Performance and Energy Consumption Analysis of Freezer Machines for Mobile Ice Cream Sellers using Eco-friendly Refrigerant MC134

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Abstract: Ice cream is widely sold by mobile ice-cream sellers. This study aims to determine the performance and energy consumption of a freezer machine for mobile ice-cream sellers using environmentally friendly refrigerant MC134 with a compressor capacity of 1/10 HP. This research was conducted using an experimental method. The size of the capillary tube using the Cap Tube 1.0.8.0 application program. The evaporator used is a bare tube type that is formed by a coil and wrapped around an ice cream box. The test is carried out by measuring the refrigerant temperature and pressure, the temperature in the ice cream box, and the electric current and voltage in the system. The results of the analysis of performance and energy consumption will also be compared if the system uses HFC134a refrigerant. From the test results, it was found that the optimum mass loaded in the system for refrigerant MC134 was 155 grams and the optimum mass for R-134a was 202 grams. The use of refrigerant MC134 is more efficient by 23.3%. The COP for MC134 refrigerant is 3.1 while the COP for R134a is 2.7. Energy consumption for MC134 is 83 kJ while for R134a it is 67.8 kJ.

1 INTRODUCTION

Ice cream is a frozen form of ice that is made by freezing a mixture of dairy products, sugar, stabilizers, emulsifiers, and other ingredients. Ice cream food is often used as a dessert. Ice cream is no stranger to all ages because almost everyone likes ice cream. To keep the ice cream cold and frozen, the mobile ice cream seller uses shaved ice cubes which are then placed around the ice cream container. But now, blue ice or ice packs have started to be used to keep the ice cream sold around cold and frozen. However, the material used as a cooler over time will certainly decrease in temperature so that the ice cream temperature will also drop.

Therefore, it is necessary to use refrigeration technology to keep the ice cream condition stable, namely using a refrigeration machine such as a freezer. Conventional refrigeration machines use a vapor-compression refrigeration cycle. The use of conventional refrigerants that have an impact on ozone depletion and global warming should no longer be produced.

The world today is looking for refrigerants that do not contribute to global warming and ozone layer depletion. Baharudin (2018) conducted a performance test on a fruit showcase machine using R134a and MC134 working fluids. From the test results, it is concluded that with R134a the actual COP = 2,528,

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and by using MC134, the actual COP = 2,710. (BC Purnomo et al., 2019) conducted a study of double expansion valves installed in parallel machines with vapor compression refrigeration cycles using MC134 by varying the cooling load 0.23; 0.33; and 0.39 kg/s and was observed while the system was operating to steady conditions, giving a positive effect on the refrigeration effect and COP. The highest refrigeration effect produced was 257 KJ/kg and COP was 5.84. In his previous research (BC Purnomo et al. (2017) concluded that the use of MC134 has the best refrigeration system performance -180º expansion valve adjustment where in that position has a low compression work value so that the compressor work becomes light and does not require a large amount of energy when operating.

Small-scale refrigeration machines such as freezers and refrigerators currently still use R134a refrigerant. This type of refrigerant belongs to the HFC group with a high global warming potential (GWP) of 1300 (DV Raghunatha Reddy et al, 2016). The study was conducted to determine the effect of evaporation temperature on the performance of air conditioning machines using R134a and MC134 refrigerants at optimal refrigerant filling pressure. The result showed that the optimal filling pressure for R134a is 20 bar-g, and for MC134 is 25 bar-g. Based on the parameters, the effect of refrigeration increased by 106.43%, compressor work increased by 70.22%, compressor power decreased by 12.64%, electrical energy consumption decreased by 14.69%, and COP increased by 21.37% for MC134 when compared to R134a (Hendri et al, 2014).

Heriyanto Rusmariyadi et al, 2019 in their research on a comparative study of the performance of the 1/5 PK freezer with R-134a and "Musicool" (MC134) concluded that the retrofit from R-134a to Musicool MC-134 is very feasible and feasible to use without changing the supporting components of the system. His research also resulted in a much faster decrease in temperature than R-134a, which was 30% faster for a setpoint temperature of -18ºC. Hydrocarbon refrigerant (HC) has better performance than refrigerants from the HCFC and HFC groups. In the European Union (EU), HFCs are currently being discontinued due to their high GWP values (J.H. Koh et al, 2017).

