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PERFORMANCE IMPROVEMENT USING SUBCOOLING ON FREEZER WITH R22 AND R290 AS REFRIGERANT FOR VARIOUS AMBIENT TEMPERATURES

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ABSTRACT

Vapor compression refrigeration cycle (VCRC) is widely used in freezers. In a simple cycle of the VCRC, refrigerant in the condenser exit is at liquid saturated line. If the refrigerant temperature in the condenser exit is further cooled to the subcooled region results in an increase in the cooling capacity due to low vapor quality of refrigerant entering the evaporator. The lower the refrigerant quality entering the evaporator, the higher the cooling capacity on the evaporator. The increase in the cooling capacity enhances the freezer performance. Subcooling uses liquid suction heat exchanger (LSHX) is applied to transfer heat from the exit of the condenser (liquid line) to the suction of the compressor. Because the temperature of liquid line is higher than that of the suction line, heat flows from liquid line to the suction line, results in the decrease in temperature of the exit of the condenser and the increase in the suction temperature (superheating). Consequently, the use of the LSHX is always followed by superheating on the suction of the compressor. The superheating causes an increase in the input power. As a result, subcooling using the LSHX is not always followed by the increase in the coefficient of performance (COP) of the freezer, depending on the type of refrigerant used. Refrigerant of R22 is widely used as refrigerant in the freezers. Because R22 has a high global warming potential (GWP), the near future this refrigerant must be phased out. Refrigerant of R290 (propane) is recommended as a substitute refrigerant for R22. The R290 is a natural refrigerant, abundant and relatively cheaper than that of R22. This paper investigates the use of LSHX subcooling in freezer with the evaporating temperature of -20 ºC for various ambient temperatures, viz., 30, 35 and 40 ºC using R22 and R290 as working fluids. It is well known that the COP of the freezer decreases with an increase in the ambient temperature. As a result, the use of the LSHX subcooler is expected to enhance the COP of the freezer for the higher ambient temperatures. There are three parameters, viz., the cooling capacity, the discharge temperature and COP improvement will be investigated in the present study. Numerical results showed that the increase in subcooling and ambient temperature increase the cooling capacity and COP improvements. In addition, the cooling capacity and COP improvements of R290 using the subcooling of LSHX were higher than that of R22 for all ambient temperatures. Also, the increase in degree of subcooling enhanced the cooling capacity and COP improvements. For R22, at the ambient temperature above 35 ºC is not recommended using LSHX subcooling in freezers, because it will increase the discharge temperature above 90 ºC. However, the use of LSHX subcooling is recommended for all ambient temperatures in freezer using R290, because the discharge temperature on the freezer is still below 80 ºC.

Keywords: subcooling, heat exchanger, LSHX, R22, R290.

INTRODUCTION

Because refrigeration system consumes a large amount of electrical energy, as a result many methods have been developed by researchers to improve the system performance. In the supermarket, the refrigeration systems (freezer and air conditioner) consume approximately 50-60% of energy total [1]. Subcooling uses an internal heat exchanger, which transfers heat from the condenser outlet to the compressor suction, may lead to an increase in the cooling capacity produced by the evaporator. This method is called subcooling using liquid suction heat exchanger (LSHX). The most important effect of the use of LSHX is the increase in cooling capacity because of the lower quality of refrigerant entering the evaporator, consequently the evaporator absorb more heat from the ambient [2]. In the other hand, the use of LSHC results in superheating in the compressor suction. The superheating has positive and negative effects to the system. The positive effect if the degree of superheating is to eliminate liquid refrigerant entering to the compressor, because this can cause damage to the compressor. The negative effect if the degree of superheating is too high, as a result an increase in the compressor discharge temperature. The increase in the compressor discharge temperature results in an increase in the power consumption. Consequently, the subcooling using LSHX does not always increase the COP [3].

