

Performance comparison of a refrigerator system using R134a and hydrocarbon refrigerant (HCR134a) with different expansion devices

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Abstract. The objective of this study is to compare the performance of refrigerator system using working fluid between R134a refrigerant and HCR134a as hydrocarbon refrigerant for substitution of R134a. The use of capillary tube (CT) 1.5 m with HCR134a showed that slightly better COP than among the others, due to the lower pressure of condenser, conversely thermostatic expansion valve (TEV) showed that better COP than among the others with R134a. COP of CT 1.25 m and CT 1.5 m using HCR134a increase about 42.89% and 18.09% compared to R134a, where the electric current of refrigerator system decrease about 11.63% and 10.98%. However, the COP of HCR134a with CT 2.7 m and TEV were obtained lower than R134a about 16.2% and 17.06% and the use of electric current is higher than R134a about 12.98% and 16.5%. The use of HCR134a provides a higher refrigeration effect than R134a about 66.71%-88.27% for various types of expansion devices. The results confirmed that HCR134a could be an alternative refrigerant for replacement of R134a refrigerant.

1. Introduction

The refrigerator systems generally operated using vapour compression refrigeration cycles. The refrigeration cycle has four main components: compressor, condenser, expansion device and evaporator. Refrigerant as the working fluid in the refrigeration cycle will absorb the heat of the evaporator so that the temperature lower than the surrounding temperature, then dissipate this heat of the condenser to surrounding where temperature around condenser higher than the surrounding temperature. The expansion device used to control the refrigerant flow from the high-pressure condensing side in condenser of the system into the low-pressure evaporating side in evaporator. There are two kinds of commonly used expansion device: capillary tubes (CT) and thermostatic expansion valves (TEV).

The pressure drop in the capillary pipe depends on the diameter and length of the pipe. Tube diameters of 0.8–2 mm with lengths of 1–4 m are common. Capillary pipes are usually made of copper with a small pipe diameter. Thermostatic expansion valve (TEV) operated such as embody of mechanism that will detect the superheat of refrigerant gas leaving the evaporator to the suction side of compressor [1]. The TEV used by maintain proper refrigerant flow works automatically depending upon the heat load of the evaporator. If the load on the evaporator increases, refrigerant will evaporate earlier and there will be more superheat at the phial position that charged with the same refrigerant as working fluid in the refrigerator system [1,2]. The evaluation on the use of various expansion valves to the performance of refrigeration system have been presented by many researchers [3-6]. Jia and Lee [7] reported the experimental investigations on the use of CT and TEV in storage-enhanced heat recovery



room air-conditioner, the results confirmed that TEV performs better performance than CT and preferred for use.

The problem of ozone depletion potential (ODP) and increased global warming potential (GWP) led scientists to evaluate more environmentally friendly refrigerants from chlorofluorocarbons (CFC) or hydro-fluorocarbons (HFC) to maintain environmental sustainability such as hydrocarbons (HC). Under the ASHRAE standard, HC refrigerants have flammable properties (A3) that are a deficiency of HC refrigerants. However, the advantages of HC are zero ODP, lowest GWP, non-toxic, and higher refrigerant performance than other refrigerants, and still in accordance with the existing refrigeration system as drop in substitute. HC refrigerants have been used in many cooling applications. Attention and secure handling of system leak for HC refrigerant is same as other refrigerant that has been used for safety reason of application [8-9].

Many researchers [10-13] have reported the better performance of hydrocarbon as alternative refrigerants to R134a, where the energy consumption of hydrocarbons (R436A and R600a) is reduced about 14.6% and 18.7% [14]. Shikalgar and Sapali [15] reported that COP of refrigeration systems with R290 as hydrocarbon refrigerant is comparable with R134a refrigerant and reducing starting torque of compressor including improvement the life span. Joybari et.al [16] conducted the energy analysis and optimization of R600a as a replacement of R134a in a domestic refrigerator system, the mass charge for R600a 66% lower than R134a and reduces the hydrocarbon refrigerant flammability risk. Chopra et al. [17] investigated the thermodynamic analyses of multiple evaporators vapour compression refrigeration systems for various refrigerants (R410a, R290, R1234YF, R502, R404a, R152a) including R134a and the result shows R152a better performances than other considered refrigerants. The use of additional coil for condenser that operated with CFC refrigerant shows better performance [18], while the use of evaporative cooling [19] can be improved refrigeration system performance.

