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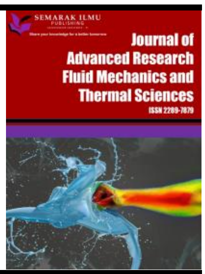


# The Use of Dimethyl Ether (DME) as a Substitute for R134a

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**ABSTRACT**

The usage of Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) is currently being phased out since both substances cause ozone depletion and global warming potential. Many investigations have been conducted in recent years to develop environmentally acceptable alternative refrigerants. Dimethyl ether (DME) is a good contender among the various alternative refrigerants because it has minimal ozone depletion potential (ODP) and global warming potential (GWP). The performance of dimethyl ether as an alternative refrigerant to R134a was evaluated in this study. This study compared the performance of a freezer while using R134a and when using dimethyl ether. The use of dimethyl ether was varied based on mass, namely 60 grams, 70 grams, and 80 grams, or in percentages as much as 40%, 46.7%, and 53.3% of the total mass if R134a. The results showed that using dimethyl ether instead of R134a improved freezer performance. Based on the mass variation, it was found that the chilling time using 80 grams of DME is almost the same as R134a. Even, the Energy Efficiency Ratio (EER) is higher than R134a. Therefore, R134a can be substituted by 53.3% mass of DME in a freezer.

## 1. Introduction

The usage of refrigeration systems in daily life is no longer unavoidable, hence the use of refrigerants tends to increase. Refrigerant has a significant impact on the performance of air conditioning and refrigeration systems as a heat transfer medium [1]. The world's most common refrigerants are chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). According to the Montreal Protocol, ozone-depleting refrigerants are phased out and replaced with ozone-friendly refrigerants [2,3]. HCFCs are still frequently utilized refrigerants in Indonesia. Although HCFCs are environmentally neutral in the sense that they cannot damage the ozone layer, they nonetheless contribute to global warming. R134a is an example of a regularly used HCFCs. R134a has a global warming potential (GWP) of 1300 but no ozone depletion potential (ODP) [4]. As a result, many studies have been conducted to identify suitable alternative refrigerants to substitute CFCs and HCFCs [5,6]. Other comparison of R134a and DME is listed in Table 1. According to this table, the heat

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capacity of dimethyl ether (DME) is more than twice than that of R134a. It also has a lower density, which mean that for the same volume of charging the system, it needs lower mass. Therefore, the mass circulated in the compressor is also lower.

**Table 1**
Characteristics of R134a and DME [7] (move to introduction)

| Characteristics | R134a | DME |
|---|---|---|
| Name | Tetrafluoroethane | Dimethyl ether |
| Chemical Formula | CF3CH2F | CH3OCH3 |
| ODP | 0 | 0 |
| GWP | 1430 | 1 |
| NBP [°C] | -26.1 | -24.8 |
| Molecular Mass [kg/mol] | 102,03 | 46,07 |
| Critical Temperature [°C] | 101,06 | 127,2 |
| Critical Pressure [kPa] | 4060 | 5340 |
| Liquid Density [kg/m³] at 25 °C | 1,206.7 | 661.4 |
| Vapor Density [kg/m³] at 25 °C | 32.35 | 12.44 |
| Laten Heat [kJ/kg] at -15 °C | 209.5 | 453.7 |

Gil and Kasperski [8] investigated the performance of the environmentally friendly such as R236ea, R236fa, R245ca, R245fa, R365mfc, and RC318. Antunes and Filho [9] studied the performance of hydrocarbon and hydrofluorocarbons refrigerant using R438A, R404A, R410A, R32, R290, and R1270. Several investigations on environmentally friendly refrigerants have also been conducted [10-12]. Devecioğlu [13] and Mariorino *et al.,* [14] investigated the application of low GWP refrigerants to replace R410A and R134a refrigerants. Bakeem *et al.,* [15], Lychnos and Tamainot-Telto [16], Kim *et al.,* [17], and Cheng *et al.,* [18] published the findings of optimizing refrigeration systems with various cycles and refrigerant alterations, including single and mixed refrigerants. There have also been studies on absorption systems using environmentally friendly refrigerants with clean and renewable energy sources [19]. A study on a hybrid system that combines vapor absorption and compression has also been conducted [20]. With its mode of operation based on environmental conditions, this hybrid system provides better energy efficiency.