Nowadays, refrigerant of R22 is widely used as refrigerant in the freezers. However, because R22 has a high global warming potential (GWP), the near future this refrigerant must be phased out and refrigerant of R290 (propane) is recommended as a substitute refrigerant for R22 [4]. The R290 is a natural refrigerant, abundant and relatively cheaper than that of R22. Many studies reported that replacement of R22 with R290 in freezer resulted in

an improvement of the COP [5, 6]. The aim of this study is to investigate the effect of the LSHX subcooler on the performance of freezer using R22 and R290 with various ambient temperatures.

Potter and Hrnjak [7] carried out an experimental investigation to study the effect of sub-cooling on various parameters in the air conditioning system using R134a and R1234yf. The experimental results showed that the presence of LSHX in the air conditioner increases the COP up to 18% and 9% for R1234yf and R134a, respectively. The results also showed that there are changes in some parameters due to the presence of subcooler using LSHX, as shown in Table-1. The table shows that the use of LSHX subcooler is always followed by increasing cooling capacity, compressor work and superheating. Because the COP is the ratio of the cooling capacity to compressor power, as a result the increase in the COP depends on their increments. Most working fluid generates COP improvement on the system when the LSHX subcooling is applied, and only few refrigerants.

Table-1. Effect of sub-cooler in the VCRC.

Quantity	LSHX
Cooling capacity	Increases
Condensing pressure Mass flow rate	Constant* Vary*
Compressor work COP	Increases Increases**
Superheating	Increases

*Depending on the degree of sub-cooling.
**Depending on the working fluid used.

THERMODYNAMIC ANALYSIS OF SUBCOOLING
Figure-1 shows the schematic and P-h (pressure-enthalpy) diagrams of LSHX subcooler in the freezer. According to the P-h diagram, the figure shows that the use of heat exchanger increases the suction temperature from point 1 to 1', and this phenomenon is called superheating. Also, from the figure, it can be seen that the subcooler decreases the exit condenser temperature, from point 3 to 3', and this is called subcooling. The superheating helps in preventing the liquid refrigerant from entering the suction compressor. The liquid phase refrigerant entering the suction causes problem in the compressor bearings and rings, or valve failure in some extreme cases.

The degree of subcooling (T_{cond} - $T_{3'}$) and the degree of superheating ($T_{1'}$-T_{evap}) is not the same due to different in specific heats of the vapor and liquid phases. The equation energy balance in the heat exchanger is used to calculate the degree of subcooling and superheating and given in equation. (1).

$$Q_{sub} = Q_{sup} = h_{1'} - h_1 = h_3 - h_{3'} \qquad (1)$$

The COP of freezer after using subcooler is

$$COP = \frac{Q_{evap}}{W_{comp}} = \frac{(h_1 - h_3) + (h_{1'} - h_1)}{(h_2 - h_1) + [(h_{2'} - h_{2'}) - (h_2 - h_1)]} \qquad (2)$$

It can be seen from equation. (2), both numerators and denominators of equation. (2) increase. The net effect, i.e., whether positive, negative or zero depends on the working fluid used and the operating temperature (evaporating and condensing temperatures).

