Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 45 No. 6
June 2024

An Experimental Study on The Performance Evaluation of Refrigerant (R134a/R1234yf) In Automobile HVAC System

Rajamanickam C.S.[a]*, Tamil Selvan P [b]

[a] Student, School of Mechanical Engineering, VIT University, Chennai - 600127, India
Email: rajamanickam.cs2013@vit.ac.in
[b] Professor, School of Mechanical Engineering, VIT University, Chennai – 600127, India
Email: tamilselvan.p@vit.ac.in

ABSTRACT

Automobile manufacturers are being compelled to use parts with lower environmental impact due to stricter environmental regulations. One promising alternative is the R1234yf refrigerant, which has a significantly lower Global Warming Potential (GWP) compared to the widely used R134a. In order to assess the performance of these two refrigerants and explore potential improvements for R1234yf, a study was conducted. The research focused on the advantages of incorporating an Internal Heat Exchanger (IHX) into a standard automobile air conditioning system that utilizes R1234yf. The tests were conducted under varying compressor speeds and air temperatures. The findings revealed that using R1234yf with an IHX achieved a comparable cooling capacity (7.25 kW) to that of an R134a system (7.05 kW), even under more challenging conditions. Furthermore, the Coefficient of Performance (COP), which indicates efficiency, was higher for the R1234yf with IHX system (4.3) compared to the baseline R134a system (4.2). Based on this study, it can be inferred that R1234yf, when combined with an IHX and a well-designed evaporator, can be a favourable choice for car air conditioning systems with minimal environmental impact. Switching from R134a to R1234yf provides a solution to address environmental concerns without compromising system performance.

Keywords: *Automobile HVAC systems; Cooling capacity; COP; Experimental analysis; IHX; R1234yf ; R134a*

1.INTRODUCTION

Various applications have employed refrigerants that have the potential to significantly contribute to global warming, with automobile air conditioning being an important area of use. R134a is a widely used refrigerant in automobiles due to its non-toxic, non-corrosive, and non-flammable properties. It is widely used in various industries, including refrigeration, polymer foam blowing, and aerosol products. In the plastic foam blowing industry, R134a is used as a blowing agent to create foam insulation for various applications, such as in construction and packaging. The automobile industry has also been using R134a as a replacement for CFC12 since 1994. CFC12 was a popular refrigerant used in automobile air conditioning systems, but it was found to have a high ozone depletion potential. R134a, on the other hand, has no ozone depletion potential, making it a safer and more environmentally friendly alternative. R134a is a chemical compound that consists of two carbon atoms, two hydrogen atoms, and four fluorine atoms. The letter 'a' in its name represents a constant or serves as an indicator.

The Montreal Protocol, established in 1987, recognized that certain refrigerants were depleting the ozone layer and recommended replacing them with refrigerants that have a reduced ability to contribute to global warming. Furthermore, the European Union (EU) has prohibited the use of R134 in newly manufactured models of mobile air conditioning systems. Vapour compression cycles, which primarily function in automobile air conditioning systems, frequently employ R134a refrigerant. However, its global warming potential of 1430 exceeds the threshold set by the Montreal Protocol, necessitating its gradual elimination and the development of a new refrigerant with a reduced capacity to contribute to global warming for automobile air conditioning systems.

There is a clear need to find better alternatives that do not deplete the ozone layer and have absolutely no association with climate change. A new refrigerant, R1234yf, has a lower GWP than R134a. The GWP of R1234yf is 4, which means it satisfies the criteria of the automobile air-conditioning guideline that was issued in July 2006. In the past, maintaining a higher coefficient of performance was not as critical due to relatively low energy prices.

However, in today's context, a higher coefficient of performance is of utmost importance for the following reasons.

i. Compared to the last refrigerant adjustment, energy expenses in general have risen sharply.
ii. The coefficient of performance drops as a result of switching to refrigerants having a reduced global warming potential. The refrigeration ratio's effect on the system's input network measured as coefficient of performance.

A vapour compression refrigeration system's coefficient of performance may be improved in two ways:

i. By increasing the refrigeration effect
ii. By reducing the work input to the system.

