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THERMAL PERFORMANCE EVALUATION OF THE VARIATION OF CONDENSER DIMENSIONS FOR FOODSTUFFS TRANSPORTATION COOLING SYSTEMS

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Abstract. The process of sending food using transportation requires a refrigeration system to keep the product fresh. Unsuitable temperatures will cause the transported products to often experience damage so that they are rejected in the mark. To achieve this, it is done through testing using a condenser with several variations of dimensions for a room temperature of 5^{o}C. The dimensions of condenser-1 are (W 23 x H 14) inch^2 x 19 mm, condenser-2 is (W 23 x H 14) inch^2 x 26 mm, and condenser-3 is (W 23 x H 14) inch^2 x 44 mm. The test results show that condenser-3 produces a faster cooling time compared to condenser-2 and condenser-1. Cooling time for condenser-3 is 1160 minutes, while condenser-2 and condenser-1 are 1560 minutes and 1860 minutes, respectively. Condenser-3 provides the lowest compression work of 42.131 kJ/kg compared to condensers 2 and 1, respectively 42.931 kJ/kg, and 46.147 kJ/kg. This has an impact on the COP value, namely condenser-3, condenser-2, and condenser-1 each of 3.437, 3.233, and 2.845. COP at condenser-3 occurs the highest. These results indicate that the largest condenser dimension gives the most optimum thermal performance results. An efficient refrigeration system has low compression work and high COP.

Keywords: condenser, thermal performance, refrigeration system, coefficient of performance.

1. INTRODUCTION

The development and application of the refrigeration system on transportation equipment have increased very rapidly. The number of transportations equipped with cooling systems aims to freshen the room air and increase comfort. Refrigeration systems are also widely applied to the preservation of food, beverages, fresh meat, ice cream, etc. This type of business requires transportation with a cooling system unit that can maintain product temperature and quality. The use of this transportation is necessary for the delivery of food from one place to another so that the quality is maintained. Inappropriate temperatures will cause products transported utilizing transportation to be damaged. This has an impact on the product or item being rejected in the market.

Cooling food aims to lower the temperature to inhibit the growth of microorganisms. It can prevent food from rotting and stale. The process of cooling food, especially those sent between places or regions, requires transportation equipped with a refrigeration system. The refrigeration system in transportation uses the vapor compression cycle. This cycle is the most widely used for refrigeration and air conditioning. Refrigeration is the process of transferring heat from a lower temperature to a higher temperature. Several studies on the application of vapor compression refrigeration systems related to foodstuffs include fishing boats; a refrigerator; a cold box for eggplant, cucumber, tomato, and beer [1][2][3]. The principle of vapor compression refrigeration consists of four main components that are interconnected, namely the compressor, condenser, expansion valve, and evaporator. The cooling fluid is called refrigerant which circulates in the refrigeration unit to absorb room heat and release it into the environment. This process of absorption and release of heat occurs due to the temperature difference between the air and the refrigerant. So the condition of the refrigerant will affect the performance of the cooling system itself. The ideal vapor-compression refrigeration cycle is shown in Figure 1.

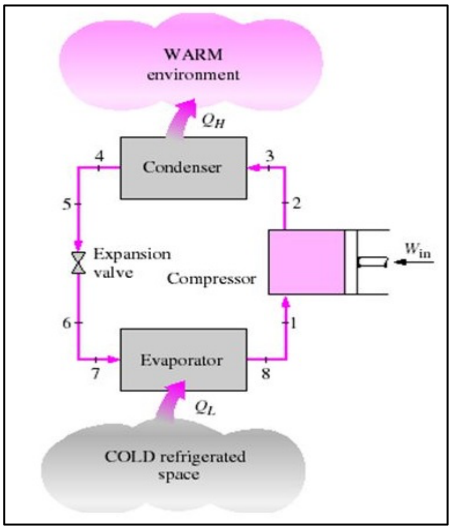

Figure 1. Ideal vapor-compression refrigeration cycle [4]

The compressor functions to suck the low-pressure refrigerant vapor that comes out of the evaporator. In the compressor, the pressure of the steam is increased so that it turns into superheated vapor. Superheated vapor flows into the condenser and undergoes a condensation process. This result is then followed to the expansion valve for the process of lowering the pressure to facilitate the evaporation process in the evaporator. The heat transfer process occurs in the evaporator and condenser. The evaporator absorbs heat from the cooling components and the heat is transferred to the condenser to be released into the environment. The condenser is an important component of the refrigeration system so a lot of research has been done regarding this component. Condensers are used to evaluate materials and refrigerants to analyze heat transfer processes; liquid smoke distillation apparatus through the cooling setting in the condenser [5][6]. The condenser is a heat exchanger unit that functions to condense a substance from a gaseous state to a liquid state [7]. The main function of the condenser is to receive steam from the compressor and condense it. The condenser is a very important component because it has a role in maximizing the efficiency of the refrigeration system.