This study is conducted to obtain the effect of different expansion devices (various length CT and TEV) on the performance comparison of refrigerator using R134a and hydrocarbon refrigerant (HCR134a) as substitute of R134a. The results presented in this research are the performance of refrigerator temperature achievement, pressure of evaporator and condenser, electric current consumption, refrigeration effect and COP. The experimental procedure performed will also be useful for future development of refrigerator system and energy saving.

2. Methods

The experimental method used in this study to conduct the performance comparison of a refrigerator system using R134a and hydrocarbon refrigerant (HCR134a) with different expansion devices (various length of CT and TEV). The experimental study was conducted in a refrigerator system test facility at Thermal Engineering Laboratory, Department of Mechanical Engineering, Universitas Riau. The refrigerator system test facility was fabricated for easy control of expansion device used in this study and for replacement of refrigerant as working fluid. This test facility originally designed for R134a refrigerant with 240 g charge and 120 Watt compressor power, where second test with HCR134a (hydrocarbon refrigerant) using 40% refrigerant charge (96 gram) compared to R134a.

Figure 1(a) shows the schematic diagram of refrigerator system test facility with points of data measurement. The expansion devices used in this test facility are three type of CT with length 1.25m, 1.5m, 2.7 m, and one type of TEV with bulb phial containing R134a

refrigerant. Each expansion devices were equipped with a refrigerant valve, if the test was carried out using CT1.25m, the refrigerant valve of the CT 1.25m was opened while the refrigerant valve on the other expansion devices were closed. Figure 1(b) shows the isometric picture of refrigerator system test facility. The components of refrigerator system test facility as shown in figure 1(b)[20] consist of compressor (1), evaporator (2), condenser (3), refrigerated box (4), fan (5), pressure gauge (6), filter drier (7), TEV (8), CT (9), thermometer (10), temperature controller (11), on/off switch (12) and steel frame (13). The data collection was captured every 5 minutes during 2 hours. The data collected from the test using measurement devices are temperature, pressure, and electric current consumption. The calculations performed using the principles of thermodynamics [20] and the thermodynamic properties of the refrigerant were taken using software of REFPROP ver. 8.

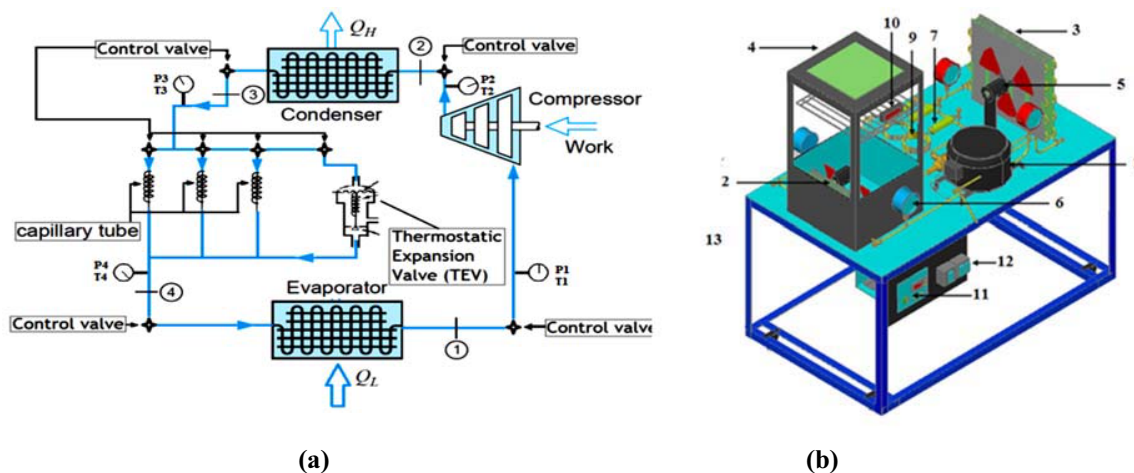


Figure 1.(a) Schematic diagram of refrigerator system test facility that modified from [20] and (b) Isometric picture of refrigerator system test facility [21]