R134a remains the most common refrigerant used in automobile air conditioning systems today. According to the Environmental Protection Agency’s (EPA) 2021 air-conditioning refrigerant regulation and motor vehicle directive, to protect environment, beginning of January 1, 2028, new passenger vehicles cannot utilize refrigerants with a global warming potential higher than 150. That is why we need to find an alternative to R134a. With certain adjustments to the expansion valve and design modifications R1234yf, a refrigerant with comparable thermodynamic qualities, may be used as a suitable alternative for R134a.

Generic experimental studies comparing R134a and R1234yf refrigerants under different operating conditions with and without an internal heat exchanger (IHX) revealed that a decrease of 13 to 6 percent in cooling capacity and coefficient of performance was observed when R134a was substituted with R1234yf. Additionally, the reduced efficiency of the internal heat exchanger contributed to a further decrease in performance, ranging from 6 to 2 percent (Esbr, J. N et al, 2013).

As a better alternative to R134a, R1234yf has a molecular weight and typical boiling point that are almost equal. Some have proposed R1234yf as a substitute for R134a in portable air conditioners since it is less likely to cause climate change and works just as well. Even though it's essential for home air conditioning, its performance isn't up to par with R410a. It should be mentioned that air conditioning is an important component of contemporary automobiles, especially in hot climates like the tropic (Alison et al, 2014).

In mobile air conditioning applications, the environmental friendly refrigerant R1234yf is being investigated as a substitute for R134a due to its comparable thermal properties. According to the various experimental results, R1234yf has the best thermal performance of all refrigerants and performs comparable to R134a in all metrics.

2.EXPERIMENTAL SETUP

2.1.Apparatus and Procedures

The fundamental vapor compression system, which acts as the operational foundation for the majority of refrigeration and air conditioning systems, consists of four primary components: a compressor, a condenser, an evaporator, and a thermal expansion valve. In this scenario, the reference system utilized for comparison purposes is an R134a HVAC system, where the R134a refrigerant is substituted with R1234yf for performance assessment..

The compressor is a crucial component in any heating, ventilation, and air-conditioning (HVAC) system as it is responsible for increasing the pressure and temperature of gas, producing superheated vapor that is then pumped into the condenser. This ensures the continuous flow of refrigerant, making the compressor vital to the HVAC system. For the experiment, an 80cc vane rotary compressor was utilized.

The condenser in the HVAC system plays a key role in converting the superheated vapor into a liquid state through a phase change process, reducing its temperature. The resulting saturated liquid is then transferred to the evaporator. In automotive HVAC systems, the condenser is typically positioned between the engine-cooling radiator and the car's grille, where the refrigerant heat is dissipated, transforming into refrigerant liquid before being transferred to the evaporator. A super high power (SPH) condenser with a diameter of 16mm was selected for the experiment. The Thermal Expansion Valve (TXV) is responsible for lowering the pressure and temperature of the refrigerant from the condenser, providing a low-pressure refrigerant with reduced temperature to enter the evaporator. This valve regulates the flow rate of refrigerant into the evaporator. Various cross-charged 2.0T TXV models were employed for this purpose.

S.No	Compressor	Condenser Airflow		Evaporator Airflow		
	RPM	Flow l/s	Temp °C	Flow l/s	Temp °C	RH %
1	800	600	45	140	43	40
2	1800	650	45	140	43	40
3	2500	700	45	140	43	40
4	800	600	37	140	35	40
5	1800	650	37	140	35	40
6	2500	700	37	140	35	40
7	800	600	27	100	25	40
8	1800	650	27	100	25	40
9	2500	700	27	100	25	40

Table 1: Validation Matrix

Table 1 illustrates the process parameters and combinations employed for the performance evaluation typically conducted in the automobile industry. The compressor rotating speed is tested at three different levels: 2500 RPM, 1800 RPM, and 800 RPM. Additionally, the evaluation includes three varying values for the condenser inlet temperature: 45°C, 37°C, and 27°C, as well as the evaporator inlet temperature: 43°C, 35°C, and 25°C.

