

Several researches on two-stage cascade vapor-compression system have been carried out. Kilicarslan investigate the COP of each the single system as well as the overall cascade system using R-134 as the refrigerant. The result state that the single cycle of the cascade system has lower COP compare then if it work in the two-stage cascade refrigeration system. Prior to this, Zubair and Khan had experimented the same refrigerant (R-134) for loses investigation in the system. Niaola investigates Cop of cascade refrigeration cycle using blend of carbon dioxide (R-744) and hydrocarbon as working fluid to study the possibility of carbon dioxide application in the cascade system. The result shows that the blend is an attractive option for low temperature circuit of cascade system.

The goal of this experiment is to study the temperature characteristics as the consequence off pressure changes in lower stage compressors in the cascade refrigerator system for super low

temperature by using R-22 in the high-pressure stage and R-23 in the lower pressure stage.

2. TEST SETUP

To measure temperature of the system, T type thermocouples are used in the experiment. This thermocouple is used because it relatively more stable for low temperature application (-200°C to -300°C) and more suitable for oxidation atmosphere environment.

Figure 3 illustrate measurement point in which the thermocouples are placed to measure the temperature of the system. There are 20 thermocouples installed on the system. Ten thermocouples are installed on the high-pressure stage; and the others are installed on the lower pressure stage.

On the figure 3, ten thermocouple, which is installed in the high-pressure stage, are: T1 at the compressor inlet, T2 at compressor outlet, T3 at condenser inlet, T4 at condenser outlet, T5 at expansion valve inlet, T6 at expansion valve outlet, T7 at cascade heat exchanger (evaporator) upper part, T8 at cascade heat exchanger middle (evaporator), T9 at cascade heat exchanger (evaporator) lower part, T10 at cascade heat exchanger outlet.

While, ten thermocouples, which are installed in the lower pressure stage, are: T11 at compressor inlet, T12 at compressor outlet, T13 at cascade heat exchanger (condenser) inlet, T14 at cascade heat exchanger (condenser) outlet, T15 at expansion valve inlet, T16 at expansion valve outlet, T17 at evaporator (heat exchanger chamber) upper part, T18 at evaporator (heat exchanger chamber) middle, T19 at evaporator (heat exchanger chamber) lower part, T20 at the condenser outlet. The temperatures that are measured by 20 thermocouples is recorded by using data logger every 10 second.

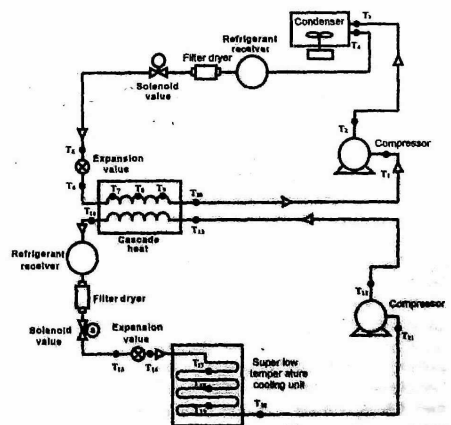


Fig.3 Temperature Measurement Point of Cascade Refrigeration System.

Low-pressure stage expansion valve is variable valve; therefore, the outlet temperature can be adjusted to the desired pressure. In this experiment, the initial outlet pressure of the expansion valve is 0.0 bars (relative to the atmospheric pressure) and the ambient temperature, as well as initial temperature, was 17°C. The experiments need 10 minutes for starting time. After high-pressure stage had been operated for 10 minutes, the low-pressure stage was operated.

There are two types of experiment conducted. On the first experiment, the second stage compressor inlet was situated below atmospheric pressure. The experiment performed for 3 hours, and 10 minutes for starting lower pressure stage. At the first hour of experiments, initial pressure was 0.0 bars. At the second hours, the inlet pressure of the second stage compressor was decreased by 0.3 Bars, and it became 0.7 bars at the third hours.

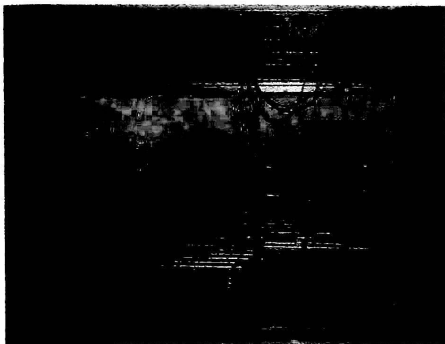


Fig.4 Experimental Device of Cascade Refrigeration System.

