Performance Evaluation Of Refrigerated Pickup Truck Using Hydrocarbon Refrigerants

Kamin Sumardi[1*],and *Ega* Taqwali Berman[2]

[12]Departemen of Mechanical Engineering, Universitas Pendidikan Indonesia, Bandung, Indonesia

Abstract. HFCs group refrigerants are still widely used in refrigerated pickup trucks. This refrigerant is a synthetic chemical and has a high potential to cause global warming and damage the ozone layer. This study aims to obtain performance data from the use of HCs as refrigerant in refrigerated pickup trucks. The research was conducted experimentally on a pickup truck with a 1500 cc engine capacity. The size of the refrigerated room is 2300 mm long, 1500 mm wide and 1400 mm high. A commercial refrigeration system (C-250e MAX, Thermo King Europe, Belgium). The size of the evaporator, which consists of a cold air supply fan and an intake fan, is 133 mm long, 985 mm wide and 525 mm high. The cooling capacity is 2770 W. The volumetric flow rate of cold air is 1100 m3/hr. The test started at 9 am and the temperature value in a gallon of water was measured for 120 minutes. The results showed that the optimal refrigerant filling was the use of R290 (35%) and R1270 (20%). The value of the coefficient of system performance obtained from the use of the two variations of HCs is 4. Thus, refrigerant HCs R290 and R1270 can replace refrigerant HFCs in refrigerated pickup trucks with refrigerant mass variations of R290 (35%) and R1270 (20%).

1 Introduction

Refrigerated pickup trucks play an important role in the food cold chain [9]. It transports products such as fresh vegetables and fruits, meat, dairy products, beverages, medicines, vaccines, and other items that are sensitive to temperature [12, 16]. During the cooling process, temperature is an important factor that must be considered in order to maintain product quality [5]. The accuracy of temperature control during the refrigerated transportation process has an effect on the ease of distribution, reducing damage, and the safety of food products to consumers [7, 22]. Globally, it is estimated that the number of refrigerated trucks operating in the world was more than 15 million in 2012 and is expected to increase by 2.5% by 2030 [1, 21].
Currently, the majority of transport refrigeration units operate on vapor compression refrigeration systems (VCRS) using synthetic hydrofluorocarbons refrigerants (HFCs) such as R404A and R134a which are considered as refrigerants that are not environmentally friendly [26]. Although HFCs refrigerants do not destroy ozone (ODP = 0), they have a high global warming potential (GWP) as shown in Table 1.

* Corresponding author: kaminsumardi@upi.edu

Table 1 Environmental effect of different groups of refrigerants [8, 13, 17]

Refrigerant Group	Refrigerant Example	ODP	GWP (100 year)	Atmospheric life time (years)	Flammability	Comments
CFCs	R11, R12, R115	0.6–1	4750–14,400	45–1700	Non-flammable	Very high ODP and GWP
HCFCs	R22, R141b, R124	0.02–0.11	400–1800	1–20	Non-flammable	Medium ODP and GWP
HFCs	R404A, R32, R134a	0	140–11,700	1–300	Non-flammable	Zero ODP & medium GWP
HFOs	R1234yf, R123ze, R1234yz	0	< 0–12	--	Flammable	Zero ODP & low GWP
HCs	290, R600, R600a, R1270	0	0	Few days	Flammable	Zero ODP & zero GWP

*Note:
CFCs: Chlorofluorocarbons; HCFCs: Hydrochlorofluorocarbons; HFCs: Hydrofluorocarbons; HCs: Hydrocarbons and HFOs: Hydrofluoroolefins; ODP: Ozone Depletion Potential; GWP: Global Warming Potential.