The enhanced configuration includes an internal heat exchanger and a high-efficiency evaporator. The internal heat exchanger (IHX) is a component utilized to improve the HVAC system's performance by subcooling the refrigerant prior to entering the evaporator. Its primary purpose is to facilitate heat transfer between low and high-pressure zones. This feature is specifically integrated into HVAC systems to enhance the heat exchange between the high-temperature liquid entering the evaporator from the condenser and the low-temperature vapor entering the compressor from the evaporator. By optimizing heat transfer, the cooling capacity and COP of the system are enhanced by reducing the necessary inlet quality to the evaporator. Consequently, manufacturers of air conditioning and refrigeration systems widely employ internal heat exchangers to improve the efficiency of the refrigeration cycle without the need to substitute commonly used refrigerants like R134a. To enhance fuel economy, it is imperative to utilize energy efficiently without compromising vehicle performance. HVAC systems consume a significant amount of energy, impacting the fuel efficiency of vehicles, which can be partially mitigated by incorporating an internal heat exchanger. However, the presence of an internal heat exchanger before a compressor may result in releasing higher temperature refrigerant into the compressor, potentially causing adverse effects on its durability. Therefore, careful consideration should be given to the application of internal heat exchangers in HVAC systems.

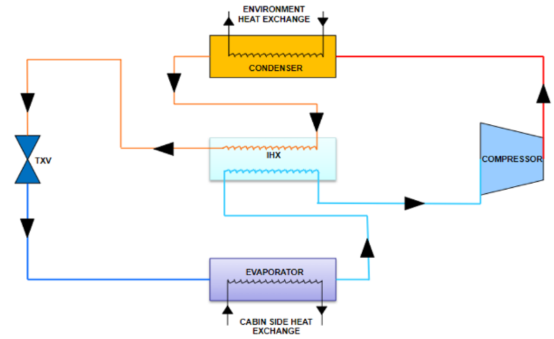

Figure 1: Experimental Set of HVAC

The impact of IHX on automotive HVAC systems utilizing R1234yf has been the subject of recent research by various scholars. Direk et al. conducted a study highlighting the importance of this technology, revealing that the cooling capacity increased by approximately 12% and the COP saw a 6% enhancement. Additionally, the compressor power exhibited an improvement of up to 8%. Volumetric and Isentropic efficiency were also found to be enhanced by minimizing total exergy destruction. Therefore, the incorporation of IHX with R1234yf in automotive HVAC systems is expected to significantly enhance both the COP and cooling capacity [15]. Traditional automotive HVAC systems typically consume a substantial amount of energy, impacting fuel efficiency. The integration of IHX with the HVAC system reduces energy consumption, thereby enhancing fuel efficiency. According to research conducted by Li et al., a 14% reduction in energy consumption can be achieved at an ambient temperature of 25°C [16].

The baseline setup's plate fin type evaporator has been substituted with a tube-fin type to reduce air side pressure drop. The evaporator, constructed of prime-surface bare-tube coil, is categorized as finned-tube evaporators. It incorporates metal fins or plates to enhance the surface area for heat transfer and is more compact in size, yet provides comparable heat transfer capacity to a larger prime-surface evaporator.

3. RESULTS AND DESCUSSION

3.1. Performance comparison of R134a and R1234yf

Based on Figure 2, it can be observed that the P-T curve for both refrigerants is similar. The saturation pressure of R1234yf is higher below 30°C and lower above 30°C compared to R134a.

The comparison of Superheat (SH) between the two refrigerants at various evaporator inlet temperatures (25°C, 35°C, 43°C) for different compressor rotating speeds (2500, 1800, and 800 RPM) is summarized in Table 2.

