Performance comparison of DME and R134a refrigerants in a room air conditioner: Effect of subcool and superheat

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Abstract. The demand for environmentally friendly refrigerants arises to anticipate two global environmental issues: global warming and climate change. The use of environmentally friendly refrigerants is one of the efforts to address these issues. This study aims to investigate the possibility of the use of dimethyl ether (DME) for substituting R134a that has been widely used worldwide. The simulation reveals that both subcool and superheat affect the performance of both refrigerants. The cooling capacity of R134a system increases with the increase of subcool and superheat. Meanwhile, even though the cooling capacity of DME increases with the increase of subcool, it decreases with the increase of superheat. For subcool 0°C, DME has a coefficient of performance (COP) 4.8% higher than that of R134a although the cooling capacity is 4.5% lower. When the subcool is set at 8°C, the cooling capacity of DME is 6.5% lower than R134a but the COP is 2.6% higher. Another important finding in this study is that the best performance of DME over R134a is obtained at low subcool and low superheat.

1 Introduction

The issues of global warming and climate change need to be anticipated by appropriate and comprehensive actions. In refrigeration and air conditioning sector, the use of environmentally friendly refrigerants is one action to address these issues [1]. DME (Dimethyl Ether) or RE170 with chemical formula of CH3OCH3 can be used as a refrigerant that has a very low global warming potential (GWP) and a zero-ozone depleting potential (ODP) [2]. The normal boiling point of this compound is -24.8°C with a critical temperature and pressure of 400.4 K and 5.336 MPa, and respectively. The molecular weight of DME is 46.07 g/mol, lower than that of R134a [3]. With these properties, DME has the potential to replace R134a as an environmentally friendly refrigerant.

There are very few reports on experimental studies on the use of DME as an alternative refrigerant and most studies are thermodynamics analysis or simulation. One of the experimental studies is the use of a mixture of propane and DME for ice cream maker [4]. In this experiment, it was reported that the equipment was able to produce ice cream in a shorter time and with increased efficiency compared to using R404a refrigerant.

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A comparative theoretical study of the performance between refrigerants R1234yf and R1234ze with DME has been reported by Bolaji [5]. The study results show that DME properties were close to R134a which has been widely used. A study of cooling systems with ejectors by Gil and Kaspersky [6] showed that DME refrigerant have higher efficiency than diethyl ether. Theoretical study by Baskaran et al. [7] showed that DME refrigerant has advantages compared to R152a in replacing R134a. Thermodynamic studies on DME mixed refrigerants (R429A, R435A, and R 510A) also show an increase in the coefficient of performance (COP) and exergy efficiency compared to R134a refrigerant [8].

Theoretical studies have also been carried out on pure DME refrigerants and mixtures of DME and carbon dioxide in air conditioning machines [9]. Molecular simulations on polypropylene glycol, DME, and trans-1233zd have also been carried out to obtain the most suitable type of lubricant for these three refrigerants [10]. Thermodynamic analysis between DME and a mixture of R510A and R511A azoetropes has also been studied [11]. As a result, the coefficient of performance of the mixture of DME/RE170, R510A, and R511A is higher compared to R134a. Another study on the mixed refrigerant RE170/R1234yf/R152a was carried out by Gil et al. [12] to increase the cooling capacity and COP of a refrigeration system with pure DME refrigerant. From this study, the optimal mixture portion was obtained to produce the best energy efficiency. Studies on increasing the efficiency of DME cooling unit for absorption cooling systems by adding ionic liquid have been reported by Liu et al. [13]. The addition of this ionic solution was expected to increase COP by up to 32%.

This theoretical study deals with the performance comparison of R134a and DME in an air conditioning with evaporating temperature of +2.5°C and subcool and superheat range of 0 to 8°C. The cooling capacity and work of compression of both refrigerants are analysed under varied subcool and superheat to obtain the coefficient of performance. Finally, the recommendation of the optimum degree of subcool and superheat for DME refrigerant is presented.

2 Methods

This study was carried out at a constant evaporating temperature of 2.5°C and constant condensing temperature of 40°C. This study simulated the use of DME as a working fluid in an air conditioner with a cooling capacity of 2.6 kW. The diagram of the air conditioner is presented in Fig. 1a and the cycle in pressure-enthalpy diagram is shown in Fig. 1b.

In this study, the subcool and the superheat were varied in the range of 0 to 8°C. This range is chosen as it is widely used in practice in the real world. Refprop software was utilized to calculate the various parameters used in this study. Firstly, the refrigerant was chosen. Then, operating conditions are determined such as evaporation temperature, environmental temperature, and discharge pressure. At the beginning of the calculation, the subcool and superheat was set at 0°C. By providing the isentropic efficiency, the discharge temperature can be determined. In this study, an isentropic efficiency of 0.6 was used.

