Characteristics of vapor compression refrigeration system with parallel expansion valves using refrigerant musicool 134

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Abstract. This research was conducted to investigate the performance of vapor compression refrigeration systems with Musicool 134 refrigerant. The scope of this study was to compare the performance of double expansion valves installed parallel to the temperature expansion valve (TEV). The temperature and pressure of the refrigerant at the variable cooling load of 0.23, 0.33, and 0.39 Kg/s were observed during the system worked until steady conditions. The results of the study show that double expansion valves installed parallel produce better performance. The highest refrigeration effect produced was 257 kJ / kg and the COP was 5.84.

1. Introduction

In the last decade, the development of Air Conditioning technology, especially the use of refrigerants as working fluids, is strongly influenced by the issue of global warming potential (GWP) and ozone depletion potential (ODP) [1]–[4]. Now, the development of refrigerants is like the period 1830 to 1930, which is back to natural refrigerants such as hydrocarbon (HC), CO2, N2 and others [5]. The natural refrigerant is an alternative to CFCs and HFCs refrigerants that have higher environmental effects, even in 2020 refrigerants containing chlorine must not be reproduced. Table 1 presents some of the commercial refrigerants used in the last few decades and their effects on the environment [2], [6].

| Refrigerants     | R134a (HFC) | R290 (HC) | R600a (HC) | R290/R60 0a mixture (HC) | R152a (HFC) | R1234yf (HFO) |
|------------------|-------------|-----------|------------|--------------------------|-------------|---------------|
| Global warming potential (GWP) | 1400        | 11        | 8          | 7                        | 140          | 4             |
| Ozone Depletion Potential (ODP) | 0          | 0         | 0          | 0                        | 0           | 0             |
| Atmospheric Life Time (years)   | 14          | <1        | <1         | <0.04                    | 2           | <0.05         |
| Acute Toxicity Exposure Level (ATEL) (ppm) | 50,000    | 50,000    | 25,000     | 40,000                   | 50,000      | 101,000       |
| Lower Flammability Limit (LFL) (vol. %) | 2           | 2.2       | 1.7        | 2.0                      | 3.9         | 6.5           |
| Minimum Ignition Energy (MIE) (mJ) Safety Group | </A1       | 0.25/A3   | 0.35/A3    | N/A/A3                   | 0.38/A2     | >1000/A2L     |
| Molar Mass (kg/kmol)   | 102.03      | 44.096    | 58.122     | N/A                      | 66.051      | N/A           |
| Vapor Density at 25°C (kg/m³) | 32.35      | 20.65     | 9.12       | N/A                      | 18.47       | N/A           |
| Critical Temperature (°C)  | 101.1       | 96.8      | 135        | 114.8                    | 113.3       | N/A           |
| Critical Pressure (kPa)  | 4061        | 4247      | 3647       | 4040                     | 4522        | N/A           |
| Normal Boiling Point (NBP) (°C) | −26.11     | −42.11    | −11.78     | −31.5                    | −24.0       | N/A           |
| Vapor Cp at 25 °C (kJ/KgK) | 1.0316     | 2.0724    | 1.8189     | 1.77                     | 1.2536      | 1.0           |

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As an alternative refrigerant, hydrocarbons (HC) have long been tested and have been widely used in various fields of air conditioning systems. Propane (R-290) and butane (R-600) and mixtures are both hydrocarbons that have excellent properties as refrigerants [7], [8]. R-290/R-600 mixed refrigerants with various compositions have shown performance equivalent to R-134a [9], [10]. Other studies show a mixture of 40% / 60% of R-290/R-600 can replace R-12 with the same good performance [1].

HC refrigerant, besides having advantages over synthetic refrigerants, also has several disadvantages. A very prominent disadvantage is that it has high flammability compared to synthetic refrigerants [11], [12]. To reduce the flammability properties can be done by adding inert gases such as nitrogen (N2) and carbon dioxide (CO2) [2], [12]. Another way can be done by designing systems and equipment that can reduce the risk of burning due to the use of HC in the AC system [13].

The use of mixed refrigerants between propane and butane (LPG) has also been tested on hybrid car air conditioning systems using a half cycle system [14]–[17], even applied to expansion valves from PTFE material [18]. Meanwhile, in Indonesia, hydrocarbon (HC) refrigerants that have been commercialized are Pertamina products called Musicool 134 (M-134). Research using Musicool refrigerant has been carried out with variations in the mass flow of refrigerants entering the evaporator by adjusting the cross-sectional area of the expansion valve to improve the performance of the refrigeration system [19].

Meanwhile, the main problem in the refrigeration system is the irreversibility of the isenthalpic expansion process, thus reducing the performance of the AC system [20]. Therefore, this paper aims to reduce losses from the expansion process by installing double expansion valves in parallel so that it is expected to improve the performance of vapor compression refrigeration systems with Musicool refrigerants.