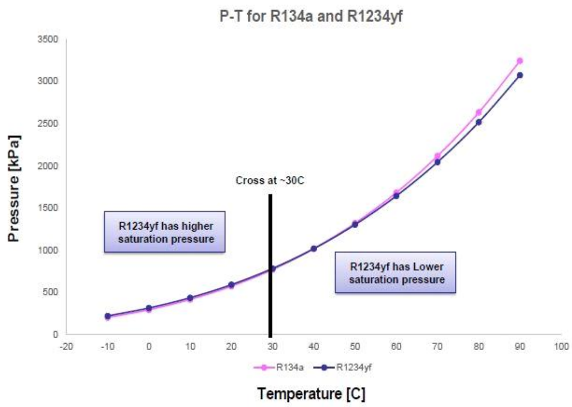

Figure 2: Pressure Vs Temperature Diagram for R134a and R1234yf refrigerants

Evaporator Airflow Temperature	Compressor Speed	Superheat Temperature						
		R134a baseline	R1234yf 2T high SH	R1234yf 2T low SH	R1234yf 2.5T high SH	R1234yf 2.5T low SH	R1234yf 1.75T high SH	R1234yf 1.75T low SH
ºC	RPM	ºC	ºC	ºC	ºC	ºC	ºC	ºC
25	800	1.5	7	1.5	5	1.3	5.8	1.7
	1800	1.8	6.8	1.1	5	1.5	5.8	1.9
	2500	1.6	6.5	0.9	5	0.8	5.8	2.1
35	800	6.2	10.3	6.2	8.7	6.4	12	8.2
	1800	4.2	10	6.3	8.4	6.2	12.2	8.5
	2500	3.9	10	0	8	6.4	10	9.7
43	800	10.2	13.2	10.2	13.9	10.2	14.5	12.3
	1800	10.2	13.2	10.2	13.9	10.2	14.5	12.3
	2500	6.4	14.1	10	12.3	8.6	16.1	14