In the next calculations, the subcool and superheat were increased to 8°C with an increment of 1°C. With the variation of both parameters, the enthalpy difference across the evaporator, compressor, and condenser at the predetermined subcool and superheat could be calculated. The mass flow rate could be calculated by

\[ m = \eta_{\text{vol}} Q \rho \]  

where \( m \) is the refrigerant mass flow rate, \( \eta_{\text{vol}} \) is the volumetric efficiency, \( Q \) is the volume displacement of the compressor, and \( \rho \) is the refrigerant density.

The cooling capacity \( (q_e) \) is calculated by

\[ q_e = m \Delta h_{\text{evap}} \]
where $\Delta h_{\text{evap}}$ is the enthalpy difference of refrigerant leaving and entering the evaporator. The condenser heat rejection ($q_c$) and work of compression ($W$) can be determined by

$$q_c = m \Delta h_{\text{cond}} \quad (3) \quad \text{and} \quad W = m \Delta h_{\text{comp}} \quad (4)$$

Here, $\Delta h_{\text{cond}}$ represents the enthalpy difference of refrigerant entering and leaving the condenser and $\Delta h_{\text{comp}}$ denotes the enthalpy difference of refrigerant leaving and entering the compressor.

![Diagram of refrigeration system](image)

**Fig. 1.** a. Sketch of a refrigeration system in a room air conditioning unit. b. Pressure-enthalpy diagram of a refrigeration system.

By referring to Figure 1b, equation (2, 3, and 4) can be written as

$$q_e = m (h_1 - h_4) \quad (5)$$

$$q_c = m (h_2 - h_3) \quad (6)$$

$$W = m (h_2 - h_1) \quad (7)$$

where

$h_1$ : Enthalpy of refrigerant leaving the evaporator
$h_2$ : Enthalpy of refrigerant leaving the compressor
$h_3$ : Enthalpy of refrigerant leaving the condenser
$h_4$ : Enthalpy of refrigerant entering the evaporator

The COP of the air conditioner can be expressed as the ratio of cooling capacity and work of compression, or

$$COP = \frac{W}{q_e} \quad (8)$$

As the mass flow rate is constant across the system, then

$$COP = \frac{h_2 - h_1}{h_2} \quad (9)$$

Equations (1) to (9) are then used to evaluate the performance of R134a and DME as working fluids in the air conditioner. The main performance parameters, namely cooling capacity, work of compression, and COP are analysed to determine the overall performance.
of both refrigerants under different degrees of subcool and superheat. This method has also been used by Setyawan et al. [14,15], Mitrakusuma et al. [16], and Setyawan [17,18].

### 3 Results and discussion

Table 1 summarizes the performance comparison of R134a and DME in terms of cooling capacity, work of compression, heat rejection by the condenser, and COP for evaporating temperature of 2.5°C and subcool of 0°C.

**Table 1.** Cooling capacity, work of compression, heat rejection, and COP of R134a and DME system at a constant subcool of 0°C and varied superheat.

<table>
<thead>
<tr>
<th>Superheat (°C)</th>
<th>Capacity (W)</th>
<th>Work (W)</th>
<th>Heat rejection (W)</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R134a</td>
<td>DME</td>
<td>R134a</td>
<td>DME</td>
</tr>
<tr>
<td>0</td>
<td>2206.4</td>
<td>2117.1</td>
<td>614.4</td>
<td>560.5</td>
</tr>
<tr>
<td>1</td>
<td>2208.7</td>
<td>2116.6</td>
<td>614.7</td>
<td>560.5</td>
</tr>
<tr>
<td>2</td>
<td>2211.1</td>
<td>2116</td>
<td>614.9</td>
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</tr>
<tr>
<td>3</td>
<td>2213.3</td>
<td>2115.5</td>
<td>615.2</td>
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<td>2215.7</td>
<td>2115.1</td>
<td>615.4</td>
<td>560.7</td>
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<tr>
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<td>2114.6</td>
<td>615.6</td>
<td>560.7</td>
</tr>
<tr>
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<td>2220.4</td>
<td>2114.2</td>
<td>615.8</td>
<td>560.7</td>
</tr>
<tr>
<td>7</td>
<td>2222.8</td>
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<td>560.8</td>
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<td>8</td>
<td>2225.2</td>
<td>2113.5</td>
<td>616.3</td>
<td>560.8</td>
</tr>
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</table>

Detailed observation of Table 1 reveals that the cooling capacity of the system using R134a increases with the increase of superheating. On average, the cooling capacity increases by 2.36 W for every increase of superheat by 1°C. On the contrary, the cooling capacity of the system with DME decreases with the increase of superheat. Every 1°C increase of superheat results in the decrease of cooling capacity by 0.45 W, on average. Therefore, in terms of cooling capacity, the increase in superheat provides advantages for systems with R134a and provides disadvantages for systems with DME. As in cooling capacity, the heat rejection in the condenser of R134a system increases with the increase of superheat. On the other hand, the DME system shows a slight decrease of heat rejection with the increase of superheat.

