

The Characteristic of Propane-Ethane as Refrigerant in the Cascade Refrigeration System

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ABSTRACT: Nowadays, demands on super low temperature condition for industrial and commercial uses are thriving. Considering of its wide application in the present and the future, study of the super-low temperature refrigeration system should be actively carried out. This study is aimed to investigate refrigeration capacity and coefficient of performance(COP) of the cascade refrigeration system, as well as to get the system which can reach evaporator temperature of -70°C . For this purpose, R290 and R170 are charged in high stage and low stage respectively. Finally the characteristics of system using R290 and R170 will be proposed.

Keywords: Cascade heat exchanger, Propane, Ethane

NOMENCLATURE

HS : HS

LS : LS

Q_e : Refrigerant capacity [kcal/h]

G : Mass flow rate [kg/h]

c : specific heat [kcal/kg $^{\circ}\text{C}$]

ΔT : temperature difference of air flowing through the LS evaporator

1. INTRODUCTION

CFCs developed in the 1930's have been most widely used in the field of refrigeration since they almost perfectly satisfied the requirements for good thermodynamic properties, chemical stability, non-flammability, non-toxicity etc (Kim et al., 1998). To get more high performance of refrigerator, many of researches had been

carried out for heat transfer in a tube like cascade heat exchanger by Gungor et al. (1986), Jung et al. (1989) and Kandlikar (1990), but these researches had a focus on the simple pipe or tube for two phase flow and boiling phenomena. All of these reports were considered about the heat transfer for parts that have a single stage refrigeration system. For instance, Kuo et al. (1996) and Adriana et al. (2004) reported about the evaporating heat transfer for horizontal tube, and Shah (1992) suggested a correlation equations for saturated boiling heat transfer.

The conventional refrigerator can only reach low temperature down to -40°C . If the lower temperature is required, multi-stage refrigeration system must be utilized. 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 between two refrigerants is carried out by the cascade heat exchanger. It consists of a cascade evaporator in the higher stage, and cascade condenser in the lower stage.

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

Generally cascade HS evaporator and cascade LS condenser are installed coaxially in the cascade heat exchanger. The HS evaporator pipe is placed inside the LS condenser.

On the other hands, as the performance of refrigerator is influenced by the evaporator, recently, almost of studies have a concerning about kinds of refrigerants to get a environmental friendly refrigerants, Havelisky (2000). These papers showed only that the reports or information of total refrigeration cycle system are not enough.

The one stage refrigeration system is most usual and had been utilized for general industrial fields, but when they need a more low temperature, the general one stage refrigeration system can not be used and they need a two stage refrigeration cycle system. Giovanni et al. (2005) and Agnew (2004) et al. reported about the cascade heat exchanger for need of previous problems.

The HS evaporator can obtain temperature in the range of -20°C to -30°C in the expansion valve outlet. At this temperature, LS refrigerant is condensed in the LS condenser. Super-low temperature area in this system is located from LS expansion valve outlet until low-pressure compressor inlet.

The goal of this experiment is to investigate refrigeration capacity and coefficient of performance (COP) of the cascade refrigeration system by adjusting LS inlet pressure and volumetric flow rate of the air flowing through the LS evaporator.

This experiment use R-290 in the high-pressure stage and R-170 in the low-pressure stage.

2. TEST SETUP AND METHOD

2.1 Test setup

The experiment apparatus consists of two cycles (fig. 1):

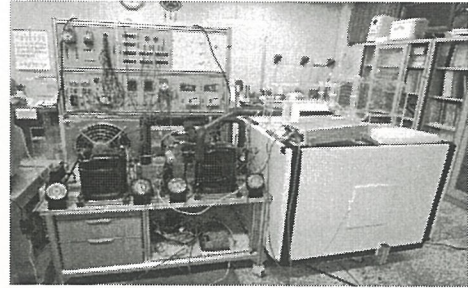


Figure 1 Experimental device of cascade refrigeration system.

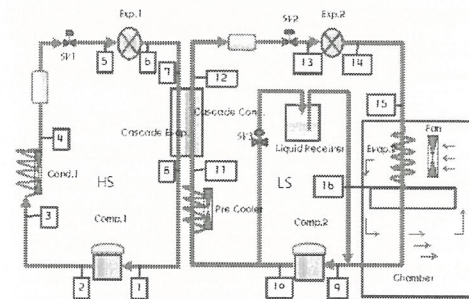


Figure 2 Schematic diagram of cascade refrigeration

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)

The cascade device where heat transfer is occurred from LS condenser to HS evaporator is a double pipe type with counter flow direction.