Table 2: Superheat (SH) Temperature of R134a and R1234yf

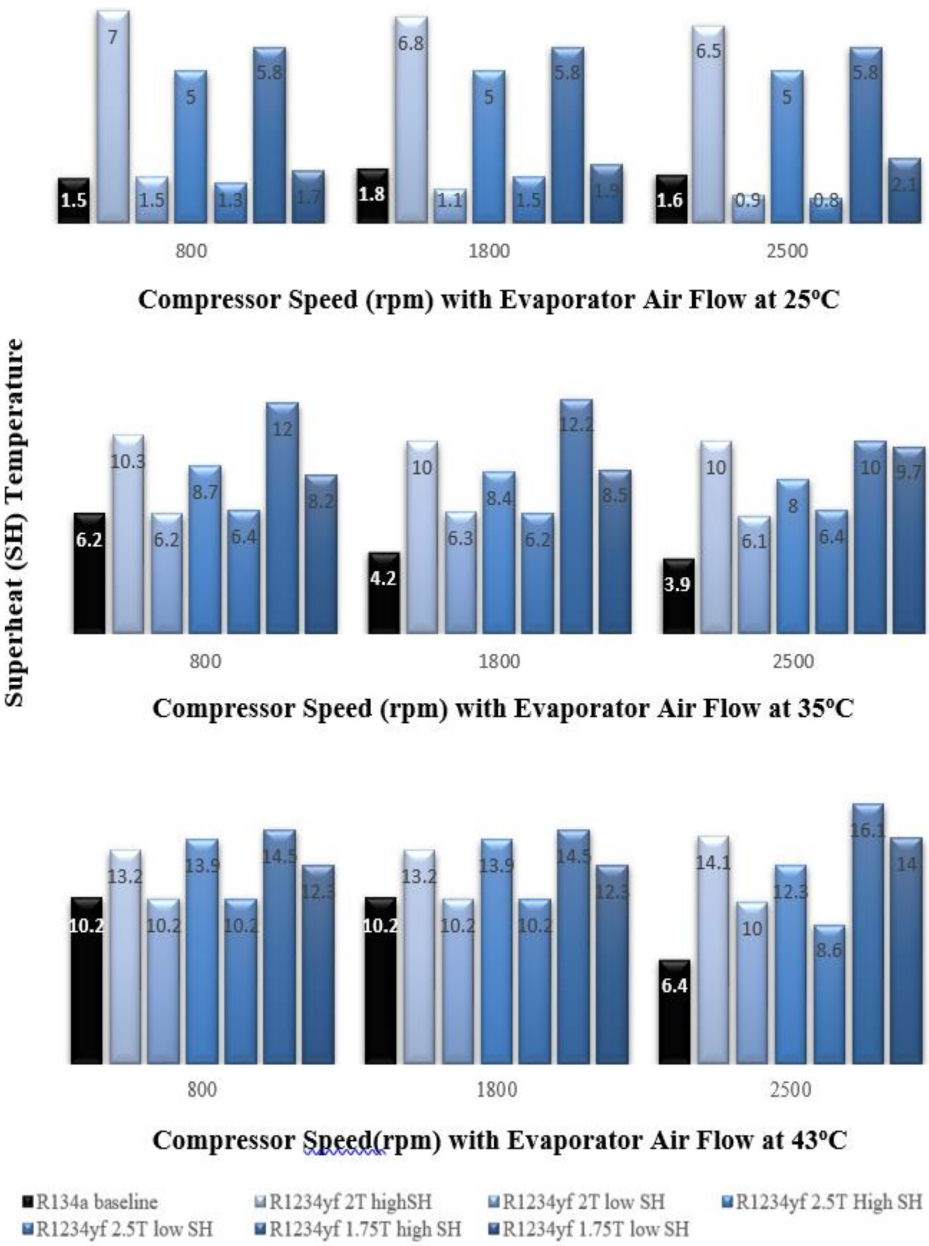

Figure 3: SH Comparison of R134a and R1234yf

3.2 Effect of IHX on Cooling Capacity

Based on Figure 4, the inclusion of IHX enhances the cooling capability of the HVAC system for both refrigerants. R134a demonstrates a higher cooling capacity with and without IHX compared to R1234yf. However, the cooling capacity of R1234yf with IHX falls within an acceptable range and is closer to the values of R134a. Varying the compressor rotating speed from 800 to 1800 RPM results in an improvement in cooling capacity, but this improvement diminishes when the speed is increased to 2500 RPM, particularly for R134a with IHX. The positive impact of IHX on cooling capacity is impeded by the rising compressor speed. When the compressor speed is set at 1800 and 2500 RPM, R134a baseline exhibits a higher COP than R134a IHX, unlike R1234yf where IHX boosts the cooling capacity more as the compressor speed increases. Additionally, the cooling capacity values are seen to rise with an increase in evaporator inlet temperature, as outlined in Table 3.

Evaporator airflow Temperature	Compressor Speed	Cooling Capacity			
		R134a baseline	R134a IHX	R1234yf baseline	R1234yf IHX
ºC	RPM	kW	kW	kW	kW
25	800	3.1	3.3	3.0	3.0
	1800	3.6	3.6	3.0	3.3
	2500	3.4	3.3	3.01	3.2
35	800	4.3	4.5	4.1	4.2
	1800	5.8	6.1	5.8	6.2
	2500	6.0	6.3	6.0	6.3
43	800	4.85	5.3	4.6	4.8
	1800	6.6	6.9	6.4	6.7
	2500	7.05	7.3	6.75	7.25