The Indonesian government intend to replace LPG with dimethyl ether (DME). In addition to being used as a fuel and propellant/aerosol, DME is a good possibility among the various alternative refrigerant solutions. It has resilient thermal properties, which enable it to increase energy efficiency. DME is also not ozone-depleting and emits a few greenhouse gases, so it fits into the environmentally friendly category. Researchers have rarely done many investigations on dimethyl ether refrigerant in the last few decades, even though there has been various research on these refrigerants. One of the researchers, Arkharov *et al.,* [21] studied DME as fuel and also as refrigerant. Much of the research is theoretical. Bolaji [22] reported on performance comparison research of R1234yf and R1234ze refrigerants with DME. According to this study, it possesses qualities like R134a which has been widely used. Baskaran *et al.,* [23] used theoretical research to show that DME refrigerant may replace R134a better than R152A. Other researcher, Apostol *et al.,* [24] gave the same suggestion that DME refrigerant can replace with R134a.The thermodynamics research also demonstrates that the DME mixed refrigerant (R429A, R435A, dan R510A) is more efficient than R134a [25,26].

Kim [27] provide the only literature on using DME as a refrigerant directly in refrigeration units. This study investigates the usage of a propane-DME mixture in an ice cream machine. As a result, the equipment can create ice cream faster and more efficiently than when utilizing R404A. The thermodynamics of DME and the azeotrope mixtures R510A and R511A have also been investigated [7]. As a result, DME, R510A, and R511A have a higher coefficient of performance (COP) than R134a.

Preliminary investigations on thermodynamic parameters and simulations of DME's application as a refrigerant have been conducted extensively, and DME has highly promising possibilities. However, experimental research is still in its infancy. As a result, this study will analyze the feasibility of DME as a refrigerant from technical perspectives. The limitation of the study is according to the specification of the unit, the capacity of the freezer is about 150 Watt, which the refrigerant charging is about 150 grams. The initial refrigerant using in the unit is R134a.

## 2. Methodology

Procedures and performance testing of DME as a replacement refrigerant for R134a in refrigeration system applications in the form of freezers were carried out in this study. The performance of the freezer while using R134a refrigerant was compared to when using DME refrigerant. Several major stages will be carried out in this research, including:

### *2.1 Refrigeration Testing with R134a Refrigerant (Initial Testing)*

Freezers were tested for a performance using ancient refrigerants to assess the refrigeration effect, compressor-specific work, condenser-specific heat dissipation, and coefficient of performance. The specification of all apparatus shows in Table 2. The temperature of the refrigerant piping was taken at location 1, 2,3, and 4 in Figure 1(a) for this test. The obtained data will be utilized as reference data or as initial data.

**Table 2**
Apparatus of the research measurement

| Apparatus Model | Operative Range | Accuracy |
|---|---|---|
| Refco Manifold Gauge BM2-6-DS | -1 bar - 10 bar | Class 1.6; 0.16 bar |
| Scale, AND SK-5001 | 0 gram – 5000 gram | 1 gr |
| APPA 52 Thermometer K-Type | -50°C~1300°C, -58°F~1999°F | ±(0.3%+1°C) at -50°C~1000°C |
| Pico Data Logger | (–270°C to +1820°C) | 0.2%; 0.025°C |
| Kyoritsu KEW2007R | AC A : 1000A<br>AC V : 600 V | AC A : ±1.5% reading (0.015 A)<br>AC V : ±1.2%reading (2.64 V) |
| Lutron DW-6163 | Power Factor : 0.01 ~ 1.00 | 0.01 |

### *2.2 Modification of Cooling Machine Piping*

Piping adjustments have been made so that DME refrigerant can be introduced without compromising the seal of the refrigeration machine piping. This investigation includes the replacement of the seal on the manifold gauge.