The temperature of refrigerant is represented by the temperature of the tube surface. 16 thermocouples were attached on the tube surface which locations are shown by Fig. 2.

The refrigerant temperature can reach super low temperature (-70°C) at LS expansion valve outlet. Hence, it is possible to get super low temperature inside the chamber. Air circulated inside the chamber through duct. And we measured the power using Clamp-on Power Meter of the CW240 model.

2.2 Experiment method

Table I. Refrigerants properties

Property	R290	R170
Molecular mass	44.10	30.07
Normal boiling point ($^{\circ}\text{C}$)	-42.2	-88.9
Critical temperature ($T_{\text{cr}}, ^{\circ}\text{C}$)	96.7	32.2
Critical pressure ($P_{\text{cr}}, \text{bar}$)	42.5	48.7

Table 1 shows property of the refrigerants used in this experiment. The property of refrigerant R290 and R170 is suitable for HS and LS respectively. R290 and R170 were charged into the compressors until the pressure were 6 bar and 20 bar respectively. In this experiment, the mass flow rate of air flowing through the LS evaporator and the compressor inlet pressure were varied to investigate the refrigeration capacity and coefficient of performance characteristics. The refrigeration capacity can be calculated as follow:

$$Q_e = Gc\Delta T = Gc(T_{\text{out}} - T_{\text{in}})[\text{kcal}/\text{h}] \quad (1)$$

And the COP can be calculated by:

$$\text{COP} = \frac{Q_e}{W_{\text{HS}} + W_{\text{LS}}} \quad (2)$$

There are two type experiments. On the first experiment, the flow rate was held constant at $160 \text{ m}^3/\text{h}$, while the LS compressor inlet pressure was varied of 1.8, 1.6 and 1.4 bar. And on the second experiment the mass flow rate was held constant $220 \text{ m}^3/\text{h}$, while

the LS compressor inlet pressure was varied the same as the first experiment.

3. RESULT AND DISCUSSION

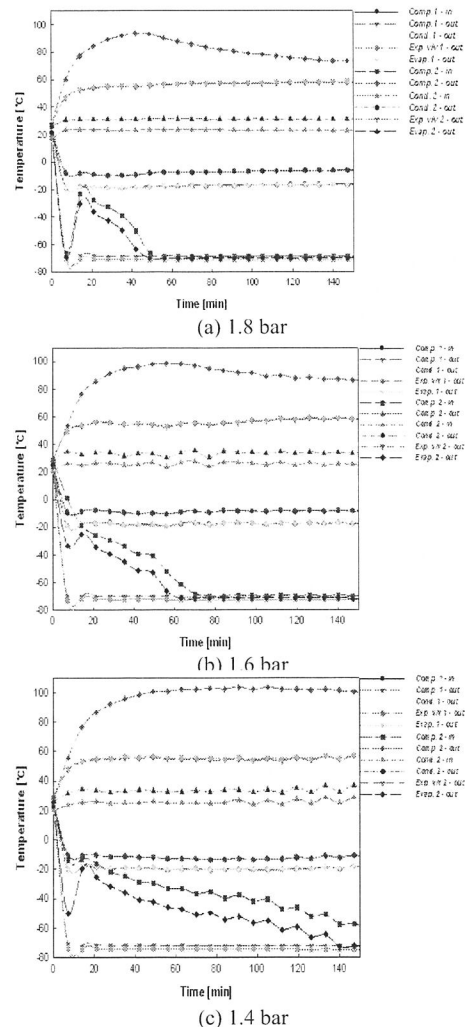


Figure 3. Illustrates temperature distribution at constant flow rate of $160 \text{ m}^3/\text{h}$ as a function of time

The pressure of LS compressor inlet in fig. 3(a) is held constant at 1.8 bar. In this graph, the temperature of LS evaporator outlet is decreasing to -70°C in 5 minutes. But when

the fan is turned on, the temperature is increasing suddenly because there is forced-convective heat transfer from air in the chamber to the evaporator. After about 40 minutes, temperature of LS evaporator outlet is decreasing again to -70°C because the temperature of the air inside the chamber is also decreasing. LS compressor inlet temperature is increasing for the first 40 minutes and then decreasing. This is because of the increase and decrease of temperature of evaporator outlet at the first 40 minutes.