Hydrocarbon refrigerants have good potential to completely replace HCFCs as refrigerants in the future because their performance is in line with those of HCFC refrigerants and the flammability problem can be overcome by the use of effective designs and improved safety. (Junghung Koh et al, 2017). The use of natural refrigerants such as CO2, NH3, and hydrocarbons such as R290, R600, R600a, and hydrocarbon mixtures are possible solutions for conventional refrigerants and are used efficiently in many systems. (Madhu Sruthi Emani, et al, 2018). Natural refrigerants such as hydrocarbons are a new alternative to conventional CFC, HCFC, and HFC refrigerants (Parashurama S.C. Et al, 2019).

One type of hydrocarbon refrigerant, produced by Pertamina Processing Unit III in collaboration with the Research & Laboratory Processing Division of the Pertamina Downstream Directorate Head Office is Musicool 134 (Puji Saksono, Gunawan, 2019). Musicool 134 which is abbreviated as MC134 is a refrigerant replacement for R134a. Hydrocarbon refrigerant is an environmentally friendly refrigerant because it does not harm global warming or the depletion of the ozone layer. MC134 is a mixed hydrocarbon refrigerant between Propane (R290) and Iso Butane (R600).

The flammability of hydrocarbons requires a full understanding of their safe use in refrigerators (Rene Van Gerwen et al, 2008). The performance of hydrocarbons is very similar to that of HCFCs and the problem of flammability can be easily overcome by the use of an effective design. Its use can be facilitated by the adaptation of certain standards and properly enforced laws.

(Tatang Hidayat, 2019) conducted a study on the potential for obtaining electrical energy savings in refrigerators by converting from R-134a to MC134 hydrocarbons to be allocated in simple type houses. From the results of his research, it was concluded that the refrigerant conversion in the refrigerator from R-134a to MC134 could be obtained by saving 20% of electrical energy.

2 STUDY OF LITERATURE

2.1 Vapor Compression Refrigeration Cycle

This freezer machine for ice cream sellers uses a vapor-compression refrigeration cycle. The main components of the vapor-compression refrigeration cycle are the compressor, condenser, expansion device, and evaporator. The important performance parameters of the vapor compression refrigeration cycle are the coefficient of performance and energy consumption.

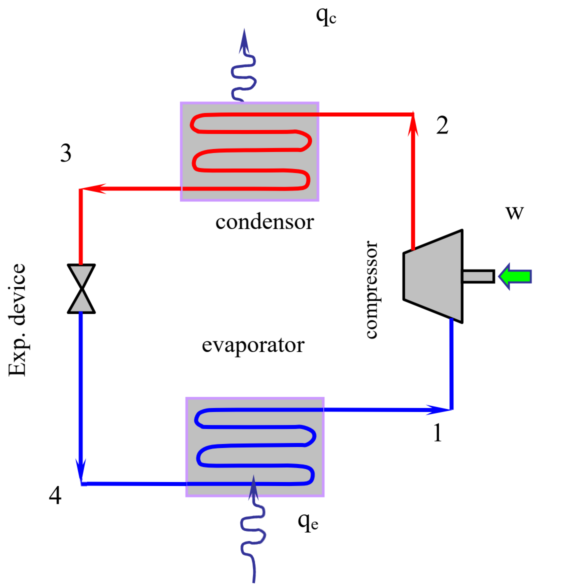


Figure 1: Work diagram of vapor compression refrigeration cycle.

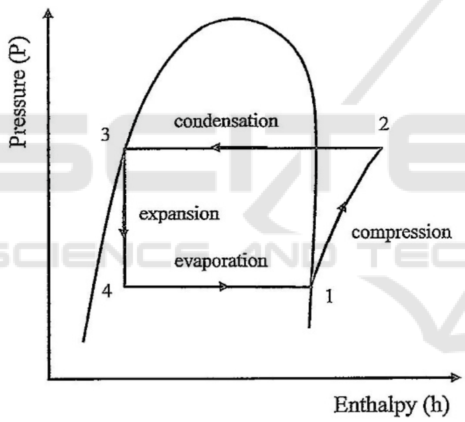


Figure 2: Pressure-enthalpy diagram of the vapor-compression refrigeration cycle.