2. Method

This research was conducted to investigate the effect of using double expansion valves installed in parallel using musicool refrigerants that are compared to TEV performance. The study was conducted by measuring the temperature and refrigerant pressure on the variable cooling load of 0.23, 0.33, and 0.39 Kg / s taken from the amount of air mass that passes through the evaporator. The research apparatus is presented in Figure 1.
3. Result and Discussion

3.1. Research Data
Table 2 and Table 3 show the results of data collection of temperature and pressure on variations in cooling loads (air flow rate across the evaporator) of 0.23, 0.33, and 0.39 kg/s.

**Table 2.** Temperature and pressure refrigerant with parallel expansion valves.

| Cooling load | T1(°C) | T2(°C) | T3(°C) | T4(°C) | T5(°C) | P1(psi) | P2(psi) | P3( psi) | P4( psi) |
|--------------|--------|--------|--------|--------|--------|---------|---------|----------|----------|
| 0.23 kg/s    | 17     | 65     | 54     | 8      | 9      | 30      | 210     | 210      | 40       |
| 0.33 kg/s    | 24     | 69     | 54     | 7      | 17     | 30      | 210     | 205      | 40       |
| 0.39 kg/s    | 25     | 68     | 54     | 7      | 19     | 30      | 200     | 200      | 40       |

**Table 3.** Temperature and pressure refrigerant with TEV

| Cooling load | T1(°C) | T2(°C) | T3(°C) | T4(°C) | T5(°C) | P1(psi) | P2(psi) | P3( psi) | P4( psi) |
|--------------|--------|--------|--------|--------|--------|---------|---------|----------|----------|
| 0.23 kg/s    | 14     | 55     | 55     | 5      | 3      | 30      | 200     | 200      | 40       |
| 0.33 kg/s    | 13     | 60     | 55     | 8      | 6      | 35      | 200     | 200      | 45       |
| 0.39 kg/s    | 12     | 60     | 58     | 9      | 7      | 35      | 200     | 200      | 50       |

Furthermore, Figure 2 shows plot data on the Musicool 134 P-h diagram for parallel expansion valves at variations cooling loads of 0.23 kg/s (left), 0.33 kg/s (right), and 0.39 kg/s (bottom).

**Figure 2.** The plot of P-h diagram of Musicool 134 on the parallel expansion valve at variations of cooling load.
Meanwhile, Figure 3 shows the plot data on the Musicool 134 P-h diagram for TEV at variations in cooling load 0.23 kg/s (left), 0.33 kg/s (right) and 0.39 kg/s (bottom).

![Figure 3](image_url)

**Figure 3.** The plot of P-h diagram of Musicool 134 on TEV at variations of cooling load

### 3.2. Discussion

From the P-h diagram presented in Figure 2 and Figure 3, the specific enthalpy is presented in Table 4 and Table 5.

| Table 4. Performance of the refrigeration system with parallel expansion valves |
|-------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Cooling load            | Compressor work (Wc) | Refrigeration effect (RE) | COP |
|                        | $h_2$ | $h_1$ | $\Delta h$ | $h_3$ | $h_4$ | $\Delta h$ | $W_c/RE$ | |
| 0.23 kg/s               | 664   | 598   | 66    | 588   | 341   | 247    | 3.74   | |
| 0.33 kg/s               | 666   | 612   | 54    | 590   | 341   | 249    | 4.61   | |
| 0.39 kg/s               | 664   | 620   | 44    | 598   | 341   | 257    | 5.84   | |

| Table 5. Performance of an of refrigeration system with TEV |
|-------------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Cooling load            | Compressor work (Wc) | Refrigeration effect (RE) | COP |
|                        | $h_2$ | $h_1$ | $\Delta h$ | $h_3$ | $h_4$ | $\Delta h$ | $W_c/RE$ | |
| 0.23 kg/s               | 642   | 598   | 44    | 578   | 460   | 118    | 2.68   | |
| 0.33 kg/s               | 642   | 598   | 44    | 578   | 462   | 116    | 2.64   | |
| 0.39 kg/s               | 642   | 595   | 47    | 580   | 484   | 96     | 2.04   | |
Figure 4 shows the performance of a vapor compression refrigeration system with Musicool 134 with a parallel expansion valve and TEV. From Figure 4, it can be seen that the refrigeration effects (RE) and COP by parallel expansion valve increase while compressor work decreases with increasing cooling load. This phenomenon occurs because the refrigerant temperature that exits the expansion valve is lower and the refrigerant temperature entering the compressor increases with increasing cooling load. The opposite condition occurs in TEV applications.

![Figure 4. Performance of the refrigeration system with parallel expansion valves (left) and TEV (right)](image)

Furthermore, the comparison of COP of refrigeration systems with parallel expansion valves and TEV is presented in Figure 5.

![Figure 5. Comparison of COP](image)

4. Conclusion
The results of this study indicate that double expansion valves installed parallel provide a positive effect on the performance of vapor compression refrigeration systems with musicool 134 refrigerants, especially for the effects of refrigeration and COP. The highest refrigeration effect produced was 257 kJ/kg and the COP value was 5.84, while the lowest compressor work was 44 kJ/kg for both systems, parallel expansion valves, and TEV. Looking at the results of this study, the use of double expansion valves is promising to conduct further research with various controlled variables.
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