3. Results and Discussion

Figure 2 shows the average box temperature of refrigerator system comparison between HCR134a and R134a at different expansion devices. The average box temperatures with CT 1.25 m and CT 1.5 m using HCR134a compared to R134a tend to be similar with slightly differences as shown in figure 2. This is because the evaporator temperature with CT 1.25 m and CT 1.5 m using HCR134a compared to R134a also slightly lower than the evaporator temperature with CT 1.25 m and CT 1.5 m as shown in figure 2. While the average box temperature with CT 2.7 m and KET using HCR134a are higher than R134a, because the condenser pressure using HCR134a also higher than R134a with CT 2.7 m and KE as shown in figure 4. Base on the proportional relationship between pressure and temperature, when the pressure of compressor increase the temperature of compressor increasing too [20].

As seen in figure 3, the average evaporator pressure with HCR134a for all expansion devices used in this study (CT 1.25 m, CT 1.5 m, CT2.7 m and TEV) higher than average evaporator pressure with the R134a. This is because the latent heat as a part of thermodynamic properties of HCR134a higher than latent heat of R134a, so that the amount of heat that can be absorbed in evaporator by more refrigerants. The higher the amount of heat absorbed in the evaporator the temperature of the refrigerant will be higher too where the evaporator pressure becomes higher too.

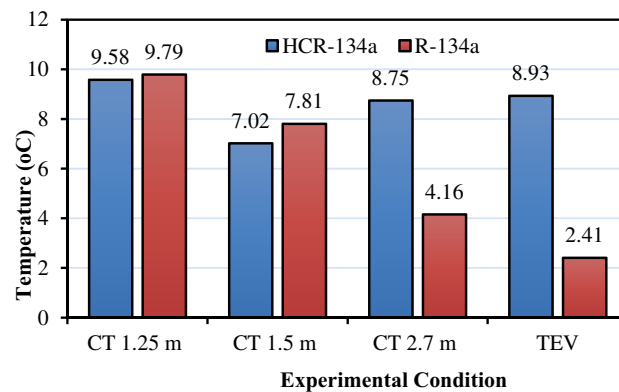


Figure 2. Average box temperature at different expansion devices comparison

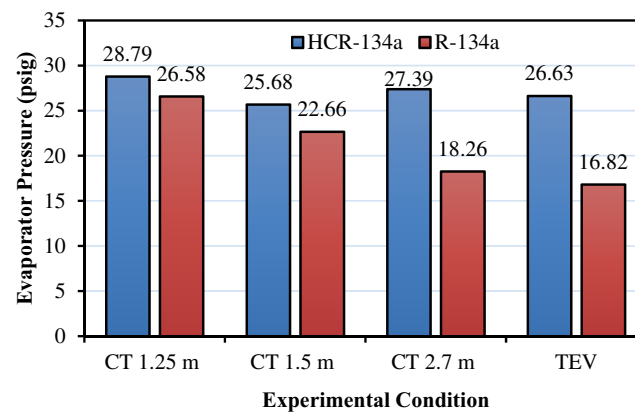


Figure 3. Average evaporator pressure at different expansion devices comparison

Figure 4 shows the average pressure of the condenser with different expansion devices using HCR13a refrigerant and R134a. It can be seen that the condenser pressure using HCR134a is lower than R134a for the capillary tubes of 1.25 m and 1.5 m, while for the CT 2.7 m and KET, condenser pressure using HCR134a is higher than R134a.