In order to preserve the environment and the health of living things, alternative refrigerants are needed to replace the HFCs group [4, 10]. Many researchers are involved in research to find alternative refrigerants with high efficiency and less environmental effects. The use of natural refrigerants has attracted changing interest over the last decade. Among natural refrigerants, hydrocarbons (HCs) have the potential to replace existing refrigerants. Hydrocarbons that are often used as refrigerants to replace HFCs are propane R-290 and propylene R1270 [15, 17].
Studies reveal that several HCs exhibit promising and attractive thermal and physical properties [3, 19, 27]. It is said that R290 provides a better alternative solution as it offers high performance, allows the use of reduced mass loads, low generation temperatures and no corrosion of metals. The high flammability of R290 is offset by the advantages of having zero ODP and less GWP (<150) [6, 11]. Another advantage that has been reported is that R290 uses less compressor power and refrigerant charge in the system than R134a to achieve the same performance [14].
On the other hand, propylene R1270 has a high latent heat of vaporization. It also has compatibility with mineral oils and components found in many refrigeration and air conditioning systems [2]. Another strength of R-1270 is that it is not harmful to the ozone layer (ODP = 0) and has a low effect on global warming, namely GWP < 2. However, this HCs refrigerant has not been widely used by refrigeration machine manufacturers in refrigerated pickup truck units [24]. This is because there are concerns from consumers regarding its flammability. These characteristics are actually harmless if the refrigerant is used with proper procedures. One of the most effective ways to reduce the potential flammability risk with the use of hydrocarbons is to reduce the load in the system [20, 23]. Therefore, this study aims to obtain performance data from the use of HCs as refrigerant in refrigerated pickup trucks.

2 Method

2.1 Refrigerated room arrangement

The refrigerated chamber for the commercial refrigeration truck used in this study. The refrigerated chamber is made of insulating walls consisting of polyurethane and aluminum panels, and the dimensions of the chamber are 2300 mm long, 1500 mm wide, and 1400 mm high. The thickness of the front and top of the insulating wall and other walls is 80 mm and 70 mm, respectively. A commercial refrigeration system (C-250e MAX, Thermo King Europe, Belgium) consisting of an evaporator, compressor, condenser and refrigerant controller is installed in the body. The size of the evaporator, which consists of a cold air supply fan and an intake fan, is 133 mm long, 985 mm wide and 525 mm high. The cooling capacity of the refrigeration system is 2770 W. The volumetric flow rate of cold air is 1100 m3/hour. The cooling load used in the room is one gallon of water.

2.2 Experimental procedure

All experiments started at 9 am and the temperature value in a gallon of water was measured for 120 minutes. The set temperature and temperature drop values (re-operating temperature) of the refrigeration system are -20 C and 2 C, respectively. The defrosting period is set to 2 hour intervals. The experiment was conducted in June 2022, and the average temperature outside from 9 am to 11 pm was 28 C (107º36'E, 6º55'S, Bandung, Indonesia). Fig. 1 shows the location where the temperature sensor is installed. The sensor for temperature control of the cooled room is installed at the bottom of the evaporator intake fan. Two temperature and humidity probes (Elitech, China) are mounted on the outside of the refrigerated chamber of the condensing unit to measure temperature and humidity every 5 minutes. In addition, the pressure and temperature of the refrigerant flowing in the refrigeration system were measured using a manifold gauge (DUOYI DY517A, China).

Fig. 1. Installation position of temperature sensor

The research was conducted experimentally using three refrigerants, namely R134a as the default refrigerant, R290 and R1270 as an alternative refrigerant. The replacement of refrigerant by R290 and R1270 uses the drop in substitute method, namely the replacement of refrigerant without changing the original component of the refrigeration system. Testing the performance of the refrigeration system is carried out in three stages to determine the difference between each refrigerant used. In the first stage the refrigeration system operates using R-134a with a refrigerant mass of 1150 gr filled. Parameter data taken include suction pressure, discharge pressure, and evaporator temperature. Furthermore, in the second stage, the refrigerant is replaced by R290. The mass of refrigerant that is filled into the refrigeration system is varied four times with a ratio of the mass of R290 to the default refrigerant from 20% to 35%. The total mass of refrigerant R-134a that is fed into the refrigeration system is m = 1150 gr. While the mass amount of refrigerant R290 that is filled is 230 gr, 287.5 gr, 345 gr, and 402.5 gr. Then the performance of the refrigeration system from each variation of the mass of the circulated refrigerant is tested. In the final stage, the refrigerant is replaced by R1270. Each test step in this stage is the same as the second stage when using the R290.
After obtaining the refrigeration system performance data from all refrigerants, then they are compared with each other by observing the decrease in the evaporator temperature, the effect of refrigeration, the heat of compression and the engine performance figure (CoP). The effect of

refrigeration, working heat of compression, and CoP of the refrigerator cooling machine are calculated using equations (1), (2), and (3).

