Jurnal
Teknologi

Full Paper

THE EFFECT OF LIQUID SUCTION HEAT EXCHANGER SUB-COOLER ON PERFORMANCE OF A FREEZER USING R404A AS WORKING FLUID

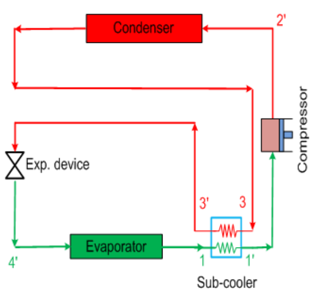
Article history
Received
31 January 2015
Received in revised form
30 April 2015
Accepted
31 May 2015

Muhammad Nuriyadi[a], Sumeru[a], Henry Nasution[b]*

[a]Department of Refrigeration and Air Conditioning, Politeknik Negeri Bandung Gegerkalong Hilir Ciwaruga Bandung 40012, Indonesia
[b]Automotive Development Centre, Faculty of Mechanical Engineering University Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author
henry@fkm.utm.my

Graphical abstract



Abstract

This study presents the effect of liquid-suction heat exchangers (LSHX) sub-cooler in a freezer. The LSHX sub-cooler is a method to increase the cooling capacity of the evaporator by lowering temperature at the condenser outlet. The decrease in temperature of the condenser outlet will cause a decrease in the quality refrigerant entering the evaporator. The lower the quality of the refrigerant entering the evaporator, the higher the cooling capacity produced by the evaporator. The LSHX sub-cooler utilizes a heat exchanger to transfer heat from the outlet of the condenser (liquid line) to the suction of the compressor. In the present study, three different LSHX sub-coolers in the freezer with cabin temperature settings of 0, -10 and -20oC were investigated. The results showed that the lowest and the highest of effectiveness of the heat exchanger were 0.28 and 0.58, respectively. The experimental results also showed that EER reduction is occurred at the cabin temperature setting of 0oC and -10oC, whereas the EER improvements were always occurred at the cabin temperature settings of -20oC.

Keywords: LSHX, Freezer, R404A, cooling capacity, EER.

1.0 INTRODUCTION

R404A is one of the families of HFCs (hydrofluorocarbons) for replacing R22 as working fluid in the refrigeration system. Refrigeration systems in the supermarket consume about 50-60% of total energy consumption [1,2]. As a result, energy savings in the refrigeration system is a high priority, given the increasingly expensive and limited energy resources. There are several methods for energy savings in the refrigeration systems. Sub-cooling using liquid-suction heat exchanger (LSHX) is a method to increase the cooling capacity of the refrigeration system. The increase in the cooling capacity improves the energy efficiency ratio (EER) of the freezer. The EER is ratio between the cooling capacity with unit of Btu/h and input power with unit of Watt. However, because the use of LSHX sub-cooler is always followed by superheating, causes the compressor work always increases as well. As a result, the effect of LSHX sub-cooler on the EER improvement is not always positive.

Domanski et al. [3] numerically investigated the performance of 38 different refrigerants in the vapor compression refrigeration cycle (VCRC) using LSHX sub-cooler. They reported that refrigerants with low vapor molar heat capacity will not improve the COP compared to basic cycle (without sub-cooling). Also, they reported that using refrigerants with very low heat capacity, caused the COP of the system decreases when the LSHX sub-cooler is applied.

Klein et al. [4] introduced a relative capacity index (RCI) to calculate the cooling capacity improvement using LSHX sub-cooler. The RCI is defined by equation,

$$RCI = \frac{(Q_{with-LSHX} - Q_{no-LSHX})}{Q_{no-LSHX}} \cdot 100\% \qquad \text{(Eq. 1)}$$

