The effect of variation of extra fan condenser and engine speed to COP of mobile air conditioners

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Abstract. Efforts to increase coefficient of performance (COP) of Mobile Air Conditioners (MAC) still continue to be done, including by increasing the extra fan condenser speed. The problem is whether it can improve the COP, it needs to be tested further. This study focuses to examine the effect of extra fan condenser and engine speed variations to COP. This study was conducted on a MAC engine stand which able to measure the pressure and temperature of MAC system. The data measured at inlet compressor (P1, T1), outlet compressor (P2, T2), outlet condenser (P3, T3), and outlet expansion valve (P4, T4), at engine speed of 1.000, 1.500, 2.000, 2.500 and 3.000 rotation per minute (RPM), respectively with variations extra fan condenser speed of 0.15, 1.74, and 2.22 m/sec. The data was plotted on p-h diagram to obtain enthalpy value, so that obtained COP value by calculation. The major result obtained are the variations of extra fan condenser and engine speed had an effect on the COP. The highest COP (4.48) was achieved at an engine speed of 2,000 RPM with extra fan condenser speed 2.22 m/sec. Increasing extra fan condenser speed causes better cooling at condenser and cooling effect on the evaporator.

1. Introduction

The problem of Mobile Air Conditioners (MAC) that is not cold or not cold at all can be caused by many factors, one of which is the poor cooling performance of the condenser. For example, the condenser is dirty, the extra fan condenser rotates slowly or not at all. To overcome this, many people make modifications by changing the speed of the extra fan condenser in the hope that it can reduce the temperature of the mobile cabin so that it is cooler and more comfortable or the performance increases. The cooling performance of MAC is defined as Coefficient of Performance (COP). COP air conditioning system is the effect of refrigeration divided by compression work [1].

Efforts to increase COP of Mobile Air Conditioners still continue to be done, for example using condensed water [2], increasing the extra fan condenser speed [3]. Whether the change in the speed of the extra condenser fan is really able to increase the cooling effect on the evaporator, needs to be tested further.

Therefore, in this study defined the problem formulation as how is the effect of the extra fan condenser speed variations and engine speed on the COP MAC? The purpose of study to examine the effect of variations in the extra fan condenser and engine speed to COP of MAC.
2. Method
The study was conducted on a modified engine stand of MAC and was able to display the results of measurements of the pressure and temperature of the MAC system, as shown at Figure 1-2.

![Modified engine stand of MAC](image1.png)

**Figure 1.** Modified engine stand of MAC.

![Schematic diagram of MAC](image2.png)

**Figure 2.** The schematic diagram of MAC [4].

Data is collected by measuring the pressure and temperature at inlet compressor (P1, T1), outlet compressor (P2, T2), outlet condenser (P3, T3), and outlet the expansion valve (inlet evaporator) (P4, T4), at engine speed of 1,000, 1,500, 2,000 2,500 and 3,000 RPM, respectively with variations in the condenser extra fan speed of the 0.15; 1.74; and 2.22 m/sec. The data obtained is then plotted on the p-
h diagram to obtain the enthalpy value at each point of pressure and temperature, so that the COP value can be calculated, according to equation 1 [4].

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COP = \frac{h_1 - h_3}{h_2 - h_1} = \frac{h_1 - h_3}{h_2 - h_1} \nonumber \]

\( \text{(1)} \)

2.1. Variable

In this study, there are two variables, including independent variable and dependent variable The Independent variables consist of variations in extra fan condenser speed (0.15; 1.74; 2.22 m/s) and variations in engine speed (1.000, 1.500, 2.000, 2.500, and 3.000 RPM). The dependent variable is COP of MAC

2.2. Hypothesis

Hypothesis in this study defined as:
H₀: There is no effect between the extra fan condenser speed and engine speed to the COP of MAC
H₁: There is an effect between the extra fan condenser speed and engine speed to the COP of MAC

2.3. Data analysis

The COP data that has been obtained is then graphed on the relationship between the variations of extra fan condenser speed and engine speed to the COP. Data analysis used SPSS software with correlation and regression test to test the effect of variations in the speed of extra fan condenser speed and engine speed to COP of MAC [5].

3. Results and discussion

3.1. Data

The data obtained from the results of this study are in the form of pressure and temperature at various points, various engine speeds and various extra speed of the condenser fan, which are written with notations (P₁, P₂, P₃, P₄) for pressure, and (T₁, T₂, T₃, T₄) for temperature, as Table 1.