$$RE = h_2 - h_1 \quad (1)$$
$$WK = h_3 - h_2 \quad (2)$$
$$CoP = RE / WK \quad (3)$$

*Note:
RE = *Refrigeration Effect* (kJ/kg)
Wk = Work of Compression (kJ/kg)
COP = Coefficient of performance of refrigeration cycle
h_1 = specific enthalpy of refrigerant at evaporator outlet (kJ/kg)
h_2 = specific enthalpy of refrigerant at compressor outlet (kJ/kg)
h_3 = specific enthalpy of refrigerant at evaporator inlet (kJ/kg)

3. Results and Discussion

Tests on the use of HCs R290 and R1270 as alternative refrigerants to replace HFCs in refrigerated pickup trucks have been carried out. The mass of refrigerant that is filled into the refrigeration system is varied from 20% to 35% of the mass of the original refrigerant with an interval of 5% increments. The filling variation is intended to determine the most optimal refrigerant mass in producing the best refrigeration system performance. System performance indicators are based on the highest value of the refrigeration effect and the coefficient of performance and the lowest compression work.

3.1 Refrigeration effect

Fig. 2 presents the amount of heat that can be absorbed by the refrigerant when flowing in the evaporator (refrigeration effect) for each mass variation of refrigerant HCs from 10 to 120 minutes of cooling time. Overall it can be seen that the heat absorption is much higher in the refrigerant mass R290 (35%) and R1270 (20%) compared to the other six refrigerant mass variations throughout the cooling time.
To begin with, the refrigeration effect values of HCs R290 (20%), R290 (25%), and R290 (30%) followed a fairly similar pattern during the first 70 minutes, all remaining between 273.5 kJ/kg and 274.7 kJ/kg. The general trend for R290 (25%) was an increase in the number of refrigeration effects during the period, with a value of 273.6 kJ/kg at minutes 120. On the other hand, R290 (20%) and R290 (30%) experienced a fluctuating downward trend, until the effect was assessed. refrigeration 274 kJ/kg and 273 kJ/kg, respectively. Likewise, the number of refrigeration effects of R1270 (25%), R1270 (30%), and R1270 (35%) showed a downward trend until the end of the cooling period. Interestingly, the total refrigeration effect of R290 (35%) and R1270 (205) starts at 280 kJ/kg, far exceeding the mass variation of other refrigerants. It then fluctuates over a period of cooling time, until at the end it reaches a total refrigeration effect of 275 kJ/kg and 281 kJ/kg, respectively.