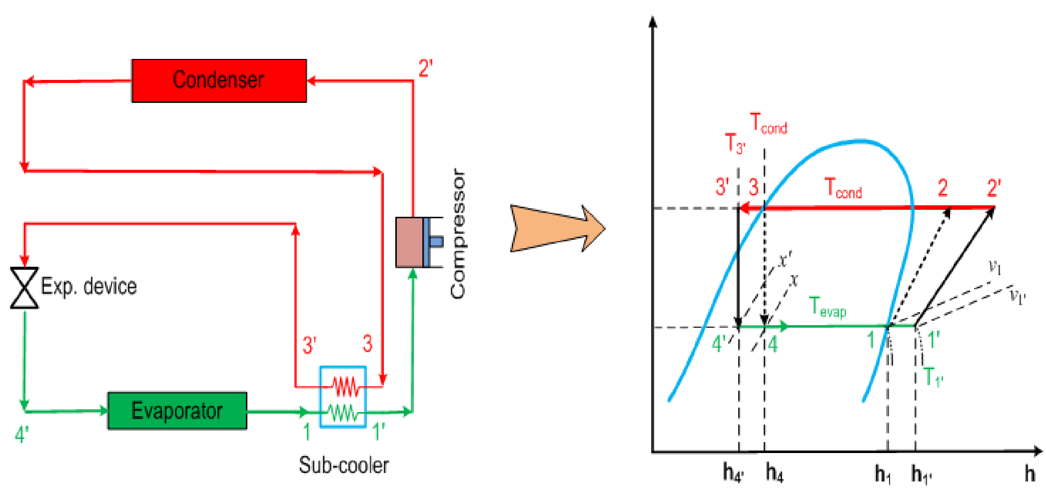
where:
Qwith-LSHX = cooling capacity with LSHX sub cooler (Watt)
Qno-LSHX = cooling capacity without LSHX sub-cooler (Watt)

Navarro-Esbri et al. [5] experimentally investigated the effect of subcooling using LSHX in VCRC using R22, R134a and R407C as working fluid. Besides studying the influence of subcooling on the performance, they also investigated its impact on the mass flow rate. Experimental results showed that the mass flow rate reduction was occurred in R22 and R134a when LSHX was applied. However, although the mass flow rate decreased, the COP did not decrease because the increase in the cooling capacity using LSHX was slightly higher than that of mass flow rate. Different results showed by R407C, namely the mass flow rate and the cooling capacity increased, as a result, the COP improvement of R407C was the highest for the compression ratio below 5.

2.0 EXPERIMENTAL

2.1 LSHX Sub-Cooler

Sub-cooler using LSHX is always followed by superheating at the low pressure (suction). The Sub-cooled condition in the condenser outlet reduces the risk of flashing gas at the inlet of the expansion device [3]. Also, the superheating in the suction reduces the possibility the fluid phase of refrigerant entering the compressor suction. Because, the fluid phase of refrigerant in the suction can cause damaging the compressor.



(a) (b)

Figure 1 (a) Schematic diagram of the freezer cycle, (b) The freezer cycle in P-h diagram.

Fig. 1 (a) shows the schematic diagram of a freezer using LSHX as sub-cooler. Meanwhile, Fig. 1 (b) shows the freezer cycle in the P-h (pressure-enthalpy) diagram. Referring to P-h diagram, the cooling capacities of the freezer without and with LSHX sub-cooler is expressed by Eq. 2 and 3. For the same mass flow rate, it can be seen that the cooling capacity with sub-cooler is higher than that of without sub-cooler. The performance of the LSHX sub-cooler to transfer energy from the warm liquid (outlet of the condenser) to the cold vapor (outlet of the evaporator) is dependent on the size and configuration of the heat exchanger. The performance of the heat exchanger is expressed by an effectiveness (ε), which is defined by Eq. 4. The effectiveness is the ratio between the actual and maximum possible heat transfer rates in the heat exchanger. The surface area of the heat exchanger affects the effectiveness of LSHX sub-cooler.