### *2.3 Refrigerant Replacement and Dimethyl Ether Refrigerant Testing*

When the initial testing phase is finished, the valve clamp for the pressure gauge is installed to collect pressure data on the system and the initial data is utilized as a reference for the afterward data collection, specifically when data collection is done with R134a. After installing the clamp, R134a is filled in the freezer by vacuuming it immediately. While charging R134a, the mass of refrigerant loaded into the system is measured. The data is then collected with the addition of pressure data. If the data is in accordance with the initial data, a DME retrofit is performed. DME is charged from 60 grams, 70 grams, and 80 grams or in a percentage 40%, 46.7%, and 53.3% by mass of R134a. Data is recorded for each charging and compared to R134a data.

*2.4 Analysis and Comparison Results (How to Define Enthalpy)*

Furthermore, performance comparisons are performed to determine the degree to which the capacity, power consumption, and energy efficiency of the two types of refrigerants differ. At this point, the REFPROP application, published by NIST, is also utilized to get total enthalpy values, which will be used for evaluating the data. These data will be used to analyse whether DME suitable for substitution for replacing R134a or not.

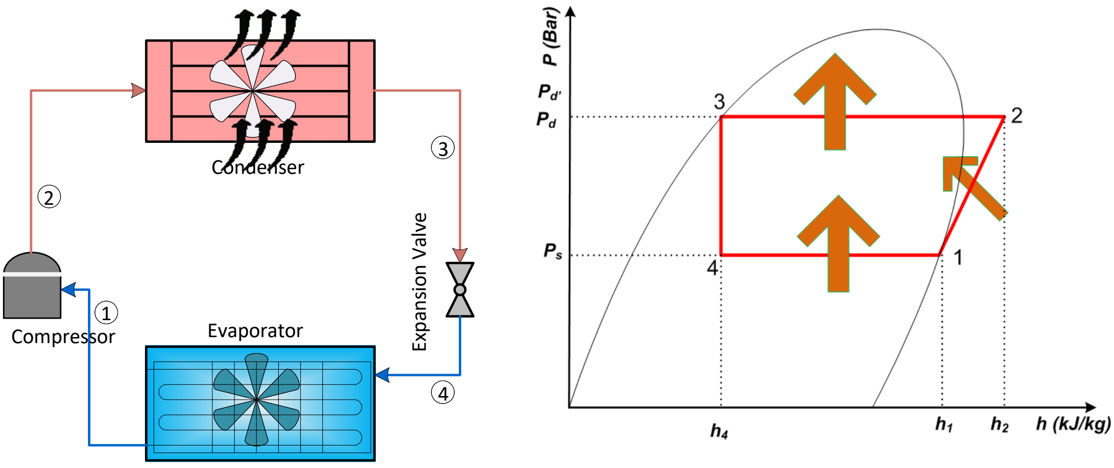


**Fig. 1.** Refrigeration system schematic (a) Main components, (b) Refrigeration cycle on pressure-enthalpy diagram (P-h)

The refrigeration effect, compressor-specific work, and condenser-specific heat dissipation may all be calculated using the refrigeration cycle shown in Figure 1(b). The refrigeration effect, $q_e$, has been defined as the difference in enthalpy (h) between refrigerant leaving and entering the evaporator as shown in Eq. (1).

$$q_e = h_1 - h_4. \quad (1)$$

The compressor-specific work, $W_k$, is defined as the enthalpy difference between the refrigerant leaving and entering the compressor refer to Eq. (2).

$$w_k = h_2 - h_1. \quad (2)$$

Meanwhile, the condenser-specific heat dissipation, $q_c$, can be estimated using Eq. (3).