Table 3: Cooling Capacity Vs Evaporator airflow Temperature

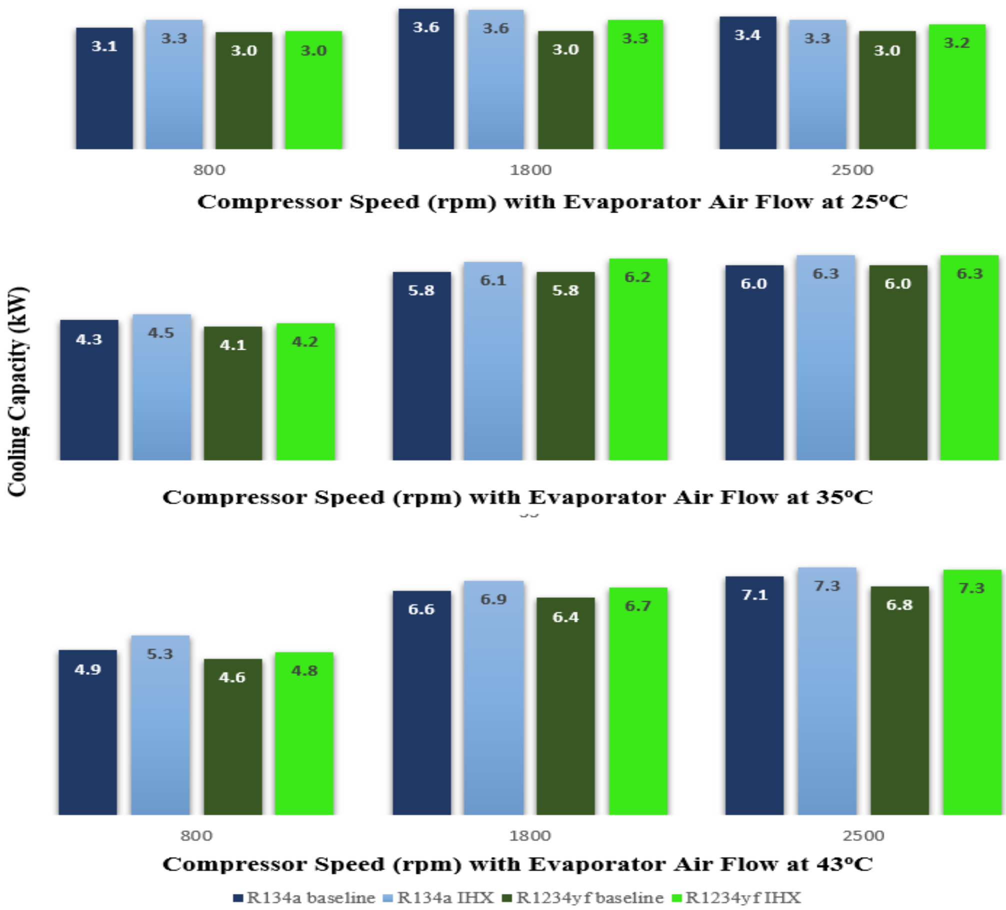

Figure 4: Cooling Capacity comparison of R134a and R1234yf

The utilization of an internal heat exchanger (IHX) results in a higher COP for R1234yf in most cases, highlighting the importance of IHX. The COP improvement is evident for both refrigerants, with R1234yf showing a more significant enhancement. It is noted that the COP decreases as the evaporator inlet temperature and compressor speed increase across all systems, as illustrated in Table 4 and Figure 5.

Evaporator Airflow Temperature	Compressor Speed	COP			
⁰C	RPM	R134a baseline	R134a IHX	R1234yf baseline	R1234yf IHX
25	800	4.2	4.3	4.2	4.3
	1800	3.5	3.6	3.4	3.5
	2500	3.1	3.3	3	3.3
35	800	3.8	4.2	3.7	4.1
	1800	2.3	2.5	2.4	2.5
	2500	2.0	2.4	2	2.3
43	800	3.2	3.3	3.2	3.2
	1800	2.4	2.4	2.3	2.4
	2500	1.4	1.5	1.3	1.4