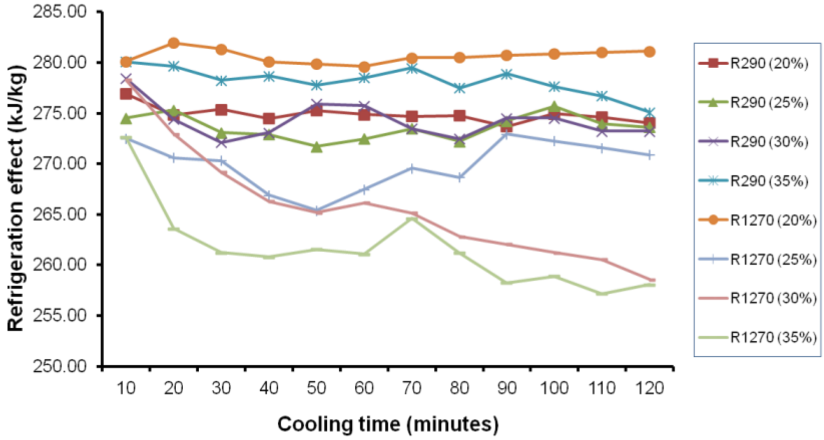

Fig. 2. Refrigeration effect of mass variation of refrigerant HCs

3.2 Work of compression

Fig. 3 shows a graph of the change in calorific value resulting from compression work of HCs R290 and R1270 with eight variations of refrigerant mass during a cooling time of 120 minutes. In general, all compression working prices of both HCs refrigerants show a sharp increasing trend. At R1270 (25%), R1270 (30%), and R1270 (35%) the compression work price starts from 62 kJ/kg to a peak of 92.6 kJ/kg at the end of the cooling time. Meanwhile, the price of compression work at R290 (20%), R290 (25%), and R290 (30%) showed a gentle upward trend. Starting from the working price of 55 kJ/kg compression at the beginning of the period until the price increases at the end of the cooling period to 73 kJ/kg. On the other hand, there is a significant difference between the R290 (35%) and R1270 (20%) compression working prices which, despite periodic fluctuations, continued to increase during this period. In fact, the compression working rates of R290 (35%) and R1270 (20%) only rose temporarily at 50 and 60 minutes, respectively. Furthermore, there is a decrease in the price of compression work until the end of the cooling time. Based on the overall results of the compression work of the two HCs refrigerants, the compression work that has the lowest price is chosen as a benchmark for the mass of refrigerant that is filled into the refrigeration system.

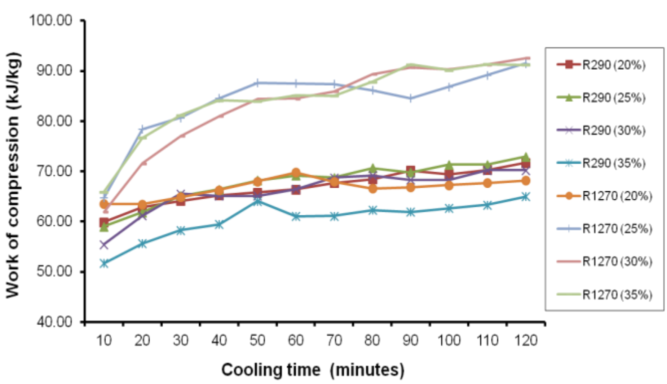

Fig. 3. Work of compression of mass variation of refrigerant HCs

3.3 Coefficient of performance

Fig. 4 depict the performance coefficient values of eight mass variations of refrigerant HCs R290 and R1270 during a cooling time of 120 minutes. Overall it can be seen that the price of the performance coefficient experienced a downward trend during the cooling time. Since the initial minutes of cooling there has been a drastic decrease in the performance coefficient of R1270 (25%), R1270 (30%), and R1270 (35%). Although the chart shows a slight increase in price the performance coefficient of R1270 (25%) in 90 minutes. However, in the last minute of cooling down, all the performance coefficients of the three variations of the HCs 1270 decreased drastically.
The same phenomenon also occurs at the coefficient of performance of the refrigerant mass R290 (20%), R290 (25%), and R290 (30%). At the beginning of the cooling time, the coefficient of performance of R290 (20%) and R290 (25%) is 4.6. While the price coefficient of performance R290 (30%) is 5.5. Furthermore, during the cooling time, all the prices for the coefficient of performance decreased until they reached a price of 3.8. On the other hand, the performance coefficient values of R290 (35%) and R1270 (20%) are higher than the other six mass variations of refrigerant HCs. Even though the price of R1270 (20%) at the beginning of the cooling time is less than the value of the performance coefficient of R1270 (30%). But at the end of the cooling time the price is the highest compared to other R1270 HCs. Likewise, the price coefficient of performance R290 (35%), since the beginning of the cooling already has the highest price. Even though the cooling time has decreased, the price coefficient of performance remains the highest compared to the others [25].