$$q_c = h_2 - h_3. \quad (3)$$

The refrigeration system's coefficient of performance (COP) can be computed using Eq. (1) and Eq. (2) as shown in Eq. (4).

$$COP = \frac{h_1 - h_4}{h_2 - h_1}. \quad (4)$$

The cooling capacity ($Q_e$) is determined by multiplying the refrigerant mass flow rate ($\dot{m}_r$) by the refrigerant effect refer to Eq. (5), or

$$Q_e = \dot{m}_r(h_1^{\cdot} - h_4). \quad (5)$$

Furthermore, power consumption ($P_i$) can be computed using the following Eq. (6).

$$P_i = V.I.cos\varphi. \quad (6)$$

The energy efficiency ratio is calculated by comparing the cooling capacity to the cooling power consumption as shown in Eq. (7).

$$EER = \frac{Q_e}{P_i} \quad (7)$$

## 3. Results and Discussion

Using REFPROP version 10, the relationship between the saturation temperature and saturation pressure, for several refrigerants including R22, Isobutane, R134a, R404A, R407C, R410A, Propane and DME is shown in Figure 2. The temperature is chosen in range from -50 $^oC$ to 50 $^oC$. For the same saturation temperature, each refrigerant has the difference pressure, and the highest pressure is obtained by R32 and R410A, and two refrigerants that give the lowest pressure given by isobutane and DME. For example, chose an evaporating temperature of 0 $^oC$, shown with thick black line, the pressure of refrigerant from the largest to the smallest, are 8.13, 7.98, 6.00, 4.98, 4.74, 4.61, 2.93, 2.67, and 1.57 bar for R32, R410A, R404A, R22, Propane, R407C, R134a, Dimethyl ether, and Isobutane respectively. The same phenomena will occur at condensing temperature which higher than the evaporating temperature. This will affect to the selection of compressor using in refrigeration system [28]. Comparing of R134a and DME, the working pressure of DME is less than R134a, which mean that the use of energy of DME is lower than R134a. The effect of evaporating temperature of DME on a refrigeration system was also reported by Mitrakusuma *et al.,* [29]. According to Arkharov *et al.,* [21] and Apostol *et al.,* [24], DME is suitable to replace R134a as a refrigerant.