The pressure and temperature data that have been obtained are then plotted on the p-H diagram to obtain the enthalpy value. The enthalpy value plotting the p-h diagram is then used to calculate the COP value based on COP formula on equation 1.
Table 1. The data of pressure, temperature, enthalpy and COP at various points, various engine speeds and various extra speed of the condenser fan.

| Engine speed (RPM) | Extra Fan speed m/s | P1 (bar) | P2 (bar) | P3 (bar) | P4 (bar) | T1 (⁰C) | T2 (⁰C) | T3 (⁰C) | T4 (⁰C) | h1 (kJ/kg) | h2 (kJ/kg) | h3 (kJ/kg) | h4 (kJ/kg) | COP |
|-------------------|---------------------|----------|----------|----------|----------|---------|---------|---------|---------|------------|------------|------------|------------|-----|
| 1.000             | 0.15                | 3.63     | 13.00    | 13.00    | 2.50     | 10.50   | 85.25   | 45.45   | 9.07    | 400        | 470        | 267        | 267        | 1.90 |
|                   | 1.74                | 3.23     | 10.50    | 10.50    | 2.40     | 8.75    | 83.20   | 43.36   | 7.13    | 400        | 469        | 256        | 256        | 2.09 |
|                   | 2.22                | 3.37     | 12.75    | 12.75    | 2.40     | 9.25    | 80.85   | 39.55   | 8.28    | 401        | 464        | 257        | 257        | 2.29 |
| 1.500             | 0.15                | 3.10     | 11.50    | 11.50    | 2.10     | 8.15    | 81.20   | 43.40   | 7.43    | 402        | 466        | 264        | 264        | 2.16 |
|                   | 1.74                | 3.17     | 12.13    | 12.13    | 2.07     | 7.53    | 82.30   | 42.75   | 7.07    | 404        | 468        | 260        | 260        | 2.25 |
|                   | 2.22                | 3.30     | 11.20    | 11.20    | 2.40     | 9.65    | 82.45   | 39.57   | 8.58    | 405        | 465        | 259        | 259        | 2.58 |
| 2.000             | 0.15                | 3.30     | 14.50    | 14.50    | 2.13     | 9.80    | 70.15   | 36.75   | 6.70    | 406        | 452        | 246        | 246        | 3.48 |
|                   | 1.74                | 3.00     | 13.00    | 13.00    | 1.97     | 8.97    | 70.15   | 37.95   | 5.72    | 407        | 451        | 233        | 233        | 3.95 |
|                   | 2.22                | 3.13     | 11.80    | 11.80    | 2.13     | 10.05   | 61.35   | 43.50   | 8.10    | 408        | 441        | 260        | 260        | 4.48 |
| 2.500             | 0.15                | 3.00     | 14.20    | 14.20    | 1.80     | 7.55    | 80.15   | 44.25   | 6.75    | 403        | 460        | 269        | 269        | 2.35 |
|                   | 1.74                | 3.00     | 13.90    | 13.90    | 2.03     | 8.12    | 73.25   | 46.72   | 6.58    | 404        | 456        | 266        | 266        | 2.65 |
|                   | 2.22                | 3.10     | 12.20    | 12.20    | 1.90     | 8.35    | 68.85   | 44.20   | 6.20    | 405        | 450        | 260        | 260        | 3.22 |
| 3.000             | 0.15                | 3.23     | 13.50    | 13.50    | 1.57     | 6.85    | 82.25   | 52.15   | 7.22    | 400        | 464        | 275        | 275        | 1.95 |
|                   | 1.74                | 3.03     | 12.15    | 12.15    | 2.00     | 7.15    | 83.15   | 44.35   | 4.55    | 402        | 465        | 260        | 260        | 2.25 |
|                   | 2.22                | 2.73     | 10.78    | 10.70    | 1.50     | 7.45    | 78.25   | 37.50   | 6.98    | 404        | 460        | 256        | 256        | 2.64 |

Remarks: P1: inlet compressor pressure, P2: outlet compressor pressure, P3: outlet condenser pressure, P4: outlet expansion valve pressure, T1: inlet compressor temperature, T2: outlet compressor temperature, T3: outlet condenser temperature, T4: outlet expansion valve temperature, h1: outlet evaporator enthalpy, h2: inlet condenser enthalpy, h3: outlet condenser enthalpy, h4: inlet evaporator enthalpy, COP: Coefficient of Performance, kJ/kg = kilo joule/kilo gram.