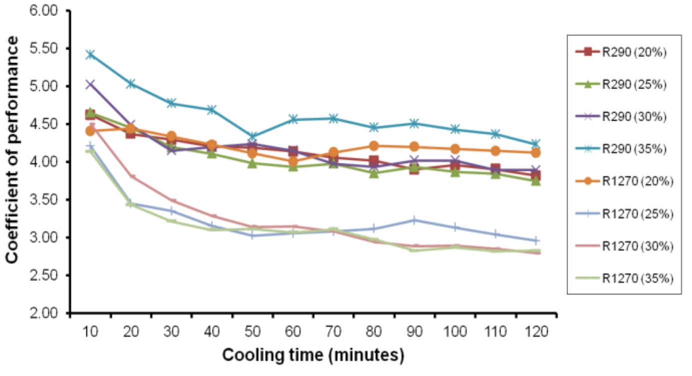

Fig. 4. Coefficient of performance of mass variation of refrigerant HCs

4. Conclusion

The use of refrigerant HCs R290 and R1270 with refrigerant mass variations ranging from 20% to 35% with an interval of every 5% increase in the refrigerated pickup truck system has been implemented. The optimal result is the use of R290 (35%) and R1270 (20%). The value of the coefficient of system performance obtained from the use of the two variations of HCs is 4. Thus, refrigerant HCs R290 and R1270 can replace refrigerant HFCs in refrigerated pickup truck systems with variations in refrigerant mass, respectively R290 (35%) and R1270 (20%).

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References

1. Adekomaya, O., Jamiru, T., Sadiku, R., & Huan, Z. Sustaining the shelf life of fresh food in cold chain-A burden on the environment. Alexandria Engineering Journal, 55(2), 1359-1365 (2016).
2. Abas, N., Kalair, A. R., Khan, N., Haider, A., Saleem, Z., & Saleem, M. S. Natural and synthetic refrigerants, global warming: A review. Renewable and Sustainable Energy Reviews, 90, 557-569 (2018).
3. Berman, E. T., Hapidz, R. A., Sumardi, K., and Mutaufiq, M. Uji Performa Wall Mounted Split Air Conditioner Menggunakan Refrigeran Hc-290 sebagai Pengganti Refrigeran HCFC-22. Flywheel, 5(1), 94-97 (2019).
4. Choudharia, C.S., & Sapali, S. N. Performance Investigation of Natural Refrigerant R290 as a Substitute to R22 in Refrigeration Systems. Energy Procedia, 109, pp. 346-352 (2017). https://doi.org/10.1016/j.egypro.2017.03.084
5. Defraeye, T., Tagliavini, G., Wu, W., Prawiranto, K., Schudel, S., Kerisima, M. A., Verboven, P., & Bühlmann, A. Digital twins probe into food cooling and biochemical quality changes for reducing losses in refrigerated supply chains. Resources, Conservation and Recycling, 149, 778-794 (2019).
6. Gao, E., Cui, Q., Jing, H., Zhang, Z., & Zhang, X. A review of application status and replacement progress of refrigerants in the Chinese cold chain industry. International Journal of Refrigeration, 128, 104-117 (2021).
7. Han, J. W., Zuo, M., Zhu, W. Y., Zuo, J. H., Lü, E. L., & Yang, X. T. A comprehensive review of cold chain logistics for fresh agricultural products: Current status, challenges, and future trends. Trends in Food Science & Technology, 109, 536-551 (2021).
8. Harby, K. Hydrocarbons and their mixtures as alternatives to environmental unfriendly halogenated refrigerants: An updated overview. Renewable and Sustainable Energy Reviews, 73, 1247-1264 (2017).
9. Islam, M., Kabir, A., Arka, A. M., & Rahman, M. A. Assessment of the transport refrigeration system in Bangladesh and numerical simulation of the refrigeration performance. In AIP Conference Proceedings 2121(1), p. 030013 (2019). AIP Publishing LLC.
10. Johnson, E. Global warming from HFC. Environmental Impact Assessment Review, 18(6), 485-492 (1998).
11. Kashyap, P. K, Kasaudhan, A., Singh, A. K., and Chaudhary, D. Performance Investigation of R290 as a Substitute to R22 Refrigeration System. International Journal of Engineering Research & Technology. 10(9), 83-90 (2021). doi: 10.17577/ijertv10is090016.
12. Kivevele, Propane (HC–290) as an Alternative Refrigerant in the Food Transport Refrigeration Sector in Southern Africa–a Review. Automotive Experiences, 5(1), 75-89 (2022).
13. Koh, J. H., & Zakaria, Z. Hydrocarbons as refrigerants? a review. ASEAN Journal on Science and Technology for Development, 34(1), 35-50 (2017).
14. Kong, X., Zhang, M., Yang, Y., Li, Y., and Wang, D. Comparative experimental analysis of direct-expansion solar-assisted heat pump water heaters using R134a and R290. Solar Energy, 203, 187-196 (2020).
15. Kumar, A., & Kama, N. Design of Domestic refrigerator using Propylene (R1270) as refrigerant. International Journal of Latest Engineering and Management Research, 2(4), 14-18 (2017).
16. Mercier, S., Villeneuve, S., Mondor, M., & Uysal, I. Time–temperature management along the food cold chain: A review of recent developments. Comprehensive Reviews in Food Science and Food Safety, 16(4), 647-667 (2017).