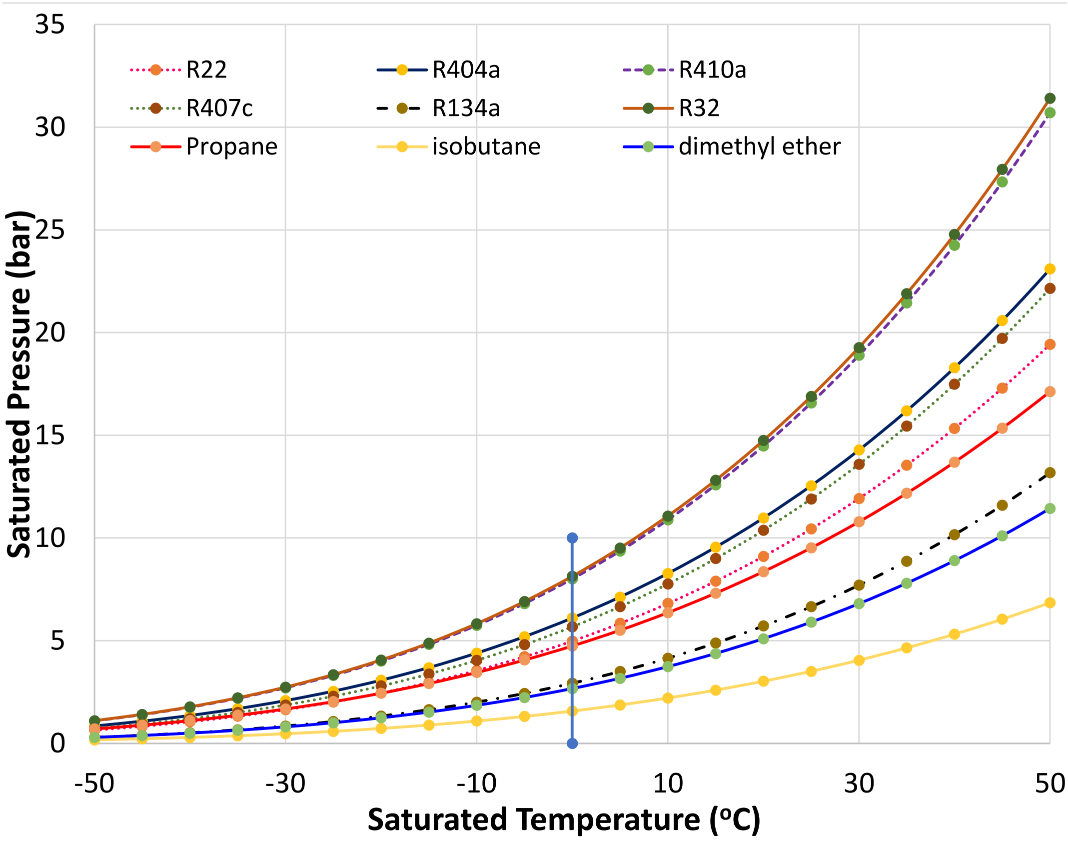


**Fig. 2.** Saturation pressures of various refrigerants as temperature changes

### *3.1 Discharge and Suction Pressure*

According to Figure 3 and Figure 4, this study revealed that DME has a lower discharge and suction pressure values than R134a. The amount of refrigerant filled into the system can affect the working pressure. Due to the figure, the charging of 80 grams (53.3% by mass) of DME, shown with the blue line, has the highest condensation pressure, even still below R134a. The charging of 60 grams (40% by mass) has the lowest condensation pressure, shown with the grey line. For the evaporator pressure, the charging of 80 grams has almost the same pressure as R134a in the first 12 minute of observation. The charging of 60 grams has negative pressure, which means below the ambient pressure. In most cases this condition is not acceptable due to the air infiltrating the system when there is a leak [30]. This could be caused by the lower compressibility of DME. On the figure, the charging of 60 grams looks more stable than other, this shows that the system is always on, which mean the refrigerant cannot absorb the heat load in the cabin, and the thermostat never reach its cut-off.