Table 4: COP with IHX Vs Evaporator airflow Temperature

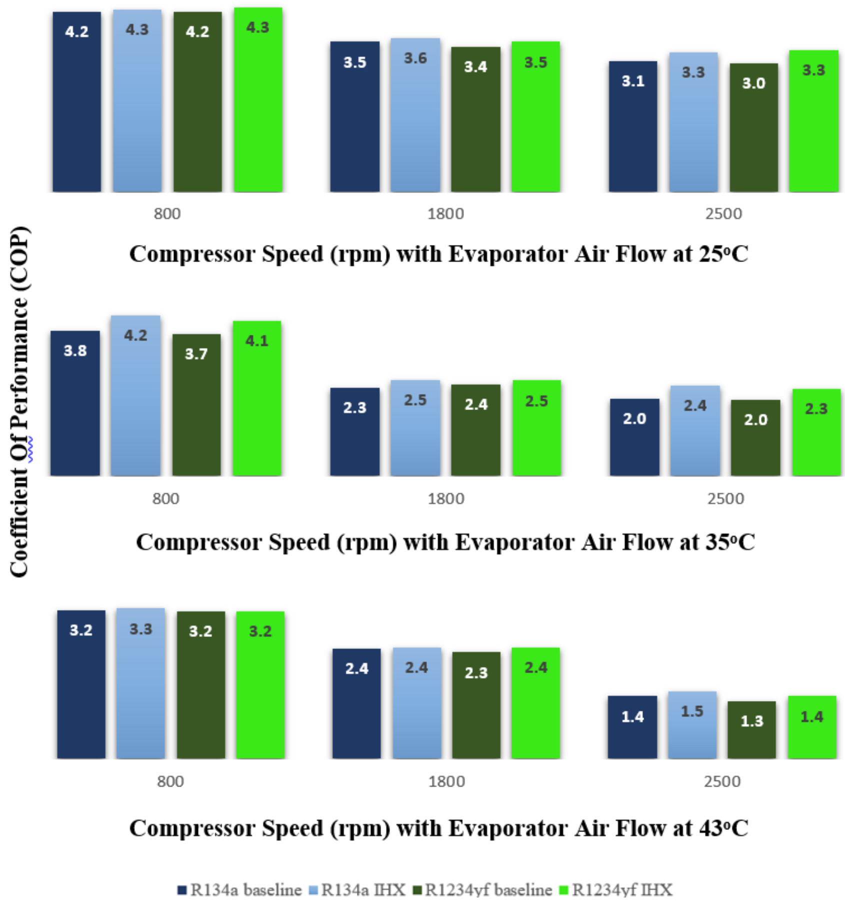

Figure 5: Cooling Capacity comparison of R134a and R1234yf

The utilization of an internal heat exchanger (IHX) results in a higher COP for R1234yf in most cases, highlighting the importance of IHX. The COP improvement is evident for both refrigerants, with R1234yf showing a more significant enhancement. It is noted that the COP decreases as the evaporator inlet temperature and compressor speed increase across all systems, as illustrated in Table 4 and Figure 5. The highest COP is achieved by R1234yf with IHX at an evaporator inlet temperature of 25°C and a compressor speed of 800RPM. Additionally, the integration of IHX in the HVAC system positively affects the compressor discharge temperature. While the highest values are seen in the R134a IHX system compared to the R1234yf IHX system, the values of the R1234yf IHX system remain within an acceptable range and exceed the compressor discharge temperature of the R134a baseline system.

Evaporator Airflow Temperature	Compressor Speed	COP			
		R134a baseline	R134a IHX	R1234yf baseline	R1234yf IHX
⁰C	RPM				
25	800	4.2	4.3	4.2	4.3
	1800	3.5	3.6	3.4	3.5
	2500	3.1	3.3	3	3.3
35	800	3.8	4.2	3.7	4.1
	1800	2.3	2.5	2.4	2.5
	2500	2.0	2.4	2	2.3
43	800	3.2	3.3	3.2	3.2
	1800	2.4	2.4	2.3	2.4
	2500	1.4	1.5	1.3	1.4

