FLYWHEEL: JURNAL TEKNIK MESIN UNTIRTA

Cooling System Performance Comparison of Refrigerant R-134a and MC-134 on Ice Slush Machine

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ABSTRACT

Ice Slush Machine uses a direct cooling vapor compression system. The primary refrigerant used in such a system mostly is hydrofluorocarbons (HFCs), such as R134a. R134a is a retrofit for refrigerant R-12 which is included in the chlorofluorocarbon (CFC) type of refrigerant. CFC-type refrigerants have a dangerous impact on the environment. Hydrocarbon refrigerant MC-134 is an alternative for R-134a because it has a low potential value for environmental damage. The secondary refrigerant used was propylene glycol and the product used was 3.5 liters of Coca-Cola. From the test results when the system using R134a had an average COP_{actual} and an average COP_{carnot} of 2.6 and 4.55, respectively, and the energy consumption was 1.571 kWh with an average efficiency of 57%, while in a system with MC-hydrocarbon refrigerant 134 obtained an average COP_{actual} and an average COP_{carnot} of 2.8 and 4.5, respectively and the energy consumption of 1.325 kWh with an average efficiency of 62%. Therefore, MC-134a had COP actual greater than R-134 and electrical energy consumption of MC-134 was less than R-134a.

Keywords: *R134a, MC 134a, Ice Slush Machine, Energy Conservation, Efficiency*

1. INTRODUCTION

Science and technology growth is rapidly developing, including in the field of refrigeration. The Ice Slush cooling process uses a vapor compression system with the brine cooling method in the cooling process [1,2].

The refrigerants used in this system are generally hydrofluorocarbon (HFCs), such as R-134a. Meanwhile, the secondary refrigerant that is often used is propylene glycol. R134a is a refrigerant that is often used in refrigeration systems because of its good performance as a medium for conducting heat. However, R134a is included in the hydrofluorocarbons (HFCs). R134a itself is an alternative refrigerant to replace R12, which is included in the chlorofluorocarbons (CFC) refrigerant [3–5]. Because refrigerants in the CFC class have an impact on the environment values,

R12 refrigerant is replaced by R134a. As an alternative to CFC and HFC refrigerants in the refrigeration system, hydrocarbon refrigerants are being used [1–3][6,7].

MC-134 is one of the refrigerants made by PT. PERTAMINA [5] with hydrocarbon as an alternative to R134a, MC-134 is derived from a mixture of propane (R290) and isobutane or R600a [8]. Apart from being environmentally friendly, MC-134 also has a good potential as a substitute for R134a. The refrigerant had supported by Indonesia's Law No. 16 of 2016. This is an affirmation of Indonesia's participation in reducing the effects of climate change and global warming [1–3,6,7].

2. METHODOLOGY

2.1 Experimental set up

The setup of the experiment is shown in Figure 1. The main components of the system were compressor, condenser, evaporator, and capillary tube. The tools used were ice slush machines with a vapor compression system and the cooling method was brine cooling [8]. The system used a capillary tube as an expansion tool.

The process started with leak tests, vacuum, and charging. These steps can be simplified into one step called tools set-up. Nitrogen was filled to check for leaks in the system. After the system was confirmed that there were no leaks, the next step was the vacuuming process [9]. Then the R-134a refrigerant was charged into the system. The data collection process was done afterward. When the data collection process did not experience problems such as the pump was not running, it was continued with data processing. After that, the R-134a was removed and the vacuum process was carried out. Then the MC-134 refrigerant was charged. Then the data collection process was done. The analysis of the results was conducted.
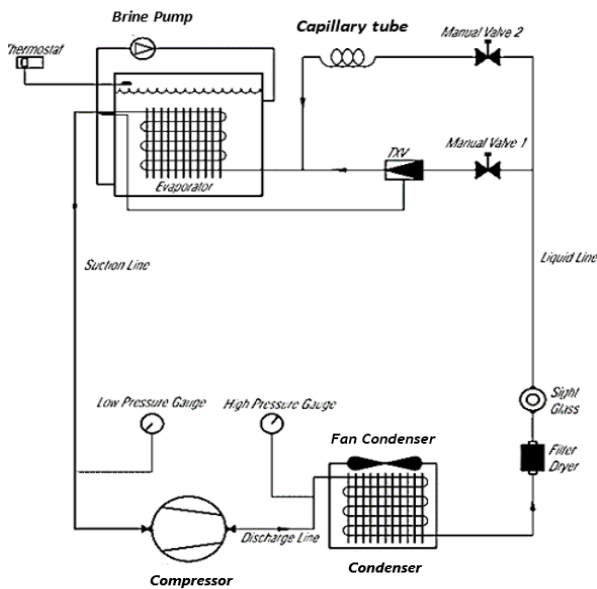

Figure 1. Experimental setup.

