The Effect of The Mass Amount of Refrigerant In The Freezer Equipped with Receiver on The Performance of Refrigeration System Cycle

by Paulus Sukusno

The Effect of The Mass Amount of Refrigerant In The Freezer Equipped with Receiver on The Performance of Refrigeration System Cycle

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Abstract. The mass of refrigerant is vital when filling refrigerant into a refrigeration system in a freezer that is equipped with a receiver. It can improve the performance of the refrigeration system if the mass of refrigerant conforms to the specification (standard) of the system. This research aims to analyze a phenomenon concerning performance of refrigeration system cycle as a result of filling refrigerant (a certain mass of refrigerant) into the refrigeration system of freezer equipped with receiver. The research was conducted on a laboratory-scale freezer that was used to cool water with a mass of 1 kg from a temperature of 27^{0}C to -22^{0}C. The data sample was taken when the machine had been operating for 30 minutes. The freezer was operated (tested) by varying the mass of refrigerant filled into the freezer. The mass of refrigerant in the receiver tank can be discovered from refrigerant temperature and pressure outlet. The result of the research indicates the effect of the mass of refrigerant on the performance of the refrigeration system cycle (compressor work, refrigeration capacity, and COP). The effect can be visually demonstrated by the presence of ice on the outside of pipeline and compressor input.

Keywords: Receiver, mass variation of refrigerant, refrigeration system, freezer.

1. Introduction

Freezing technology requires a lot of energy because it requires an energy-saving freezer. A research analyzing performance parameters such as entropy generation, COP, and continuous efficiency examined on different envionmental condition has been conducted by [1], by using three ozone-friendly hydrofluorocarbon (HFC) refrigerants (R32, R134a and R152a) in a vapor-compression refrigeration system. [2],[3] presented a method to analyze energy which is applicable to indicate cooling potential and irreversibility of cycle by utilizing heat source at low temperature.

The technology of food preservation by freezing requires more energy than other technology of food preservation such as curing and canning as revealed by [4]. [5] stated that freezing machine with vapor-compression refrigeration is the most commonly used means in the food freezing process. An analysis of energy and exergy for refrigeration system on domestic products conducted by [6] is a method to find out the amount of energy consumption of freezing and the effect of equipment replenishment to increase the energy efficiency in a freezing process. Therefore, energy-saving freezing machine or effort to save energy is required

Experiments assessing exergetic efficiency on freezing process with various gradual temperature of freezing media conducted by [7],[8]. The experiment indicated that exergy loss on each stage of freezing process can be calculated and temperature setting on each stage of the process is vital to diminish the irreversibility of the process.

[9] conducted researches analyzing energy loss in the components of refrigeration system such as compressor, condenser, evaporator and expansion valve. In their research, they recommended a model of low temperature freezer which is able to save energy in the freezing process.

This research aims to analyze a phenomenon concerning performance of refrigeration system cycle as a result of filling refrigerant (a certain mass of refrigerant) into the refrigeration system of freezer equipped with a receiver. By discovering the phenomenon occured, the mass of refrigerant should always be noticed when filling the refrigerant into the freezer.

2. Theory

Thermodynamics equations are required to determine the coefficient of performance of the refrigeration system. Coefficient Of Performance (COP) is a coefficient indicating energy changes (enthalpy) occured on working fluid (refrigerant) and is defined as the ratio of the magnitude of the refrigeration effect (RE) to the compressor work (w_K) based on enthalpy changes on p-h diagram for refrigerant (R404A) and thus expressed in equation 5.

Compressor

$$w_K = (h_2 - h_1) \quad (1)$$

Condenser

$$q_{HP} = (h_2 - h_3) \quad (2)$$

Expansion valve

$$h_3 = h_4 \text{ (assumed)} \quad (3)$$

Evaporator

$$q_{RE} = (h_1 - h_4) \quad (4)$$

Coefficient of Performance

$$COP = \frac{q_{RE}}{w_K} = \frac{(h_1 - h_4)}{(h_2 - h_1)} \quad (5)$$

Annotation:

h_1 : enthalpy at compressor inlet [kJ kg^{-1}].

h_2 : enthalpy at compressor outlet [kJ kg^{-1}].

h_3 : enthalpy at condenser outlet [kJ kg^{-1}].

$h_{3'}$: enthalpy at receiver outlet [kJ kg^{-1}]

h_4 : enthalpy at evaporator outlet [kJ kg^{-1}].

w_K : enthalpy due to compressor work [kJ kg^{-1}].

q_{HP} : enthalpy due to heating effect [kJ kg^{-1}].

q_{RE} : enthalpy due to cooling effect [kJ kg^{-1}].