17. Mohanraj, M., Jayaraj, S., Muraleedharan, C., & Chandrasekar, P. Experimental investigation of R290/R600a mixture as an alternative to R134a in a domestic refrigerator. International Journal of Thermal Sciences, 48(5), 1036-1042 (2009a)
18. Mohanraj, M., Jayaraj, S., & Muraleedharan, C. Environment friendly alternatives to halogenated refrigerants-A review. International Journal of greenhouse gas control, 3(1), 108-119 (2009b).
19. Mutaufiq, M., Sulistyo, H., Berman, E. T., & Wiyono, A. Investigasi Eksperimental Retrofit Refrigeran pada Alat Praktik Refrigerator dengan Refrigeran Produk Domestik yang Ramah Lingkungan. Flywheel: Jurnal Teknik Mesin, 1(1), 51-56 (2019).
20. Palm, B. Hydrocarbons as refrigerants in small heat pump and refrigeration systems–a review. International journal of refrigeration, 31(4), 552-563 (2008).
21. Rai, A., & Tassou, S. A. Environmental impacts of vapour compression and cryogenic transport refrigeration technologies for temperature controlled food distribution. Energy Conversion and Management, 150, 914-923 (2017).
22. Ramaube, M and Z, Testing and Performance Evaluation of a R404A Transport Refrigeration System Retrofitted With R290. AIUE Proceedings of the 17th Industrial and Commercial Use of Energy (ICUE) Conference 2019, Cape Town, ISBN 978-0-6399647-4-4, (2019). Available at https://ssrn.com/abstract=3658977 or http://dx.doi.org/10.2139/ssrn.3658977
23. Shishov, V. V., & Talyzin, M. S. Efficiency of refrigeration equipment on natural refrigerants. Chemical and Petroleum Engineering, 56(5), 385-392 (2020).
24. So, J.H.; Joe, S.Y.; Hwang, S.H.; Jun, S.; & Lee, S.H. Analysis of the Temperature Distribution in a Refrigerated Truck Body Depending on the Box Loading Patterns. Foods, 10, 2560 (2021). https://doi.org/10.3390/foods10112560
25. Sumardi, K., Berman, E. T., & Mutaufiq, M. The Performance of Vapor Compression Refrigeration System Using R-1270. Flywheel: Jurnal Teknik Mesin, 7(1), 21-27 (2021).
26. Tassou, S. A., De-Lille, G., & Ge, Y. T. Food transport refrigeration-Approaches to reduce energy consumption and environmental impacts of road transport. Applied Thermal Engineering, 29(8-9), 1467-1477 (2009).
27. Zheng, H., Tian, G., Zhao, Y., Jin, C., Ju, F., & Wang, C. Experimental study of R290 replacement R134a in cold storage air conditioning system. Case Studies in Thermal Engineering, 36, 102203 (2022). https://doi.org/10.1016/j.csite.2022.102203