Tabel 1. Material Used [10]

Material	Quantity
R134a	400 gram
MC-134	160 gram
Propylene Glycol	4,8 liter
Water	11,2 liter
Coca Cola	3,5 liter

R134a was used as the primary refrigerant and then replaced by MC-134 with a weight of 40% of the mass of R134a. The secondary refrigerant was a mixture of 30% propylene glycol and 70% water. The materials for the ice slush machine with coca-cola products with its amounts are shown in Table 1.

2.2 Tools and equipment

Observation of the tools was used before performing a performance test of the performance comparison of the ice slush machine. The following are the specifications of the tools:

- Compressor : Vasco LT91 ¼ PK
- Condenser : Dragon-type water cooled
- Expansion device : Capillary tube 1.73 m long and 0.031 in diameter
- Primary refrigerants : R134a and MC-134
- Secondary refrigerant : Propylene Glycol
- Pressure Gauge : Royal High-Pressure Gauge (0-500 psi) and Royal Low-Pressure Gauge (0-350 psi)
- Thermostat : Elite STC-200 range -40 °C - 70 °C
- Ammeter : FORT FT-45 range 0-20 A
- Voltmeter : FORT FT-45 range 0-500V

2.3 Procedure

The basic principle of work on this ice slush machine is the same as the vapor compression refrigeration system in general, the only difference lies in the use of secondary refrigerants as a medium for auxiliary absorption of heat [11].

Before the compressor works, the pump was first turned on so that the brine was evenly mixed. After a few minutes the pump started up, the next step was to turn on the compressor. The compressor pressed the vapor phase refrigerant so that the refrigerant was pressurized and had a high temperature. After that, the refrigerant flowed into the condenser where the heat was to be removed into the environment assisted by the condenser fan. The refrigerant, which was originally a vapor, changed its phase to liquid.

The liquid refrigerant flowed into the expansion device. In the expansion device, the refrigerant was lowered in pressure. The refrigerant phase then turned into a mixture. After that, the refrigerant went to the evaporator. In the evaporator the primary refrigerant absorbed the heat of the brine,

then the brine circulated using a pump and absorbed heat from the cabin. During the absorption of heat in the evaporator, the primary refrigerant phase changed into a mixture of vapor and flowed back into the compressor so that the refrigeration cycle occurred [12].

3. RESULTS AND DISCUSSION
3.1 Data Measurement
The time used for each data collection was 360 minutes. The data for calculating the ice slush machine used the average data when the product temperature was reached and before the system was turned off. The data can be seen in Table 2.

Table 2. Measurement data [10]

No.	Measurement Point	R134a	MC-134	Unit
1	Pressure *Discharge*	12,4	11,3	Bar
2	Pressure *Suction*	1,2	1	Bar
3	Temperature *Discharge*	68,2	66	℃
4	Temperature *Suction*	-3,2	-3,05	℃
5	T out kondenser	34,4	28,9	℃

3.1.1 Calculation of the measurement data of R-134a
The measurement data in Table 1 was the measured data on the measuring instrument, while the data needed to plot the P-h diagram must be absolute pressure. Therefore, to get absolute pressure 1 bar must be added. The following are the results of the data that will be plotted on the P-h diagram:

Discharge pressure	: 13.4 Bar absolute
Suction pressure	: 2,2 Bar absolute
Discharge temperature	: 71.2 ℃
Suction temperature	: -6.2 ℃
Condenser outlet temperature	: 37.4 ℃

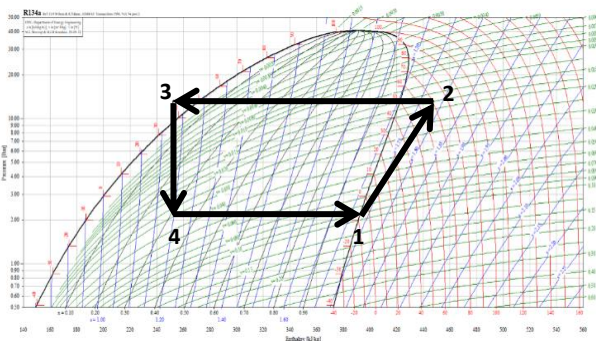After that, the P-h diagram was plot on the cool pack software [13], which is shown in Figure 2.