In order to determine the performances of the freezer, the parameter values in each point in Figure-1 in P-h diagram must be determined. Some assumption are made to carry out simulation: i.e., (a) steady state condition, (b) no heat transfer except on the condenser and the evaporator, (c) no pressure loss in the pipeline, (d) the condensing temperature is 10 °C above the ambient temperature (e) the evaporating temperature is -20 °C and (f) the enthalpy value on the discharge temperature (h_2) is determined using equation. (3) and entropic efficiency of the compressor (η_{comp}) follows equation. (4)
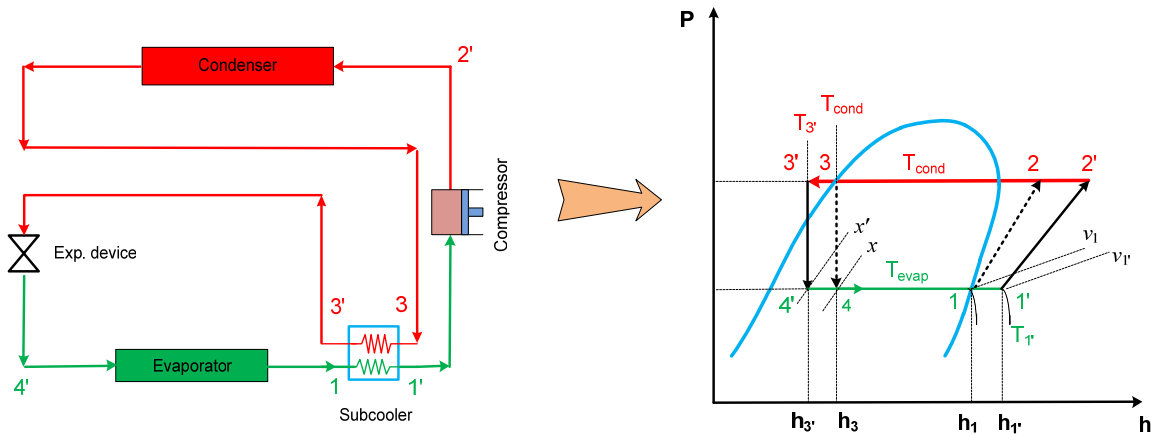
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Figure-1. Schematic and P-h diagrams of the LSHX subcooler in freezer.

$$h_2 = h_1 + \frac{(h_{2,is} - h_1)}{\eta_{comp}} \qquad (3)$$

$$\eta_{comp} = 0.874 - 0.0135 \frac{P_2}{P_1} \qquad (4)$$

The cooling capacity (CC) improvement due to using LHSX subcooler is defined with equation. (5). In addition, COP improvements are determined using equations similar to equation. (5).

$$CC_{imp} = \frac{CC_{with} - CC_{wo}}{CC_{wo}} \qquad (5)$$

RESULTS AND DISCUSSIONS

The main purpose of the subcooling is to increase the cooling capacity. Figure-2 shows that the cooling capacity improvements using R290 were always higher than that of R22. The cooling capacity improvement increases with the increase in ambient temperature and degree of subcooling. The higher the degree of subcooling, the higher the cooling capacity. For the degree of subcooling of 2 ºC and 10 ºC, the cooling capacity improvement with R22 as refrigerant are 1.83% and 2.09%, respectively, for the ambient temperature of 30 ºC. Furthermore, for R290 as working fluid with the degree of subcooling of 2 ºC and 10 ºC, the cooling capacity improvement are 2.31% and 2.71%, respectively, for the ambient temperature of 30 ºC. The cooling capacity improvement also increases with the increase in ambient temperature. For instance, for the degree of subcooling of 10 ºC with R22 as working fluid at ambient temperature of 30 ºC and 40 ºC are 8.80% and 10.13%, respectively. Meanwhile, for R290 as refrigerant with the degree of subcooling of 10 ºC at ambient temperature of 30 ºC and 40 ºC are 11.29% and 13.29%, respectively.

The higher the degree of subcooling may lead to the higher the discharge temperature, as shown in Figure-3.