In Fig. 3 (b), The LS compressor inlet pressure is held constant at 1.6 bar. The temperature of LS evaporator outlet and compressor inlet is decreasing to -70°C in 60 minutes. Temperature of HS and LS condenser outlet tends to fluctuate. This is because the pipe at condenser inlet is exposed to atmosphere so that unsteady heat transfer occurred from the ambient air to the pipe (the heat transfer rate depends on the ambient air velocity and temperature during the experiment).

In Fig. 3 (c), the LS compressor inlet pressure is held constant at 1.4 bar. In this graph, we can see that the temperature of evaporator outlet is decreasing to -68°C in 140 minutes. It means 5 minutes before the test is finished.

From Fig. 3 (a) to (c), it can be concluded that the temperature of LS evaporator inlet reaches super low temperature (under -70°C) faster if the pressure is increased. This is because the amount of refrigerant through the LS evaporator also increases by the pressure-increase. If the mass flow rate of refrigerant increases, the heat transfer rate from the air in the chamber to the evaporator will increase also.

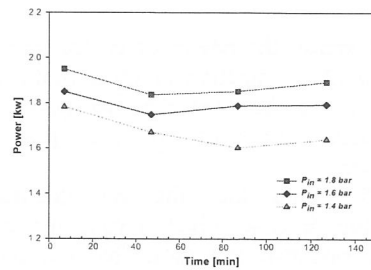


Figure 4. Total power of compressor

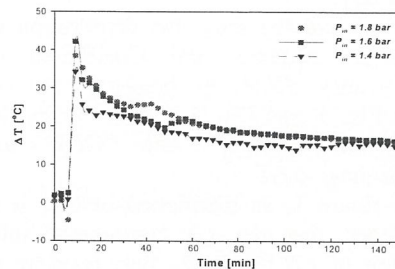
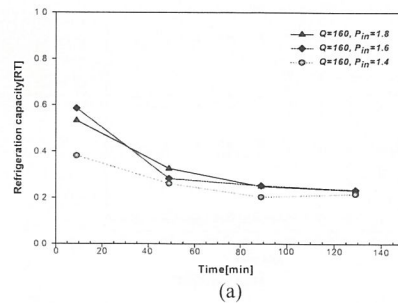
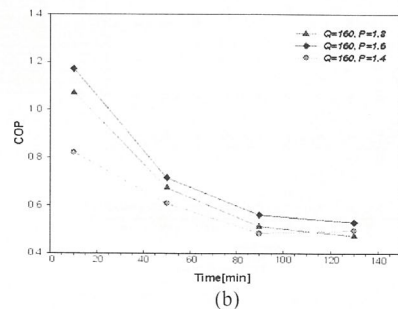


Figure 5. Temperature difference of air flowing through the LS evaporator as function of time



(a)



(b)

Figure 6. Coefficient of performance and refrigeration capacity of two stage cascade refrigeration system

Fig. 4 shows the power of compressor of HS and LS as function of time. From this figure, it can be seen that the power of compressor increases if the pressure increases.

Fig. 5 shows that the ΔT decreases according to time which means the heat transfer rate also decreases. This is because the temperature of air in the chamber is decreasing.

Fig. 6(a) and (b) show the distribution of refrigerant capacity and Coefficient of Performance (COP) as function of time. From Fig. 5 and Fig. 6 it is seen that the refrigerant capacity and COP are proportional to ΔT .

From figure 3, as mentioned before, it is concluded that the LS compressor inlet pressure of 1.8 bar is the best pressure to reach the super low temperature. But on the other hand, the highest COP is reached at pressure 1.6 bar.