On the second experiment, the second stage compressor inlet was situated over atmospheric pressure. The experiment performed for 3 hours; 40 minutes include 10 minutes for starting low-pressure stage, and 30 minutes for initiation time to reach its balanced state. The pressure was increased 0.2 bars every 30 minutes.

Figure 4 show the equipment setup for this experiment. Pipes in the middle of evaporator and condenser as well as on the cascade heat exchanger are covered with isolator, thus no heat transferred out system.

The low-pressure stage evaporator is located inside the acrylic cylinder.

3. RESULT AND DISCUSSION

3.1 High Pressure stage experiment result

Figure 5 illustrates experiment result at the first experiments of vacuum pressure condition. For the first hour (00:10 to 01:10), inlet pressure of the low-pressure compressor was 0 bars. In the high-

pressure stage, temperature of compressor outlet T2 and condenser inlet (T3) was floated to 40°C and 50°C respectively. In spite of small fluctuation in the beginning, temperature of compressor outlet as well as condenser inlet was gradually increase until the inlet pressure of low-pressure stage compressor was descended to -0.3 bars. From the second hours (1:10) when the compressor inlet pressure was -0.3 bars, until the third hours when the pressure was decreased to -0.7 bars, these temperatures gradually decreased.

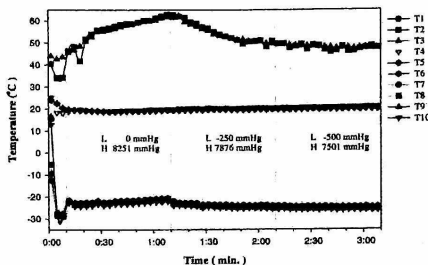


Fig. 5 Temperature distributions of high-pressure Stage, at inlet compressor pressure: 0.0 to -0.7 bars.

In the meantime, temperature of the condenser outlet (T4) and evaporator inlet (T5) was tend to steady at constant temperature even though the low-pressure compressor inlet pressure was adjusted to -0.3 bars and -0.7 bars.

Temperature of the expansion valve (T6) outlet as well as in the high-pressure evaporator (T7-T10) and compressor inlet (T1) undergo small decrement. However, in the first hours it tended to increase.

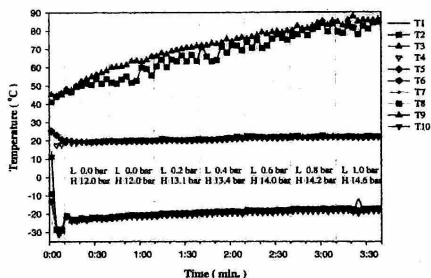


Fig. 6 Temperature distributions of High-pressure Stage, at compressor inlet pressure: 0.0 to 1.0 bar.

In the experiment of over-atmospheric pressure condition, after second stage was started, all the temperature tend to increase with different slope as consequences of the inlet pressure increment in the low-pressure compressor. Temperature of

compressor outlet (T2) and condenser inlet (T3) inclined steeper than the other temperature in the high-pressure stage. This means that the compressor work will be increased as the pressure of the compressor inlet increase. Meanwhile, temperature of expansion valve outlet (T6), evaporator inlet (T7), inside (T8–T9), outlet (T10) and compressor inlet pressure were increasing slowly.

Figure 6 illustrate the temperature distribution of the high pressure stage on the second experiment.

The lowest temperature attained by the high-pressure stage system is about -27°C , it occurs when the pressure of compressor inlet at -0.7 Bars.

3.2 Low Pressure Experiment Result

The first experiment of low-pressure stage in the vacuum condition has similar result with the high-pressure stage. All the temperature has a tendency to decrease as the low-pressure stage compressor inlet was decreasing.

When the low-pressure stage inlet compressor is 0.0 bars, temperature of cascade condensers inlet (T12) and outlet (T13) reach 100°C and 90°C respectively. After the pressure was dropped off to -0.3 bars on the next hour, temperature of cascade condensers inlet and outlet dropped to 80°C and 60°C respectively. On the following time hours, it tend to constant yet little fluctuation can be observed. In the end of experiment, when the pressure was -0.7 bars, temperatures of the compressor outlet pressure was -85°C .