The figure shows that the discharge temperatures of R290 were always lower than that of R22 for all the ambient temperatures and the degree of subcoolings. The figure also shows that for R22, at the ambient temperature above 35 ºC is not recommended using LSHX subcooling in freezers because the discharge temperature will be above 90 ºC. Because of for safety reason, the compressor with the discharge temperature above 90 ºC is not recommended. However, the use of LSHX subcooling is recommended for all ambient temperatures in freezer using R290, because the discharge temperature on the freezer is still below 80 ºC. For example, at the ambient temperature of 40 ºC with the degree of subcooling of 10 ºC, the discharge temperatures are approximately 80 ºC and 114 ºC for R290 and R22, respectively.
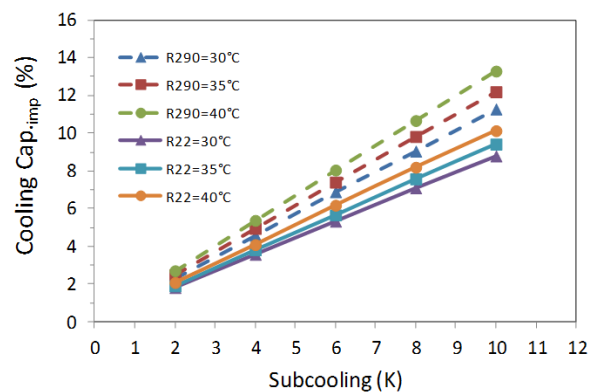

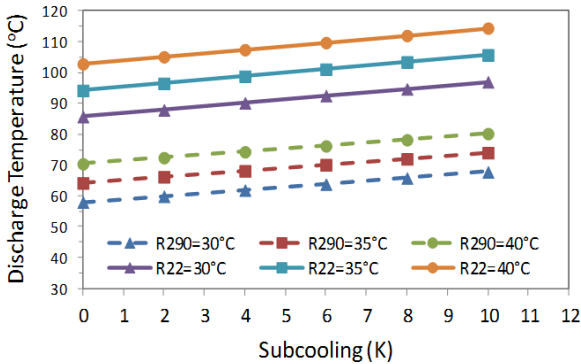**Figure-2.** Effect of ambient temperature on the cooling capacity.

Figure-3. Effect of ambient temperature on the discharge temperature.

Figure-4 shows the effect of LSHX subcooler on COP improvement. The figure shows that the COP improvement increases with the increase in ambient temperature and degree of subcooling. Similar to the cooling capacity improvement, the COP improvement of R290 is always higher than that of R22. It means that the use of LSHX subcooler is recommended if the freezer using R290 as working fluid however is not suggested for R22 because the COP improvement is not significant. The COP improvements of subcooling using LSHX with R22 and R290 as refrigerant for the degree of subcooling of 10 ºC are 4.86% and 7.46%, respectively. Meanwhile, the COP improvement for the degree of subcooling of 2 ºC with R22 and R290 are only 0.81% and 1.22%, respectively. As a result, in order to yield significant COP improvement on freezer using LSHX subcooler with R290 refrigerant is recommended for the degree of subcooling above 10 ºC.
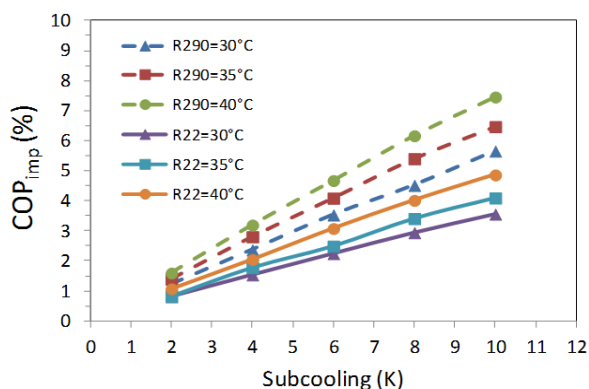

Figure-4. Effect of ambient temperature on the COP improvement.

CONCLUSIONS

The results showed that the use of LSHX subcooler increased the cooling capacity and COP however also increased the discharge temperature. The increase in cooling capacity and COP increased with

increase in ambient temperature. The cooling capacity and COP improvements of R290 were higher than that of R22. The use of LSHX at the ambient temperature above 35 ºC is not recommended in the freezers using R22 as refrigerant, because the discharge temperature will be above 90 ºC. Meanwhile, to generate a significant COP improvement on freezer using LSHX subcooler with R290 as refrigerant, the degree of subcooling is above 10 ºC.

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