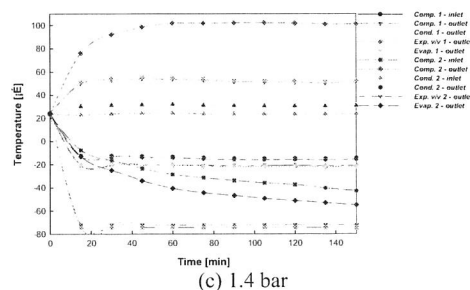
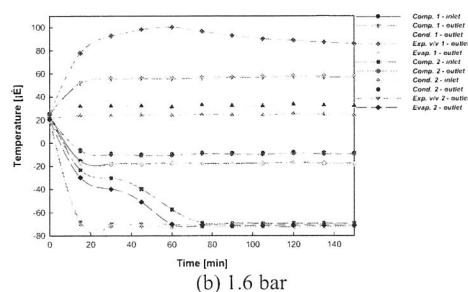
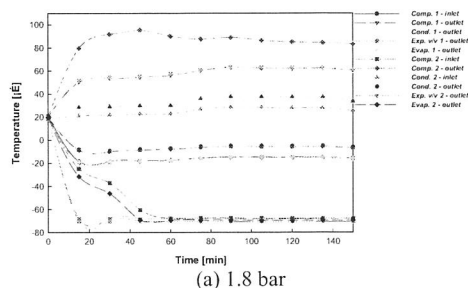


Figure 7. Temperature distribution at constant flow rate of 220 m^3/h as a function of time

Fig. 7 (a) and (b) show similar temperature distribution to the previous experiment of constant flow rate of 160 m^3/h .

But, it can be seen from Fig.7 (c) that the LS evaporator outlet temperature is still unsteady until the end of the experiment. It is because the air flow rate is high and the refrigerant mass flow rate inside the LS evaporator is low. From Fig. 9., it can be seen that the power of compressor increases if the pressure increases.

Fig. 10(a) and (b) show the distribution of refrigerant capacity and Coefficient of Performance (COP) as function of time. Fig. 8 and Fig. 10 show that the refrigerant capacity and COP are proportional to ΔT . Same as the first experiment, it is concluded that the LS compressor inlet pressure of 1.8 bar is the best pressure to reach the super low temperature. But on the other hand, the highest COP is reached at pressure 1.6 bar.

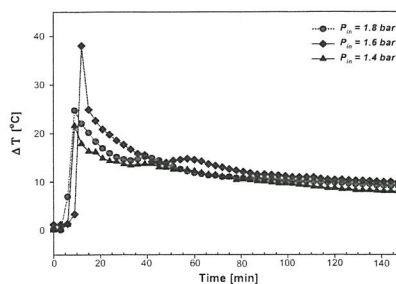


Figure 8. Temperature difference of air flowing through the LS evaporator as function of time

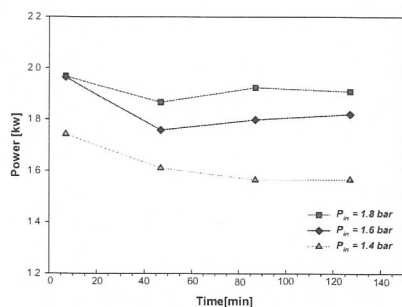


Figure 9. Total power of compressor

4. CONCLUSION

In this experiment, the flow rate of air flowing through the LS evaporator and the compressor inlet pressure were varied to investigate the refrigeration capacity and coefficient of performance characteristics

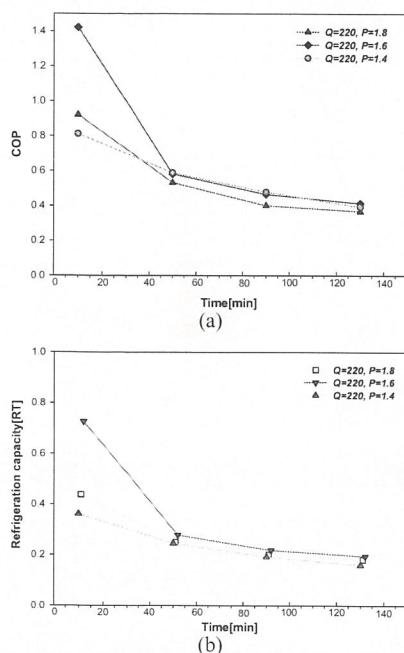


Figure 10. Coefficient of performance and refrigeration capacity of two stage cascade refrigeration system

The information from this study can be summarized as follow:

1. Super low temperature ($-70^{\circ}\text{C} \sim -70^{\circ}\text{C}$) at LS evaporator inlet can be achieved by using this cascade system.
2. The refrigerant capacity and coefficient of performance (COP) are function of time and proportional to ΔT .
3. LS compressor inlet pressure of 1.8 bar is the best pressure to reach the super low temperature. But on the other hand, the highest COP is 0.6 RT/1.2 and 0.75 RT/1.45 at pressure of LS compressor inlet of 1.6 bar.

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