2.1.1 Coefficient of Performance (COP)

The coefficient of performance is the amount of useful energy, namely the effect of refrigeration divided by the work required by the system, namely the work of compression. Mathematically, COP is expressed by the formula:

$$COP = (h_1 - h_4) / (h_2 - h_1) \qquad (1)$$

2.1.2 Energy Consumption (E)

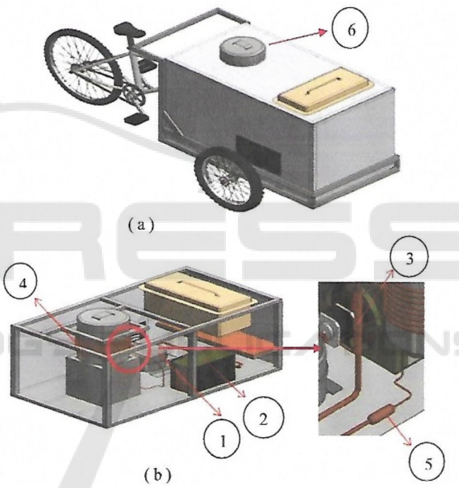
To calculate the energy consumption (E) is used the formula:

$$E = [(V \times I \times \cos \varphi) \times t\,] / 1000 \quad (kWh) \qquad (2)$$

3 RESEARCH METHODS

This research was carried out through an experimental test on a prototype mobile ice cream freezer designed with a compressor capacity of 1/10HP using R-134a, and MC134 refrigerant. The size of the capillary tube is determined using the Captube 1.0.8.0 application program where the diameter and length of the capillary tube are found to be 0.6096 mm in inside diameter, and 2,25 m long.

The evaporator used in this freezer has a heat transfer area of 0.47 m^2 with an outer diameter of 9.525 mm copper pipe, and a pipe length of 15.8 meters. The evaporator pipe is formed into a coil and wrapped around the outer wall of the ice cream box. Pressure and temperature were measured at 4 measurement points that were already installed on the prototype mobile ice cream freezer.



No	Parts
1	Compressor
2	Condensor
3	Capillary tube
4	Evaporator
5	Filter/dryer
6	Ice-cream box

Figure 3: Mobile ice cream freezer machine design.

For temperature, the measurements are added at 2 more points, namely in the middle of the evaporator, and in the middle of the condenser. Pressure is measured using an oil pressure gauge in Psi units. While the temperature is measured with a type K thermocouple which is connected to the temperature display in Celcius units. To determine the COP of R-134a, the Mollier Chart 1.2.0.3 application program will be used, while to determine the COP of MC-134 using the P-h diagram of MC134.

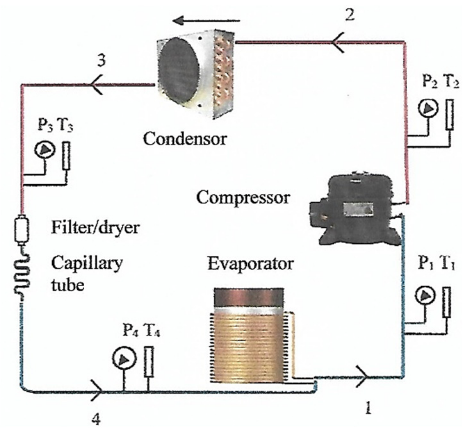


Figure 4: Piping diagram and measuring instrument set up.

Table 1: Technical specifications of mobile ice cream freezer machine.

1	Total measurement	
	(LongxWidexHeight)	(2250x100x112) mm
2	Condenser	
	Type	Finned-tube
	Outside diameter	9.525 mm
	Number of stages	7
	Number of rows	2
3	Compressor	
	Type	Hermetic
	Merk	Tecumseh
	Model	TH830JH-092-A6
	RLA	7.5
	FLA	0.7
	Refrigerant	R134a
	Voltage (V)	220
	Frequency (Hz)	50
4	Evaporator	
	Type	Coil
	Material	Copper
	Outside diameter	9.525 mm
	Length	15,8 m
5	Capillary Tube	
	Inside diameter	0,6096 mm
	Length	2,25 meter

4 RESULTS AND DISCUSSION

Because this MC134 hydrocarbon refrigerant is used as a substitute for R134a refrigerant, in addition to testing the MC134 hydrocarbon refrigerant, testing is also carried out on R-134a refrigerant. Both types of refrigerants were tested at the optimum refrigerant filling pressure.

From the testing of the two types of refrigerants on the freezer machine for mobile ice-cream sellers, the optimum mass of refrigerant HFC-134a filled into the system is 202 grams while the optimum mass for MC134 refrigerant is 155 grams. Judging from the mass of the refrigerant, the optimum mass of MC134 is equal to 76.7% of the optimum mass of HFC-134a. The test results in the form of system performance and energy consumption will be explained in the graph below.