$$Q_{no-LSHX} = \dot{m} \cdot (h_1 - h_3) \qquad \text{(Eq. 2)}$$

$$Q_{with-LSHX} = \dot{m} \cdot (h_{1'} - h_{3'}) \qquad \text{(Eq. 3)}$$

$$\varepsilon = \frac{(T_{1'} - T_1)}{(T_3 - T_2)} \qquad \text{(Eq. 4)}$$

$$EER = \frac{Q}{W} (Btu/Wh) \qquad \text{(Eq. 5)}$$

Meanwhile, the EER improvement is expressed by equation,

$$EER_{imp} = \frac{(EER_{with-LSHX} - EER_{no-LSHX})}{EER_{no-LSHX}} \cdot 100\% \quad \text{(Eq. 6)}$$

According to Eq. 6, the EER improvement may be positive or negative. If positive, it means that the EER of the system using the LSHX sub-cooler is higher than that of without sub-cooler. Conversely, when EER is negative, it indicates that the EER of the system using the LSHX sub-cooler is lower than that of without sub-cooler.

3.0 RESULTS AND DISCUSSION

The present study used three different temperature settings in the cabin, namely 0, -10, -20^{o}C, whereas the condenser temperature was maintained constant. Also, there were three different sub-coolers applied in this study. Experimental studies were carried out on a freezer with the compressor capacity of 1 HP (9.75 kW). A flow meter was installed after the condeser to measure the mass flow rate of refrigerant. Based on the experiments, the effectiveness of LSHX for the three different temperatures setting in shown by Table 1. The table shows that the effectiveness of LSHX tends decreasing with the increase in the cabin temperature setting.

Table 1 The effectiveness of LSHX for various cabin temperature settings

Temperature Setting	LSHX-1 (ε)	LSHX-2 (ε)	LSHX-3 (ε)
Tcabin = 0^{o}C	0.58	0.49	0.40
Tcabin = -10^{o}C	0.53	0.45	0.36
Tcabin = -20^{o}C	0.56	0.48	0.28

Using Eq. 1, the RCI of freezer can be determined. The calculated RCI are presented in Fig. 2 for different cabin temperature settings and LSHX effectiveness. The figure showed that the effectiveness of the LSHX subcooler changed when the cabin temperature setting is changed, although there is no change in the surface area of LSHX sub-cooler. Furthermore, the figure showed that for the cabin temperature setting of 0^{o}C, the RCI was always negative. It means that there is no cooling capacity enhancement at this temperature setting. In other words, it is not recommended using LSHX sub-cooler in the freezer if the cabin temperature is about 0^{o}C. The use of LSHX sub-cooler would be advantageous at the cabin temperature settings below 0^{o}C. Also, the figure showed that the highest RCI was occured at cabin temperature setting of -20^{o}C. As a result, for the freezers which have the cabin temperature below -20^{o}C, it is recommended to use LSHX sub-cooler. The figure also shows that the LSHX-2 yields the highest RCI. It can be concluded that that the RCI is affected by the cabin temperature setting and effectiveness of the LSHX sub-cooler.

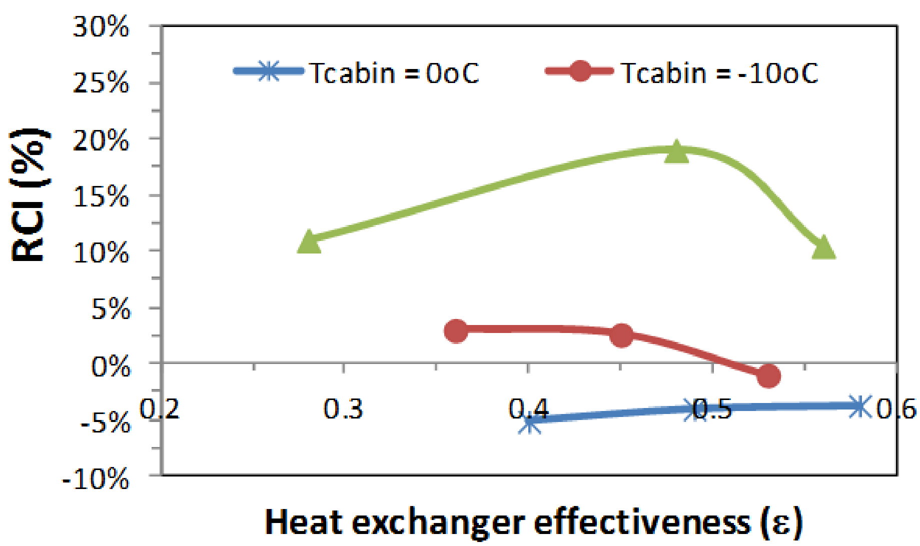


Figure 2 Relative capacity index (RCI) as a function of LSHX effectiveness for various cabin temperatures.