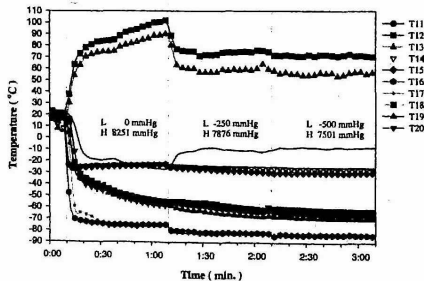


Fig. 7 Temperature distributions of Low pressure Stage Cascade Refrigerator, at inlet compressor pressure: 0.0 to bars -0.7 .

Fig 7 shows that all temperatures tend to decrease when the pressure of compressor inlet pressure was decreased.

On the next experiment, when the compressor inlet pressure was operated more than atmospheric pressure, the temperatures distribution of low-pressure stage is increasing gradually as the inlet pressure was increased.

Temperature of low-pressure condenser inlet (T13) has relatively in unsteady circumstance; this temperature fluctuates during the experiment. It

increases rapidly after starting time from 5°C to 22°C than it continue to increase to 103°C and then tends to unstable in the range of $99^{\circ}\text{C} - 113^{\circ}\text{C}$.

Temperature of at condenser outlet (T14) and expansion valve inlet (T15) was dropped to -25°C when the low-pressure stage was started. It continued to decrease until the end of experiment. (T16) at expansion valve outlet, evaporator upper part (T17), at evaporator middle (T18), evaporator lower part (T19) at the condenser outlet (T20) have similar response, it dropped to about -75°C in the initiation time. Meanwhile, the temperatures of (T16–T20) were increasing gently.

The highest temperature reached by compressor outlet was more than 120°C , it was reached when the compressor inlet pressure was 1 bar. Smallest increment was occurred at expansion valve inlet (T15).

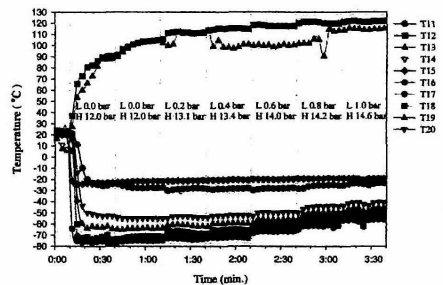


Fig. 8 Temperature distributions of Low pressure Stage Cascade Refrigerator, inlet compressor pressure: 0.0 to 1.0 bar.

Figure 8 shows the relationship of the lower stage inlet pressure to the temperature distribution in the lower pressure stage evaporator at over atmospheric pressure. The temperature increases equivalent to the lower stage compressors inlet pressure.

3.3 Cascade Refrigerator System

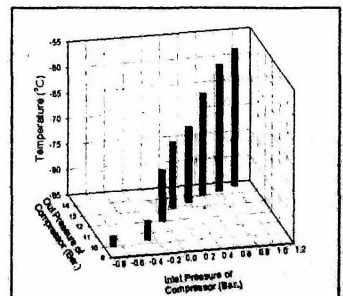


Fig. 9 Temperature Distribution in the low-pressure stage evaporator inlet as function of the low-pressure stage inlet and outlet pressure.

Figure 9 show that the lowest temperature which can be obtained by this cascade refrigeration system arrangement is down to -85°C . This temperature is reached when inlet pressure of the low-pressure compressors is -0.7 bars and the compressors outlet pressure is 9.9 bars. Thus, the temperature distributions have equivalent relationship with inlet pressure and compressors outlet pressure of the low-pressure stage compressors. Figure 7 summarize relationship of the low-pressure compressors inlet pressure and outlet pressure to the super-low temperature characteristics.

4. CONCLUSION

Super low temperature cascade refrigerator has been built and tested, this experimental device was built to study the temperature distribution of the cascade refrigeration system using several type refrigerant, in case of these experiment, R-22 and R-23 are employed as refrigerant at high pressure stage and low pressure stage respectively.

The result of this experiment explains relationship of the low-pressure stage compressor inlet to the overall temperature characteristics in the cascade refrigeration system. More low the low-pressure stage inlet and outlet pressure, more low the temperature of the cascade refrigeration system. The major obstacle to reach more low temperature is the compressor limitation. The vacuum pressure can cause compressor oil to evaporate thus endanger the system itself. Consequently, careful attention of vacuum controlling is required.

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