In terms of the work of compression, system with R134a has an average work of 615.4 W. This gives an average COP of 3.60. The average compression work of system with DME is calculated at 560.7 W. It provides an average COP of 3.77. In comparison to R134a, the DME system has a 4.8% higher COP. The range of COP is in accordance with the results of Setyawan et al. [14,15].

The increase of superheat causes the increase of work with different rate of change for both refrigerants. A change of work by 0.23 W per 1°C increase of superheat is shown by the system with R134a. Meanwhile, the system with DME shown a lower rate of change, i.e.,
0.04W per 1°C of superheat. As a result, the COP of R134a system increases with the increase of superheat. Meanwhile, the COP of DME system decreases with the increase of superheat.

Fig. 2 depicts the cooling capacity and COP of R134a and DME systems at a constant subcool 0°C and varied superheat.

![Cooling capacity and COP of R134a and DME systems at various superheat and constant subcool of 0°C.](image)

If the subcool increases, for example to 4°C, the cooling capacity for both refrigerants increases. Table 2 summarizes the cooling capacity, work of compression, heat rejection by the condenser, and COP of R134a and DME for evaporating temperature of 2.5°C and subcool of 4°C. Here, the average cooling capacity of the system with R134a is 2303 W, while DME system has an average of 2175 W. The cooling capacity of DME system is 5.6% lower than that of R134a. However, the average compression work of R134a is 8.9% higher than DME. As a result, DME gives a higher average COP (3.88) than that of R134a (3.75). Overall, the performance of DME is 3.6% better than that of R134a. Figure 3 shows the cooling capacity and COP of R134a and DME systems for a constant subcool of 4°C.

### Table 2. Cooling capacity, work of compression, heat rejection, and COP of R134a and DME systems at a constant subcool of 4°C and varied superheat.

<table>
<thead>
<tr>
<th>Superheat (°C)</th>
<th>Capacity (W)</th>
<th>Work (W)</th>
<th>Heat rejection (W)</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R134a</td>
<td>DME</td>
<td>R134a</td>
<td>DME</td>
</tr>
<tr>
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<td>2173</td>
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<tr>
<td>8</td>
<td>2311</td>
<td>2172</td>
<td>615.7</td>
<td>560.5</td>
</tr>
</tbody>
</table>
Fig. 3. Cooling capacity and COP of R134a and DME systems at various superheat and constant subcool of 4°C.

Further increase of subcool to 8°C results in the increase of cooling capacity of R134a system to 2389 W and DME system to 2234 W. Here, the capacity of DME system is 6.5% lower than that of R134a. However, the compression work of R134a system is 8.8% higher than that of DME. As a result, the COP of DME system is 2.6% higher than that of R134a. The cooling capacity of R134a and DME systems as a function of superheat at a constant subcool of 8°C is depicted in Fig. 4.

Fig. 4. Cooling capacity and COP of R134a and DME systems at various superheat and constant subcool of 8°C.

From Table 1 and 2 and Fig. 2 to 4, it can be concluded that AC system with refrigerant R134a has a higher cooling capacity with the increase of superheat and subcool. The cooling capacity of the DME system increases with the increase of subcool but decreases with the increase of superheat. For all ranges of subcool and superheat used in this study, the COP of DME system is higher than that of R134a. However, the COP difference becomes smaller with increasing degrees of superheat and subcool. Thus, thermodynamically DME can be used to replace R134a with the best performance at low degrees of subcool and superheat.
4 Conclusion

A study of the effect of subcool and superheat on the performance of air conditioning unit using R134a and DME has been carried out. The ranges of subcool and superheat used in this study are 0 to 8°C. As the subcool increases, the cooling capacity of systems with R134a and DME increases. However, the cooling capacity of DME system decreases with the increase of superheat. At subcool of 0°C the cooling capacity of DME system is 4.5% lower than that of R134a. However, its compression work is lower, so that it has an average COP 4.8% higher than that of R134a. At the subcool of 8°C, the cooling capacity of DME system is 6.5% lower than that of R134a. However, its COP is 2.6% higher than that of R134a. Thermodynamically DME can be used to replace R134a. The best performance of DME over R134a can be achieved at low subcool and low superheat.

References