Figure 2. P-h R134a diagram [13].

Based on Figure 2, from software get the value :

h_1 = 393.9 kJ/kg
h_2 = 447.8 kJ/kg
h_3 = h4 = 252.2 kJ/kg
Tc = 50.67 ℃ = 50.67 + 273.15 = 323.8 K.
Te = -7.65 ℃ = -7.65 + 273.15 = 265.5 K.

By using this enthalpy value, the actual COP can be calculated, following [14]:

COPa = (393,9-252,2) / (447,8-393,9)
COPa = 2.62

After that, determine the COP$_{Carnot}$ using the condensation temperature and the evaporation temperature, so :

COPc = 265.5 / (323.8-265.5)
COPc = 4.55

After knowing the actual COP and COP$_{Carnot}$ values, and then calculate the system efficiency value, so :

η = 2,6 / 4,55 x 100
η = 0.57 x 100 = 57% (efficiency)

3.1.2 Calculation of MC-134 measurement data
The absolute pressure value and the refrigerant temperature were calculated using the same way as in the measurement data R134a. The following are the results of the data that will be plotted on the P-h diagram:

Discharge pressure	: 12.3 Bar absolute
Suction pressure	: 2 Bar absolute
Discharge temperature	: 69 ℃
Suction temperature	: -6.05 ℃
Condenser outlet temperature	: 31.9 ℃

The P-h diagram is shown in Figure 3;

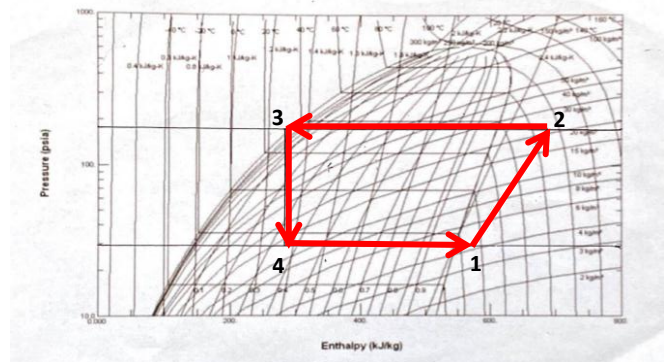**Figure 3.** P-h diagram of MC-134, time = 155 minutes.

Based on Figure 3, from software the following value was gained:

h_1 = 575.0 kJ/kg
h_2 = 679.1 kJ/kg
h_3 = h4 = 283.3 kJ/kg
Tc = 33.8 ^{o}C = 33.8 + 273.15 = 306.95 K
Te = -22 ^{o}C = -22 + 273.15 = 251.15 K

Tc is the value of the condensation temperature at the saturated liquid point when the system is in an ideal cycle, while Te is the value of the evaporation temperature at the saturated vapor point when the system is in an ideal cycle.

By using the enthalpy value obtained from the P-h diagram image, so the actual COP can be calculated :

COPa = (575-283,3) / (679.1-575)
COPa = 2.8

After that, determine the COP_{Carnot} using condensation temperature (Tc) data and evaporation temperature (Te), following :

COPc = (251.15) / (306.95 -251.15)
COPc = 4.5

After knowing the actual COP and COP_{Carnot} values, the system efficiency value, here:

η = 2.8 / 4.5 x 100
η = 0.62 x 100 = 62 (efficiency)

3.1.3 COP Analysis

The measurement data used for the calculation of COP on the ice slush machine used the system average data when the product temperature was reached and before the system was turned off, COP measurement data can be seen in Figure 4.
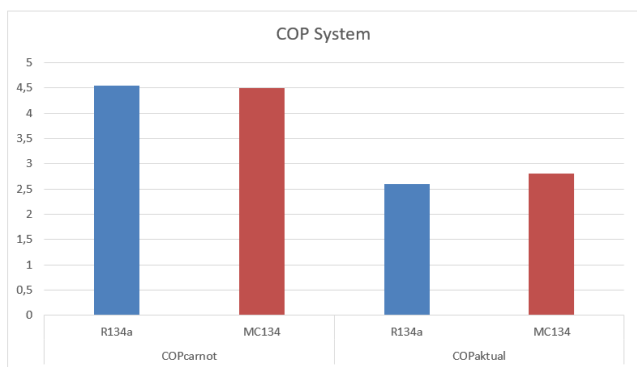

Figure 4. Comparison of COP Systems.