4.1 Variation of COP and Cooling Time

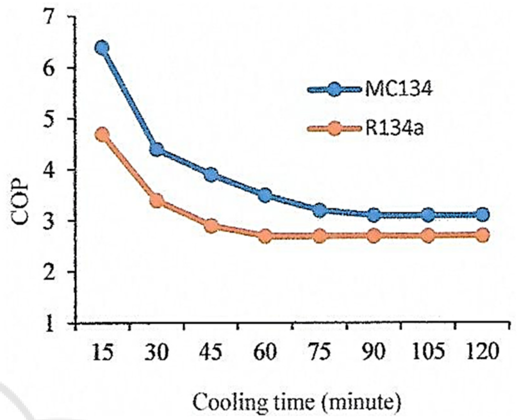


Figure 5: Variation of COP and cooling time.

From Fig. 5 above, it can be seen that the curves for R-134a and MC134 at the beginning of cooling the COP curve are larger. However, the longer the cooling time the COP curve decreases and tends to be constant after 60 minutes. This is because the longer the cooling time the evaporator temperature continues to decrease until it reaches a temperature of -19^{o}C. The average COP for R134a was 2.7 and the COP for MC134 was 3.1. The curves for R-134a and MC134 look identical, so it can be said that MC134 is very suitable to be used as a substitute for R-134a. This is also in line with research conducted by Heriyanto Rusmariyadi et al, 2019.

4.2 Variation of Electric Power and Cooling Time

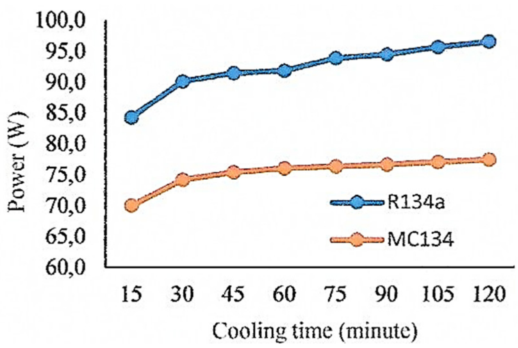


Figure 6: Variation of electric power and cooling time.

From Fig. 6 above, it can be seen that at the beginning of cooling the required power using refrigerant R-134a and MC134 is smaller. This is because the compression ratio is still small, but over time, with increasing cooling time, the power required tends to increase. Up to 75 minutes the increase in power has slowed down and tends to reach a constant value. The average power required by the compressor for R-134a is 92.2 W while for MC134 it is 75.3 W. So by using MC134 refrigerant the use of electrical power is 18.8% more efficient. The results of this study are in line with the results of research from various sources

4.3 Variation of Energy Consumption and Cooling Time

From Fig. 7 below, it can be seen that the curve of energy consumption and cooling time is identical to the curve of electric power with cooling time (fig. 6). This is because the calculation of energy consumption depends on the electrical power and the length of the test time. So the average energy consumption using refrigerant R-134a is 83 kJ while using refrigerant MC134 is 67.8 kJ.

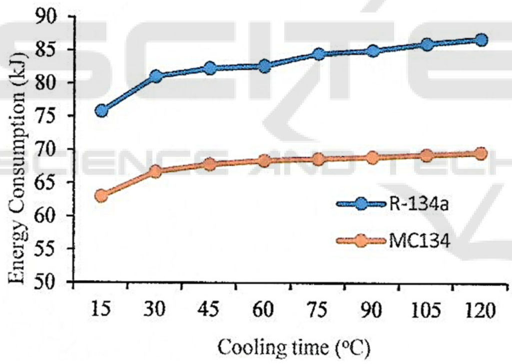


Figure 7: Variation of energy consumption and cooling time.

5 CONCLUSION

Hydrocarbon refrigerant is very appropriate to be used as a substitute for synthetic refrigerants such as HFC and HCFC because it has better performance and has no impact on global warming. Refrigerant MC134 which is filled into the system has a lower mass compared to R134a which is 23.3% smaller so that the compressor work is lower. COP of refrigerant MC134 is 3.1 while R134a is 2.7. Energy consumption of refrigerant MC134 is lower than R134a which is 28%. So refrigerant MC134 is very appropriate to be used as a replacement refrigerant from R134a.

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NOMENCLATURE

Cos φ power factor
E Energy consumption, kWh
h Enthalpy, kJ/kg
I Electrical current, Ampere
q Heat, kJ/kg
V Electrical voltage, Volt
w Work compression, kJ/kg

ABBREVIATION

C Degree Celcius
CFCs Chlorofluorocarbons
COP Coefficient of Performance
EU Europian Union
Exp Expansion
G Gauge
GWP Global Warming Potential
HCs Hydrocarbons
HCFCs Hydrochlorofluorocarbons
HFCs Hydrofluorocarbons
HP Horse Power
kJ Kilo-Joule
MC Musicool
P Pressure
Psi Pound per square inch
T Temperature
W Watt

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