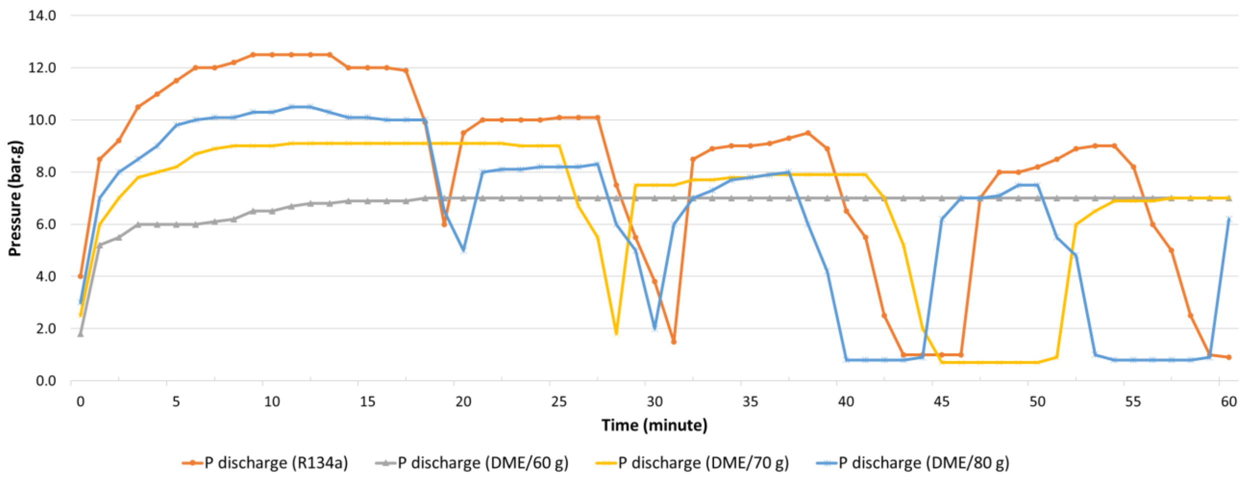


**Fig. 3.** Discharge pressure comparison between Dimethyl Ether and R134A

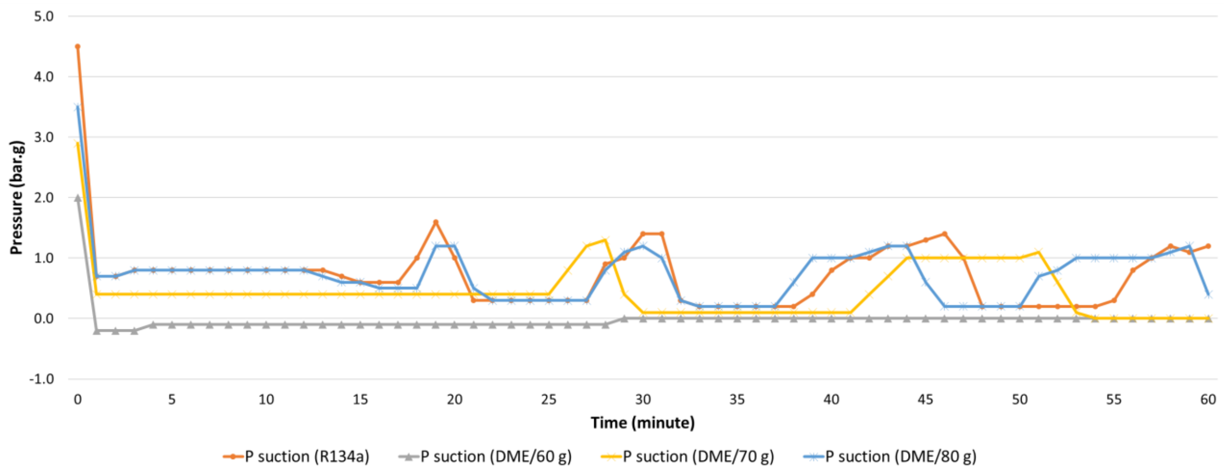


**Fig. 4.** Suction pressure comparison between Dimethyl Ether and R134A

### *3.2 Cabin Temperature*

Figure 5 shows the decreases of temperature for the four different refrigerants filled into the system. In this figure, R134a has the highest cooling rate and the charging of 60 grams of DME has the lowest cooling rate as explained in the previous paragraph. For example, to reach zero degree Celsius, R134a takes 13 minutes, while the charging of 70 grams and 80 grams of DME are in the range of 17 minutes. Meanwhile, the charging of 60 grams of DME takes more than an hour. It can be said that R134a has the highest cooling capacity. This observation also shows that the cooling capacity produced by DME which charging of 70 grams and 80 grams have the higher cooling capacity. As an alternative refrigerant for R134a, DME with the proper charging of refrigerant in the system, can produce the same performance as R134a.