The condenser is a heat exchanger with the type commonly used is shell and tube. A heat exchanger is the implementation of heat transfer between two fluids with different temperatures and is separated by walls and without mixing the fluids [8][9]. The fluid flow system in the condenser can be in the form of refrigerant in the pipe while gas outside the pipe or vice versa. The rate of heat transfer that occurs in the condenser is a function of the refrigeration capacity, evaporation temperature, and condensation temperature [10]. The condenser must be able to release the energy absorbed by the evaporator and the heat of compression provided by the compressor. In research [11] explained that the increase in the rate of heat release of the high stage condenser has an impact on increasing the coefficient of performance in the cascade system. The condenser is an important component of Air Conditioning (AC) which functions as a heat exchanger and the amount of heat generated by the condenser can affect comfort [12]. The distribution of refrigerant through the condenser has an impact on refrigerant mass, heat transfer, pressure drop, and temperature in each tube [13]. The refrigerant distributed to the condenser is most sensitive to operating conditions and the total refrigerant cost [14].

In connection with the above, the effect of adding condenser dimensions on the thermal performance of the transport refrigeration system will be studied for a room temperature of 5°C. By increasing the capacity of the condenser, it has implications for the process of releasing heat to the environment which affects the process of absorption of heat from the cooled space that occurs in the evaporator.

2. METHODS

The research uses materials in the form of refrigerant 134a (R134a) and refrigeration oil. The equipment used includes a manifold gauge, digital thermometer, digital tachometer, digital scale, vacuum machine, and three units of condenser dimensions (W 23 x H 14) inch^2 with a thickness of 19 mm (condenser-1), 26 mm (condenser-2), and 44 mm (condenser-3). The research was carried out on a truck refrigerator unit installed on a transportation device with a vapor compression system. Experiments using R134a cooling fluid were carried out for a constant room temperature of 5°C and a constant refrigeration load of 2,000 Watt. The variables measured in this study were the refrigerant pressure and temperature at the compressor suction pipe (P_1 and T_1), the refrigerant pressure at the condenser inlet (P_2 and T_2), and the refrigerant temperature at the condenser outlet pipe (T_3). The research scheme is shown in Figure 2.

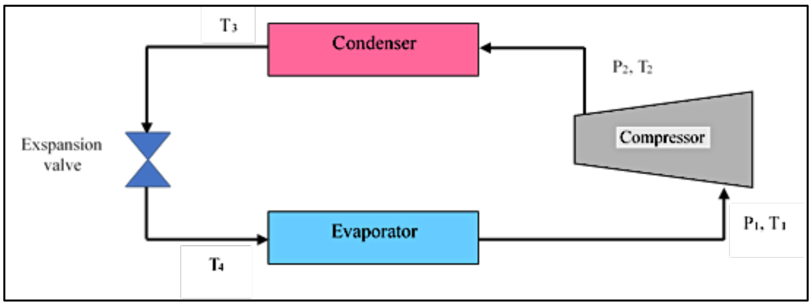

Figure 2. Schematic of research data measurement

The calculation uses the average value of each repetition and is converted from units of measurement to absolute units with the following Equation.

$$P_{abs} = P_{gauge} + P_{atm} \tag{1}$$

P_{abs} is absolute pressure (kPa), P_{gauge} is measurement pressure (Psig), and P_{atm} is atmospheric pressure (kPa) = 101.325 kPa. After obtaining the absolute average pressure, then look for the average temperature value on each digital thermometer. After the pressure and temperature values are obtained, the enthalpy can be found at each point by using table R134a. From the enthalpy value, thermal performance is calculated based on compression work (W_c), mass flow rate ($\dot{m}$), refrigeration effect (q_r), and coefficient of performance (COP) as follows.

$$W_c = h_1 - h_2 \tag{2}$$

W_c is the work of compression (kJ/kg), ($\dot{m}$)is the mass flow rate (kg/s), h_1 is the initial enthalpy of compression (kJ/kg), and h_2 is the final enthalpy of compression (kJ/kg).