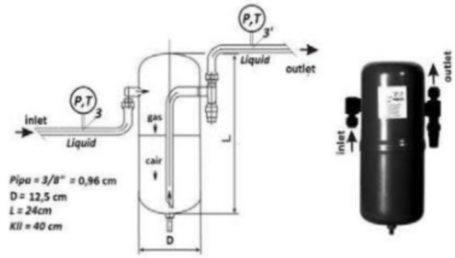
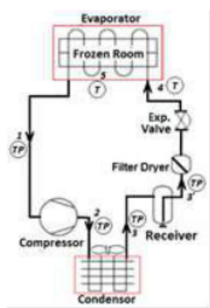
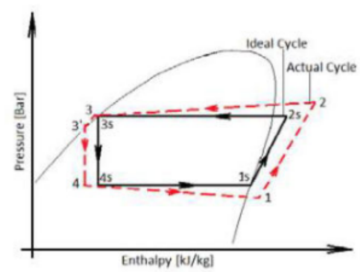


Figure 1. Receiver

Figure 1 shows the diagram of refrigeration system of freezing machine equipped with a receiver. The outflow of refrigerant from condenser flows into the larger volume receiver, resulting a decrease in temperature and pressure. The decrease of temperature and pressure of refrigerant in the receiver is indicated by a shift from point 3 to point 3' on the diagram as shown in at Figure 3.



(a).



(b).

Figure 2. (a). Scheme of freezer is used receiver (b). Cycle of refrigeration system

Annotation:

1. Temperature and pressure at compressor inlet
2. Temperature and pressure at compressor outlet
3. Temperature and pressure at condenser outlet

3'. Temperature and pressure at receiver outlet

4. Temperature in the evaporator
5. Product temperature (water-ice).

Figure 2 is how refrigeration system of the freezer works. The compressor pulls in refrigerant to compress (point 1 to 2). The condenser cools the refrigerant by flowing air (point 2 to 3). The receiver ensures the refrigerant enters the expansion valve in saturated liquid phase that allows pressure and temperature to decrease (point 3 to 3'). Then, the evaporator vaporizes the refrigerant by absorbing heat through object (for example, water to ice at point 5) in the evaporator (point 4 to 1). And so on, the refrigeration system works in a closed cycle.

3. Research Methodology

This research uses a laboratory-scale freezer with R-404A refrigerant. The specification details of the freezer are presented in Table 1. The freezer is equipped with receiver and three expansion valves (nozzle number 01, 02 and 03) used to adjust the gradual temperature in the evaporator. The freezer is used to test the cooling process of one kilogram of water into ice.

Table 1. Specification of the freezer

Compressor	: Type; SC12CL, 220-240V/50Hz, n = 2900 rpm, Ve 12 cm^3/rev.
Evaporator	: Type; plate touch (210 x 210 x 3) mm^3
Condenser	: Type; Tinned Tube n 30, d 3/8”, air conditioner
Expansion Valve	: Danfoss TS2: Oriffice No. 02
Refrigerants	: R 404A
Receiver	: Merk; Airmender, A 127 mm, L 240 mm.
Pressure gauge	: Bourdon Barometer Type analog
Thermometer	: Thermocouple digital type TC4Y Accuracy $\pm$ 2^0C
Wattmeter	: Multifunction Mini Ammeter D02A, Accuracy $\pm$ 1 %

4. Result and Discussion

Table 2. Sample of measuring data of the research on refrigeration system with various masses of refrigerant in the system of freezer equipped with receiver.

No.	Condition of Refrigerant	P_1	P_2	P_3	$P_{3'}$	T_1	T_2	T_3	$T_{3'}$	T_4	P_K
		[Bar]	[Bar]	[Bar]	[Bar]	[^{0}C]	[^{0}C]	[^{0}C]	[^{0}C]	[^{0}C]	[W]
1.	Normal	1	14.8	14.6	4.8	-20	63	34	0	-26	530
2.	Less	1.6	15.0	14.8	1.8	11	82	36	-25	3	515
3.	More	4	19.2	19.0	19.0	-2	40	34	30	-6	623

Annotation: The measurement data was collected when the freezer has been operating for 30 minutes.