Figure 3 shows the electrical energy consumption by the freezer using LSHX for various cabin temperatures. The figure shows that the energy consumption increases with decreasing temperature of the cabin. The highest energy consumption occurs in the LSHX-2, whereas the lowest energy consumption occurs in the LSHX-1. Although, the LSHX-3 has the lowest effectiveness, however, in present study, the energy consumption using the LSHX-3 was similar to the LSHX-1. The energy consumptions per hour of the freezer without LSHX were lower than that of with LSHX, namely 225, 230 and 275 Wh/h for the cabin temperatures of 0, -10 and -20°C.

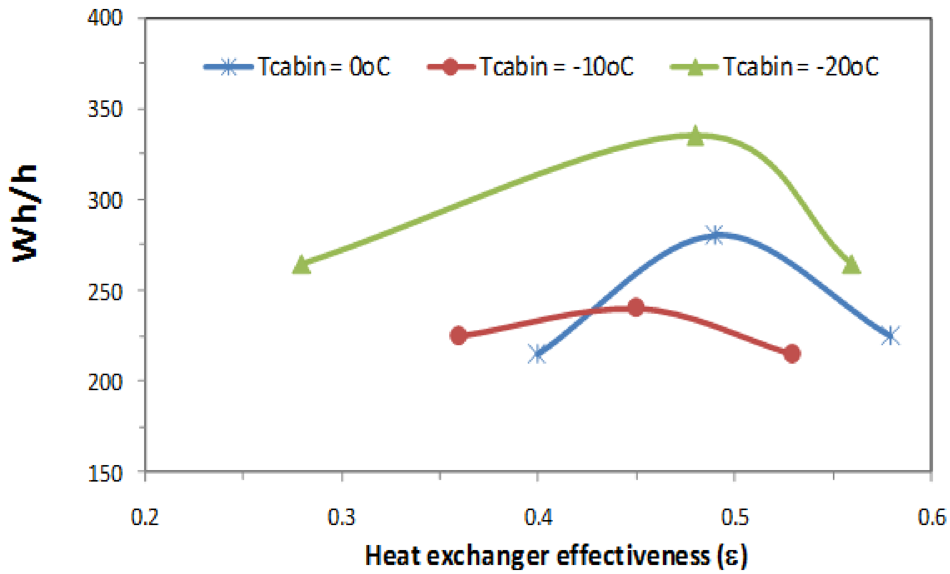


Figure 3 Energy consumption per hour of the freezer using LSHX for various cabin temperatures.

As mentioned in the previous section that besides increasing the cooling capacity, the use of LSHX sub-cooler also increases the compressor work, as a result, the EER of a freezer does not always increase. Fig. 4 shows that the EER of freezer using three different LSHX sub-coolers with three different the cabin temperature settings. The continuous lines represent the EER vs. effectiveness of the LSHX sub-cooler, whereas the dash lines are represent the EER of freezer without LSHX sub-cooler. It can be seen from the dash lines that the EER of freezer without LSHX sub-cooler with the cabin temperature settings of 0, -10 and -20°C are about 2.5, 4.9 and 5.6, respectively. Furthermore, the figure also showed that at the cabin temperature settings of 0oC and -10oC, the EER improvement was not always positive. Meanwhile, at the cabin temperature setting of -20oC, the EER improvement was always positive. It means that the use of LSHX sub-cooler at the cabin temperature settings of 0oC and -10oC do not always cause the EER improvement. Meanwhile, at the cabin temperature setting of -20oC always generates the EER improvement. As a result, it is recommended using LSHX sub-cooler in the freezer if the evaporating temperature below -20oC.