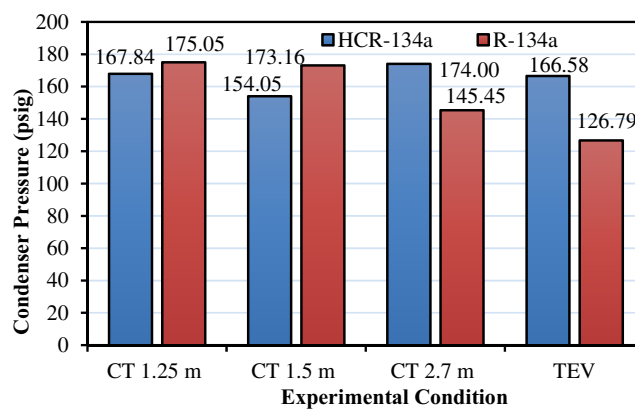


Figure 4. Average condenser pressure at different expansion devices comparison

Figure 5 shows the comparison of average of electric current consumption of compressor using HCR134a and R134a refrigerant with different expansion devices. The experimental result shows that the electric current consumption of compressor using refrigerant HCR134a is lower than R134a about 10.8% and 9.7% for capillary tube 1.25 m and 1.5 m, so that the condenser pressure using HCR134a refrigerant become lower than R134a for testing with CT 1.25 m and 1.5 m where reducing the compressor work due to the lower of electric current consumption using HCR134a. Conversely in the test with CT 2.7 m and KET, the compressor electric current consumption using HCR134a refrigerant are higher about 12.6% and 16.8% respectively than using R134a. This is because the condenser pressure using HCR134a is higher than R134a refrigerant with CT 2.7 m and KET, so the compressor work become heavier and increasing of the electric current consumption using HCR134a refrigerant.

Figure 6 shows a comparison of the refrigeration effect between HCR134a refrigerant and R134a refrigerant with different expansion devices. The analysis of test results obtained that refrigeration effect using HCR134a refrigerant higher than R134a refrigerant with different expansion devices, this is due to the latent heat value of HCR134a refrigerant is higher than refrigerant R134a, which means that amount of heat that can be absorbed by HCR134a refrigerant on evaporator is higher and produce a larger refrigeration effect.

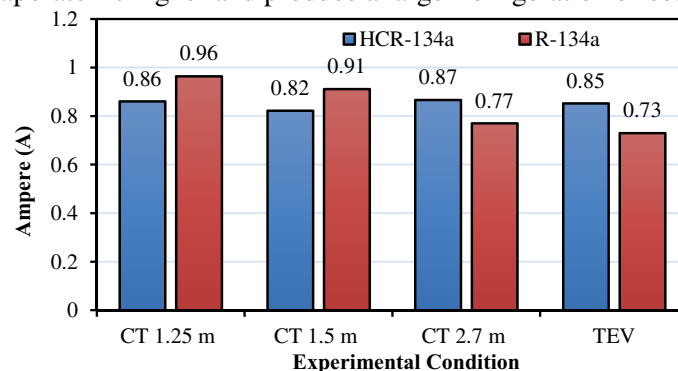


Figure 5. Average electric current consumption at different expansion devices comparison

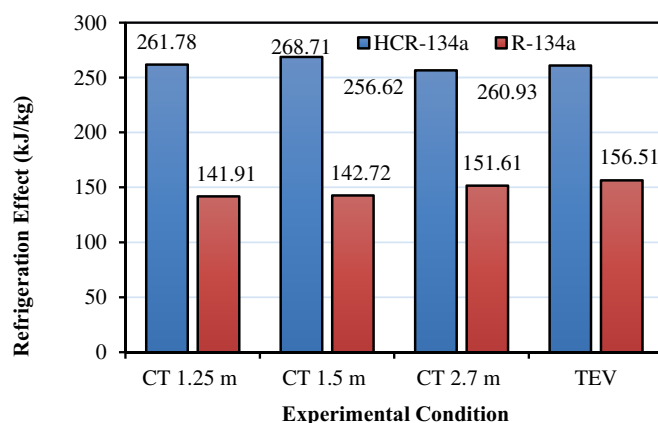


Figure 6. Average refrigeration effect at different expansion devices comparison

Figure 7 compares the COP between HCR134a refrigerant and R134a with different expansion device. It can be seen that COP using HCR134a gives higher result with capillary

tube 1.5 m and 1.25 m, this is due to the HCR134a refrigerant has higher refrigeration effect than R134a refrigerant. However, contrary the COP of refrigerator system using HCR134a refrigerant is lower than R134a refrigerant in with CT 2.7 m tube and KET.