P_1 = Refrigerant pressure at compressor inlet [Bar]
P_2 = Refrigerant pressure at compressor outlet [Bar]
P_3 = Refrigerant pressure at condenser outlet [Bar]
$P_{3'}$ = Refrigerant pressure at receiver outlet [Bar]
T_1 = Refrigerant temperature at compressor inlet [^{0}C]
T_2 = Refrigerant temperature at compressor outlet [^{0}C]
T_3 = Refrigerant temperature at condenser outlet [^{0}C]
$T_{3'}$ = Refrigerant temperature at receiver outlet [^{0}C]
T_4 = Refrigerant temperature at evaporator inlet [^{0}C]
T_5 = Temperature of product (water-ice) [^{0}C]
P_K = Real electrical power driving the compressor [W]

The measurement data in Table 2 is plotted in a R-404A p-h diagram by Coolpack © and then is analyzed based on equations. The results as diagram are shown in Figure 3 and 4.

Figure 3 (a) shows that a p-h diagram of refrigeration system filled with refrigerant with a mass conforms to standard (the augment of refrigerant mass is as much as 20% to 80% of receiver tank volume) results in lower temperature at the evaporator that provides higher refrigeration capacity (q_{RE}). Figure 3 (b) indicates that a p-h diagram of refrigeration system filled with refrigerant with a mass less than standard produces lower outlet receiver refrigerant temperature and pressure resulting in lower refrigeration capacity (q_{RE}). Meanwhile, Figure 3 (c) points out that a p-h diagram of refrigeration system filled with refrigerant with a mass more than standard produces compression of saturated gas resulting in greater compressor work (electrical power driving the compressor).

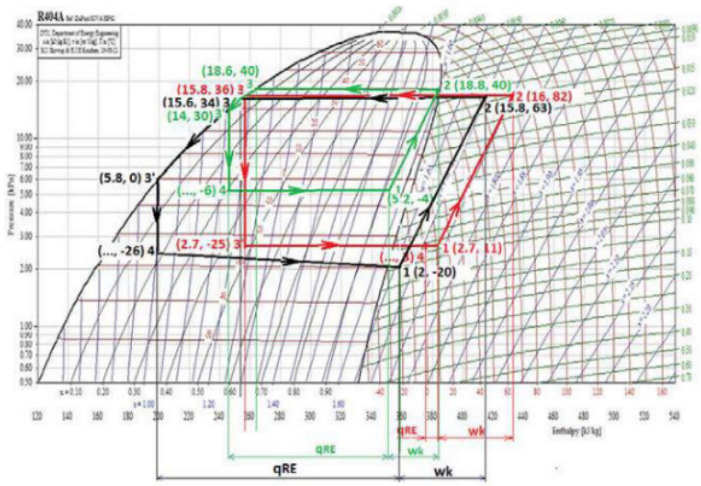
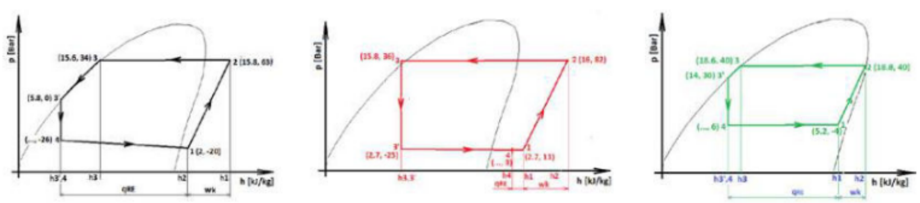


Figure 3. P-h diagram of R-404A taken from EES software as a result of plotting data in Table 2.



(a) (b) (c)

Figure 4. P-h diagram of R-404A in a freezer with various masses of refrigerant: (a) normal, (b) less, and (c) more

Table 3 provides refrigerant enthalpy on each measuring point plotted in p-h diagram. The results of compressor work, COP, and refrigeration effect analyzed using equation 1 to 5 are shown in the same table. The table indicates that freezer with normal mass of refrigerant in the system has higher refrigeration effect (q_{RE}) and COP.

Table 3. The analysis result of COP, compressor work, and effect cooling the refrigeration system

No.	The mass of refrigerant in the system	h_1	h_2	h_3	$h_{3'}$	h_4	w_K	q_{RE}	COP
		[kJ.kg^{-1}]					[kJ.kg^{-1}]		-
1.	Normal	358	414	255	198	198	46	160	3,48
2.	Less	384	433	356	356	375	49	9	0,18
3.	More	351	385	264	245	245	34	106	3,12

4. Conclusion and Recommendation

If the mass of refrigerant conforms to the standard when it is filled into the freezer equipped with receiver, it will increase the Coefficient Of Performance (COP). The freezer filled with refrigerant with a mass conforms to the standard has COP of 3.48 and electrical power of 530 W. Meanwhile, the freezer filled with refrigerant with less and more mass than the standard has COP of 0.18 & 3.12 and electrical power of 515 W & 623 W, respectively.

When filling refrigerant into a freezer equipped with a receiver, notice that the mass of the refrigerant must be 80% of the tank volume.

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