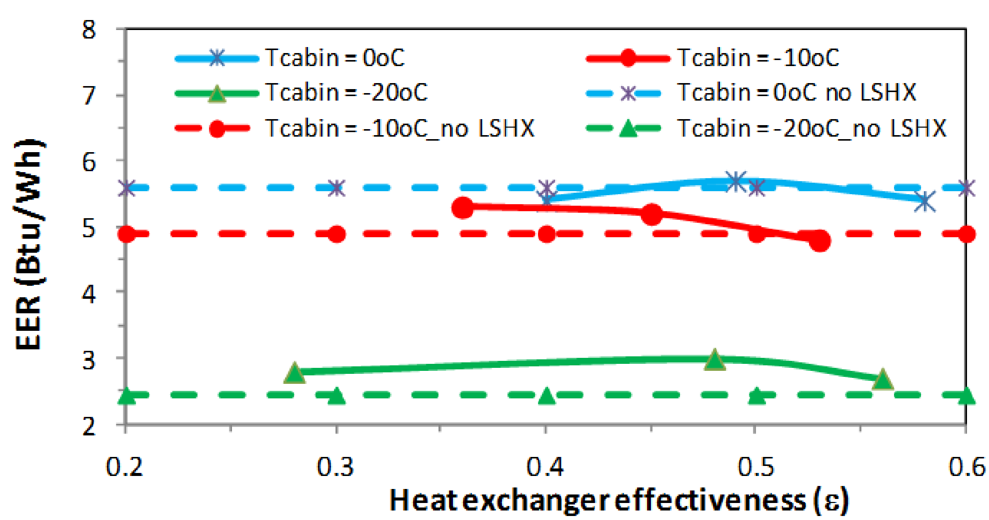


Figure 4 Energy efficiency ratio (EER) as a function of LSHX effectiveness for various cabin temperatures.

4.0 CONCLUSION

Based on the experimental investigation on the freezer using LSHX sub-cooler, the following conclusions could be drawn:

- The LSHX sub-cooler in a freezer did not always increase the RCI, especially at the cabin temperature setting of 0oC.
- The LSHX sub-cooler in a freezer always increased the RCI when the cabin temperature setting was -20oC.
- At the cabin temperature setting of -20oC, the use of LSHX sub-cooler in a freezer always increased the EER.

Acknowledgement

The authors acknowledge the support by Politeknik Negeri Bandung. The authors are also grateful to Automotive Development Center (ADC), Universiti Teknologi Malaysia (UTM) for the facilities and management support.

References

[1] Qureshi, B. A. and Zubair, S. M. 2012. The Effect Of Refrigerant Combination On Performance Of A Vapor Compression Refrigeration System With Dedicated Mechanical Sub-Cooling. *Int. J. Refrig*. 35: 47-57.

[2] Qureshi, B. A. and Zubair, S. M. 2012. The Impact Of Fouling On Performance Of A Vapor Compression Refrigeration System With Integrated Mechanical Sub-Cooling System. *Appl. Energy*. 92: 750-762.

[3] Domanski, P. A., Didion, D. A. and Doyle, J. P. 1992. Evaluation Of Suction Line-Liquid Line Heat Exchanger In The Refrigeration Cycle. *In proceeding: International Refrigeration and Air Conditioning Conference, Purdue University, Paper*. 149: 131-139.

[4] Klein, S. A., Reindl, D. T. and Brownell, K. 2000. Refrigerant System Performance Using Liquid-Suction Heat Exchangers. *Int. J. Refrig*. 23: 588-596.

[5] Navarro-Esbri, J., Cabello, R. and Torrella, E. 2005. Experimental Evaluation Of The Internal Heat Exchanger Influence On A Vapor Compression Plant Energy Efficiency Working with R12, R134a and R407C. *Energy*. 30: 621-624.