Refrigeration effect (q_r) is the heat absorbed in the evaporator in processes 4-1 as shown in Equation 3.

$$q_r = h_1 - h_4 \tag{3}$$

q_r is the refrigeration effect (kJ/kg), h_1 is the initial enthalpy of compression (kJ/kg), and h_4 is the final enthalpy of expansion (kJ/kg).

The coefficient of performance (COP) of a standard vapor compression cycle is the refrigeration effect divided by the compression work.

$$COP = \frac{q_r}{W_c} = \frac{h_1 - h_4}{h_2 - h_1} \tag{4}$$

3. RESULTS AND DISCUSSION

The dimensions of the condenser influence the time of cold as shown in Figure 3.

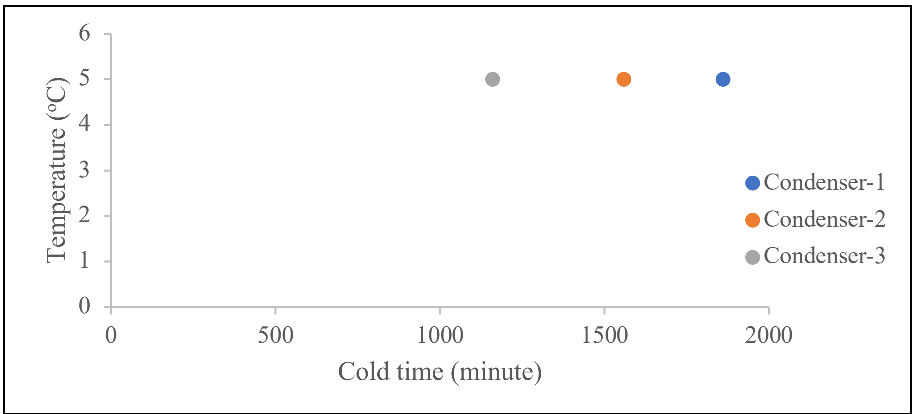

Figure 3. Distribution of cold time at a temperature of 5°C

Condenser-3 with dimensions (W 23 x H 14) inch^2 x 44 mm has a faster cooling time compared to condenser-2 (W 23 x H 14) inch^2 x 23 mm and condenser-1 (W 23 x H 14) inch^2 x 19 mm. Cooling time for condenser-3 is 1,160 minutes, while condenser-2 and condenser-1 are 1,560 minutes and 1,860 minutes, respectively. Faster cool downtime as a result of lower pressure on condenser-3 so compressor work is also lower. The lower the compressor work causes the amount of heat released (q_{out}) by condenser-3 to be greater than that of condensers-2 and 1. The lower the temperature conditioned by each condenser dimension, the longer it takes to cool down. This affects the heat transferred or absorbed by the evaporator is getting bigger.

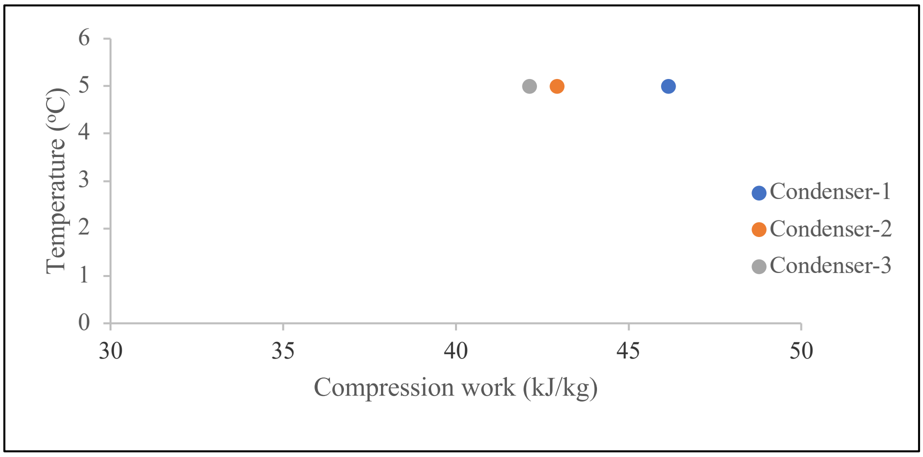

Figure 4. Distribution of compression work at a temperature of 5°C

The dimensions of the condenser affect the compression work which has an impact on the room temperature. The relationship between compression work and room temperature is shown in Figure 4. At room temperature 5°C shows that the lowest compression work occurs in the condenser with the largest dimensions (condenser-3). While the highest compression work occurs at the smallest condenser dimension (condenser-1). Condenser-3, condenser-2, and condenser-1 have compression work of 42.131 kJ/kg, 42.931 kJ/kg, and 46.147 kJ/kg, respectively. This condition is caused because the compressor outlet pressure is inversely proportional to the dimensions of the condenser. The larger the dimension of the condenser, the lower the compressor outlet pressure.