In Figure 4, it can be seen that the COP_{Carnot} in both systems has a COP value greater than the actual COP due to several factors. Factors that can affect the actual COP value are the effect of refrigeration and compressor work [15]. In systems with the primary refrigerant R134a, the average COP-actual value is 2.6 and COP_{Carnot} 4.55. While the primary refrigerant system MC-134 obtained a COP actual value of 2.8 and COP_{Carnot} of 4.5. The graph above shows that the system with MC-134 primary refrigerant has a greater COP actual value than the system with R134a refrigerant [16].

3.1.4 Efficiency Analysis

The measurement data used to calculate the efficiency of the ice slush machine used the system average data when the product temperature was reached and before the system was turned off. Efficiency measurement data can be seen in graph Figure 5.
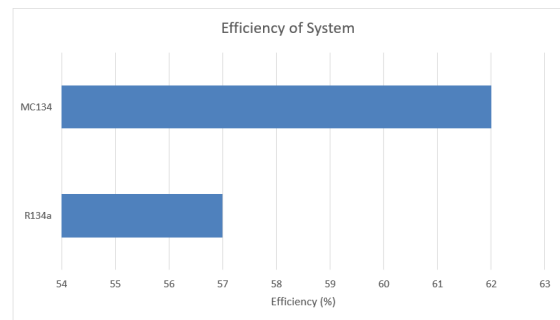

Figure 5. Comparison of system efficiency.

From graph Figure 5 above, it can be seen that the efficiency values in the two systems have different values. The system using the primary refrigerant R134a has an efficiency value of 57%, while the system with the primary refrigerant MC-134 has an efficiency value of 62%. This shows that the system with the primary refrigerant MC-134 has a better efficiency value than the system using the primary refrigerant R134a [17].

3.1.5 Current versus time (analysis)

The results of data collection of electric current against time is shown by the Figure 6.
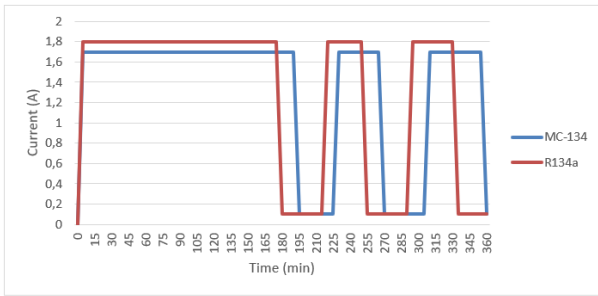
Figure 6. Comparison chart of system flow (current).

Figure 6 is a graph of the measured flow in the system. Compressor work greatly affects the electric current. The heavier the compressor works, the greater the current required [18].

In the graph above, it can be seen that systems using MC-134 primary refrigerant require a slightly smaller current than systems with primary refrigerant R134a, this is because the mass of MC-134 refrigerant is lighter than R134a so that the compressor works lighter when operating. In the graph above, the flow has decreased significantly, this is because the compressor has been cut off and the current will return to normal when the compressor is cut-in [19].

3.1.6 Time Analysis of Energy Consumption
The results of taking current and voltage data can be calculated using the formula as follows:

1. Based on data collection, the system used R134a refrigerant obtained an average voltage of 220 V, an average current of 1.8 A, an average cos phi of 0.85 (source from PLN), and a long system on for 280 minutes. The total energy consumption is [14]:

   E   = Power x time
       = V x I x cos phi x (running time / 60)
       = 220 x 1.8 x 0.85 x (280/60)
       = 1,5708 ≈ 1,571 kWh

2. Based on data collection, the system used MC-134 refrigerant obtained a voltage of 220 V, a current of 1.7 A, an average cos phi is 0.85, and a system time of 250 minutes. The total energy consumption is:

   E   = Power x time
       = V x I x cos phi x (running time / 60)
       = 220 x 1.7 x 0.85 x (250/60)
       = 1,3246 ≈ 1,325 kWh

From the results above, the electrical energy needed by the system with refrigerant R134a is 1.571 kWh, while the system with refrigerant MC-134 is 1.325 kWh. This shows that the system with MC-134 refrigerant is 16% more energy efficient than the system with R134a refrigerant [20,21].

4. CONCLUSION
From the results, the system using R-134a has an average COP_{actual} and an average COP_{Carnot} of 2.6 and 4,55 respectively, then the energy consumption is 1.571 kWh with an average efficiency of 57%, compared to the system with MC hydrocarbon refrigerant 134 which has an average COP_{actual} and an average COP_{Carnot} of 2.8 and 4.5 and energy consumption of 1.325 kWh with an average efficiency of 62%. Therefore, in terms of efficiency, COP, and electrical energy consumption, the MC-134 are better than R-134a.

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