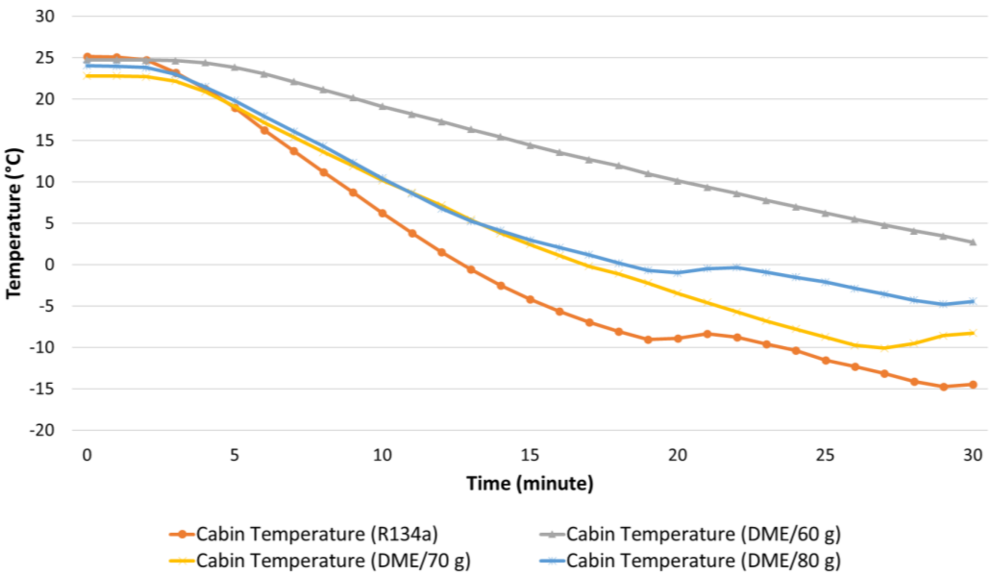


**Fig. 5.** Temporal cabin temperature comparison between Dimethyl Ether and R134a

### *3.3 Power Consumption and Energy Efficiency Ratio*

Figure 6 shows the power consumption for the first 60 minutes of the observation. The charging of 80 grams cuts off the system on 18 minutes, while R134a at 16 minutes. The charging of 70 grams cuts off at 26 minutes, while the charging of 60 grams never cut off for this period of observation. The power consumption of the freezer when using R134a is higher than DME as shown in the graph. Because DME has a higher evaporation enthalpy, it reduces the load on the compressor and can minimize power usage. Based on that, the freezer with a mass 80 grams performs better than the other two mass variation since the resulting power consumption is lower. Lower pressure at the same of saturation temperature gives smaller compression ratio, which result reducing the power consumption. This effect is also reported by Bolaji *et al.,* [7], Arkharov *et al.,* [21], Baskaran *et al.,* [23], and Apostol *et al.,* [24].

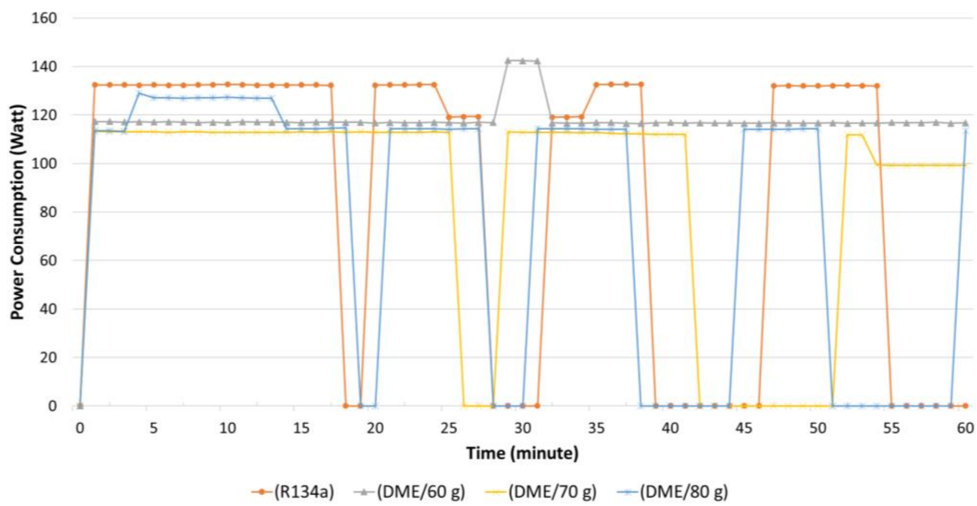


**Fig. 6.** Assessing the energy efficiency of Dimethyl Ether and R134a

According to the calculation of EER, Table 3 shows the comparison of the energy efficiency ratio of the system. The charging of 80 grams, has the best EER comparing to other variation of DME charging. Even R134a has lowest chilling time, but still has the highest EER. The charging of 60 grams, show less charging of refrigerant, and become the smallest EER among the DME refrigerant variation used in this experiment.