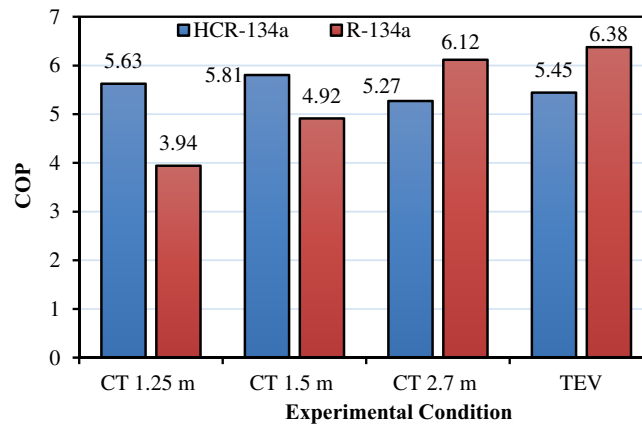


Figure 7. Average COP at different expansion devices comparison

4. Conclusions

The use of different length of CT (1.25 m, 1.5 m, and 2.7m) and TEV in refrigerator system using HCR134a (hydrocarbon refrigerant) compared to R134a refrigerant by experimental investigations. The test result was showed that TEV as expansion device system could better regulate the refrigerant flow than CT where COP of TEV higher than CT. It was found that HCR134a as hydrocarbon refrigerant showed increase the performance with CT 1.25 m and 1.5 m, but decrease the performance with CT 2.7 m and KET. HCR134a hydrocarbon refrigerant could be an alternative refrigerant for replacement the existing R134a refrigerant.

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References

- [1] HundyGF, Trott AR and Welch TC 2008 *Refrigeration and Air-Conditioning* 4th (London: Butterworth-Heinemann) p 103
- [2] Miller R and Miller MR 2006 *Air Conditioning and Refrigeration* (New York: McGraw-Hill) p 300
- [3] Sulaimon S, Nasution H, Aziz AA, Abdul-Rahman AH and Darus AN 2014 *J. Eng. Technol. Sci.* **46** 141
- [4] Choi JM and Kim YC 2002 *Energy* **27** 391
- [5] Peng JW, Li H and Zhang C L 2016 *Appl. Therm. Eng.* **99** 1190
- [6] Aziz A, Mainil RI, Mainil AK and Saputra E 2017 *AIP Conf. Proc.* **1788** 030023
- [7] Jia J and Lee WL 2015 *Energy Build.* **101** 76
- [8] Dalkilic AS and Wongwises S 2010 *Int. Commun. Heat Mass Transf.* **37** 1340
- [9] Harby K 2017 *Renew. Sustain. Energy Rev.* **73** 1247
- [10] Saravanakumar R and Selladurai V 2013 *J. Therm. Anal. Calorim.* **9** 8

- [11] El-Morsi M 2015 *Energy***86** 344
- [12] Pendyala S, Prattipati R and Raju AVSR 2017 *Int. J. AirCond.***25**1750019
- [13] Thakar SM, Prajapati RP and Solanki DC 2017 *IOSR J. Mech. Civ. Eng.***14** 92
- [14] Rasti M, Aghamiri S and Hatamipour MS 2013 *Int. J. Therm. Sci.***74**86
- [15] Shikalgar ND and Sapali SN 2017 *Energy Procedia***109** 34
- [16] Joybari MM, Hatamipour MS, Rahimi A and Modarres FG 2013 *Int. J. Refrig.***36** 1233
- [17] Chopra K, Sahni V and Mishra RS 2014 *Int. J. Air-Conditioning Refrig.***22** 1450003
- [18] Aziz A, Satria AB and Mainil RI 2015 *Int. J. Automot. Mech. Eng.***12** 3043
- [19] Aziz A, Mainil RI, Mainil AK and Listiono H 2017 *AIP Conf. Proc.***1788**030024
- [20] Borgnakke C and Sonntag RE 2009 *Fundamentals of Thermodynamics* 7th(New Jersey: John Wiley & Sons) p 450
- [21] Hartanto BH 2014 *Expansion Device Effect on The Performance of Vapor Compression Refrigeration System*(in Indonesian) Bachelor thesis (Pekanbaru: Universitas Riau) p 29