Furthermore, COP data at various of extra fan condenser speeds and various engine speeds are shown at Figure 3.

Figure 3. Graphic of COP at various extra fan condenser speed and engine speed.
3.2. Discussion
In the graph as shown in Figure 3, it can be seen that at the extra fan condenser speed of 0.15 m/s, the COP value is 1.90 at engine speed 1,000 RPM; 2.16 at engine speed 1,500 RPM; 3.48 at engine speed 2,000 RPM; 2.35 at engine speed 2,500 RPM; and 1.95 at engine speed 3,000 RPM. At engine speed 1,000 RPM, the COP value is still low, and at the higher engine speed (2000 RPM), the COP value was increase, and then decrease again after the engine speed is above 2,000 RPM.

At the extra fan condenser speed 1.74 m/s, COP value is 2.09, at engine speed 1,000 RPM; 2.25 at engine speed 1,500 RPM; 3.95 at engine speed 2,000 RPM; 2.65 at engine speed 2,500 RPM; and 2.25 at engine speed 3,000 RPM. At the engine speed 1,000 RPM, the COP value is still low, and at the higher speed (2,000 RPM) the COP value was increase, and decrease again after the speed is above 2,000 RPM.

At the extra fan condenser speed 2.22 m/s, the COP value is 2.29, at the engine speed 1,000 RPM; 2.58 at engine speed 1,500 RPM; 4.48 at engine speed 2,000 RPM; 3.22 at engine speed 2,500 RPM; and 2.64 at engine speed 3,000 RPM; At the engine speed 1,000 RPM, the COP value is still low, and at the higher speed (2.000 RPM) the COP value was increase, and decrease again after the speed is above 2,000 RPM.

At low engine speed (1,000 RPM) the COP value is still low, and the COP value increases as the engine speed increases and decreases again after 2,000 RPM. This happens because on the higher engine speed, the compressor shaft speed is higher, so the refrigerant pressure increases and the COP value is also increase. However, at the engine speed above 2,000 RPM, even though the compressor shaft speed is higher, the compressor is quite hot, so the refrigeration effect decreases, and the COP value was also decrease.

The COP value at the extra fan speed 2.22 m/s is 4.48, better than at the extra fan speed 0.15 m/s and 1.74 m / s (3.48 and 3.95) as shown in Figure 3. The lowest COP value at the extra fan speed 0.15 m/s and engine speed 2.000 RPM is 3.48, and the highest COP value at an extra fan speed 2.22 m/s and engine speed 2.000 RPM is 4.48, because the higher engine speed (above 2000 RPM) the refrigerant flow rate was decreases. Increasing the extra fan speed on the condenser causes an increasing the refrigeration effect, so the COP was increase also. This result is related to study of Effendy [6] and Tjahjono [7]. If the speed of the extra fan increases, the COP was reached to the optimum certain conditions (2,000 RPM). At engine speed 1.000 RPM, the COP value is not optimal yet, because at engine speed 1.000 RPM the MAC just started working. The MAC compressor already works, but is not optimal because the engine requires a lot of power to be able to move the compressor. Therefore, it can be interpreted that the load from the engine is too large at engine speed 1.000 RPM. At the engine speed 2.000 RPM the function of MAC components is optimal because the compressor speed flow off the refrigerant in accordance the needed of other components, and if the engine speed is increased, the MAC performance will decrease. In the engine speed above 2.000 RPM the COP value decreases again because at that speed, the compressor is quite hot, so that the refrigerant pressure is increases and the refrigeration effect is decreases, so the COP value also decreases.

4. Conclusion
The extra fan condenser speed variation greatly affects the COP of the Mobile Air Conditioner. At the extra fan condenser speed 0.15 m/s, the highest COP value 3.48 is achieved at 2,000 RPM engine speed; at the extra fan condenser speed 1.74 m/s, the highest COP value 3.95 is achieved at 2,000 RPM engine speed; at the extra fan condenser speed 2.22 m/s, the highest COP value 4.48 is achieved at 2,000 RPM engine speed. The increasing of the the extra fan condenser speed causes an increasing the refrigeration effect, so that the COP increases. If the extra fan condenser speed increases, the COP will reach the optimum in certain conditions (2,000 RPM engine speed). At 2.000 RPM engine speed, the performance of Mobile Air Conditioner components is optimal because the compressor is able to flow refrigerant as needed. For further action in order to obtain the best COP value on mobile air conditioner, the extra fan condenser must be ensured that it can rotate at maximum rotation and engine speed is around 2000 RPM.
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