**Table 3**
Energy Efficiency Ratio (EER)

| Parameter | Unit | R134a | DME | | |
|---|---|---|---|---|---|
| | | | 80g/53.3% | 70g/46.7% | 60g/40% |
| Cooling capacity | Watt | 396,13 | 390,01 | 363,24 | 364,47 |
| Power Consumption | Watt | 130,22 | 113,96 | 110,24 | 118,30 |
| EER | - | 3,04 | 3,42 | 3,29 | 3,08 |

*3.4 The Uncertainty Analysis*

From Table 3, the parameter of cooling capacity and EER calculated based on REFPROP version 10 which is we assume the uncertainties are equal to zero. The uncertainty of the power consumption is calculated based on the equation proposed by Taylor and Thompson [31]:

For the $q = f(x_1 x_2, \cdots, x_n)$ then the uncertainty of q is:

$$\Delta q = \sqrt{\left(\frac{\partial q}{\partial x_1} \cdot \Delta x_1\right)^2 + \left(\frac{\partial q}{\partial x_2} \cdot \Delta x_2\right)^2 + \cdots + \left(\frac{\partial q}{\partial x_n} \cdot \Delta x_n\right)^2} \quad (8)$$

The Power Consumption is calculated using Eq. (6), and the uncertainty of P can be calculated using the following equation:

$$\Delta P = \sqrt{\left(\frac{\partial P}{\partial V} \cdot \Delta V\right)^2 + \left(\frac{\partial P}{\partial I} \cdot \Delta I\right)^2 + \left(\frac{\partial P}{\partial Cos\varphi} \cdot \Delta Cos\varphi\right)^2} \quad (9)$$

Then we have:

$$\Delta P = \sqrt{(I.Cos\varphi \cdot \Delta V)^2 + (V.Cos\varphi \cdot \Delta I)^2 + (V.I \cdot \Delta Cos\varphi)^2} \quad (10)$$

According to the specification of the voltmeter and amperemeter as shown on Table 2, the maximum uncertainty of current, voltage, and power factor measurement are 0.015 A, 2.64 V, and 0.01 respectively. From the measurement of current, voltage, and power factor have the maximum value 1 A, 226.7 V, and 0.57 respectively, then we have the uncertainty of the power calculated is 3.34. The power consumption can be written for the maximum value as 129.22 + 3.34.

## 4. Conclusions and Future Perspectives

The study of the using DME as a replacement of R134a has been conducted. Based on the study, the variation of mass charging of DME are 60 gram, 70 gram, and 80 gram. Besides DME has an environmentally beneficial, the power consumption is lower than R134a, giving DME systems a high work efficiency rating. This is also confirmed by cabin temperature of DME system that is almost the same as R134a. With this evident, the DME charging of 53.3% mass of R134a (or 80 grams) can be proposed as the best choice in the tested freezer. From the performance test of the refrigeration system employing DME as a substitute for R134a, it can be concluded that DME is suitable to replace R134a. Future research may explore and optimize DME blends with refrigerants to enhance performance, efficiency, and safety. Studying the thermodynamic properties and compatibility of

DME blends and the use of suitable oil could offer new opportunities to customize refrigerants for specific applications and lead to improved designs of refrigeration and air conditioning systems optimized for DME in the future. This may involve developing new heat exchanger designs, compressor technologies, and control strategies to enhance DME-based system efficiency and performance. Based on our research, DME can widely use in refrigeration systems because the government has released the policy for using hydrocarbons as a refrigerant.

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