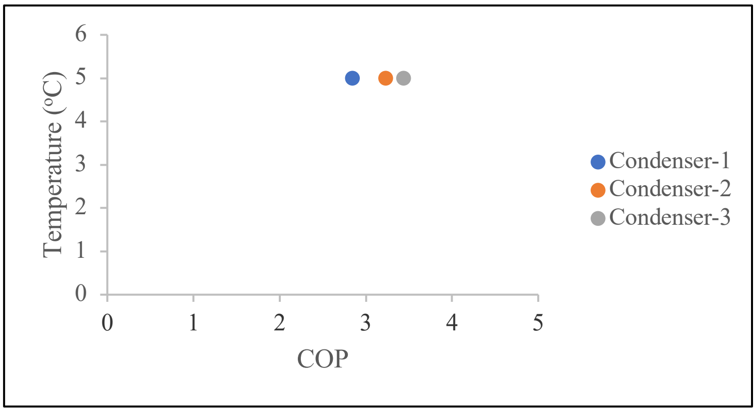

Figure 5. Distribution of coefficient of performance (COP) at a temperature of 5°C

Figure 5 shows the relationship between 5°C room temperature and the coefficient of performance (COP). Condenser-3 has a higher COP value than condenser-2 and 1. This is because the compression work on the cooling system influences the COP. The lower compression work has an impact on the higher COP, and vice versa. The lowest compression work occurs in condenser-3 as shown in Figure 4. COP on condenser-3, condenser-2, and condenser-1 were 3.437 each, 3.233, and 2.845. COP is inversely proportional to the work of compression and directly proportional to the dimensions of the condenser. Compression work affects the COP as shown in Figure 6.

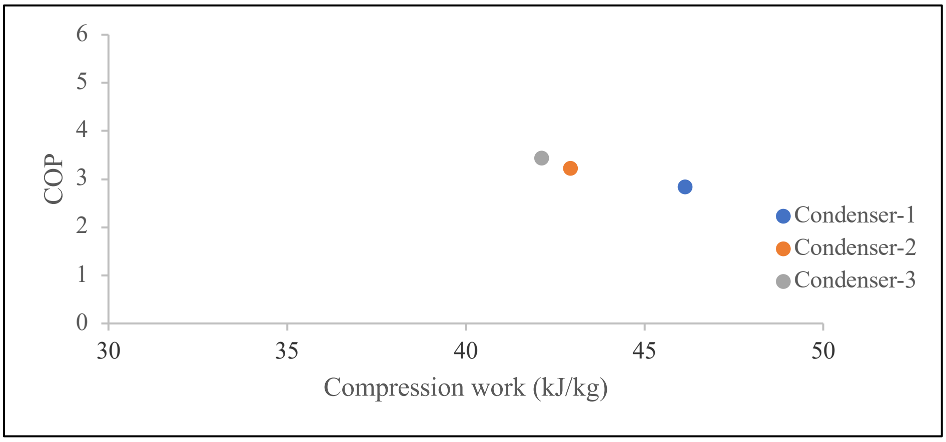

Figure 6. Relationship coefficient of performance (COP) with compression work at a temperature of 5ºC

The lower the compression work, the higher the COP. This occurs in the use of condenser-3 for the refrigeration system. Compression work required for refrigeration is inversely proportional to COP. An efficient refrigeration system has low compression work and high COP. The results of this study are in line with [15] that the longer the condenser causes the more effective heat transfer because the fluid mechanism process is getting shorter to return the fluid from the condenser to the evaporator.

4. CONCLUSION

Refrigeration systems are important for food preservation in the process of storage and shipping. In this study, an evaluation of the thermal performance of the use of condenser dimensions for the transportation refrigeration system was carried out. The largest condenser dimension provides optimum thermal performance. This can be seen from the results of the study, namely, the largest condenser dimension produces the lowest compression work, faster cooling time, and higher COP.

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