Table 5: Compressor Discharge Temperature

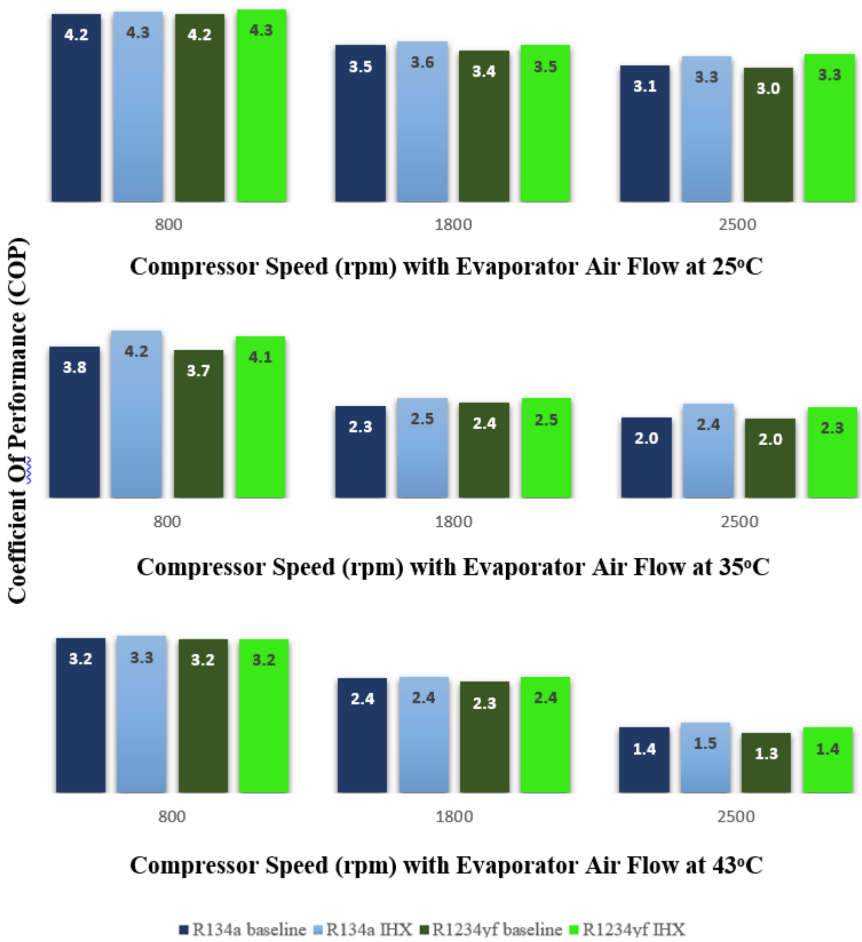

Figure 6: Compressor Discharge Temperature

By incorporating IHX and a high efficiency evaporator, the performance of R1234yf in HVAC systems can be enhanced. The results indicate that the R1234yf IHX system outperforms the R134a baseline system in terms of cooling capacity, COP, and compressor discharge temperature.

4.CONCLUSIONS

The experimental study conducted aimed to investigate the cooling capacity of R1234yf with an internal heat exchanger (IHX) compared to a baseline using R134a. At a compressor speed of 800 RPM and an evaporator airflow temperature of 25°C, the cooling capacity for R134a is 3.6 kW, whereas it increased to 4.3 kW for a higher temperature of 35°C. The same trend is observed for R1234yf, where the cooling capacity climbs from 3.3 kW to 4.2 kW as the temperature rises from 25°C to 35°C. By increasing the evaporator airflow temperature from 25°C to 43°C at a compressor speed of 1800 RPM results in a rise in cooling capacity from 5.8 kW to 6.6 kW for R134a and from 6.2 kW to 6.7 kW for R1234yf which showed a increase of 8%. The result elucidates that the cooling capacity increases with higher compressor speeds. At an evaporator airflow temperature of 35°C, the cooling capacity for R134a rises from 5.8 kW at 1800 RPM to 6.0 kW at 2500 RPM. The same trend is seen for R1234yf, where the cooling capacity increases from 6.2 kW to 7.05 kW as the compressor speed goes from 1800 RPM to 2500 RPM which showed increase cooling capacity of 13.7%. The results of the study revealed that the use of R1234yf with IHX led to improved performance in several key areas when compared with R134a. This suggests that R1234yf with IHX is more energy-efficient, potentially leading to reduced fuel consumption and lower greenhouse gas emissions.

The experimental results with the compressor speed and coefficient of performance (COP) with IHX for different evaporator airflow temperatures showed that the compressor speed and COP both are lower for R1234yf compared to R134a at all evaporator airflow temperatures. At an evaporator airflow temperature of 25 °C which is the lower ambient operations, for the compressor speed for R134a is 2500 RPM the COP was 3.1, while the for same compressor speed for R1234yf COP is 3.3. When the compressor speed and evaporator airflow temperature both increased then the COP decreased for same refrigerant, but when R134a is compared with R1234yf with IHX COP showed a improvement of 6.5%. Considering refrigerant type of R134a, when the compressor speed is 2500 RPM and the COP 2.0 at an evaporator airflow temperature of 35°C, while the for R1234yf COP was 2.3 which showed an improvement of 15% improvement. The result clearly indicates that at higher operating conditions of speed and temperature, R1234yf with IHX was comparable or showed improvement with R134a systems. This is an important finding as it indicates that R1234yf with IHX shall effectively meet the cooling demands of automobile air conditioning systems.

Experimental studies confirm that R1234yf with IHX surpasses the average performance of the R134a baseline. This translates to lower energy consumption for the same cooling output, making the system more environmentally friendly and cost-effective in the long run. In terms of cooling capacity, the IHX configuration is equally impressive. It allows the R1234yf system to either match or even exceed the cooling capacity of the R134a baseline.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my esteemed guide, Dr. Tamil Selvan P, for his invaluable guidance and support throughout this research project. His in-depth knowledge, constant encouragement, and insightful feedback were instrumental in shaping this work. His patience in explaining complex concepts and his willingness to dedicate his time for discussions were truly motivating. I am particularly grateful for his guidance in research work. This research would not have been possible without his unwavering support and belief in me.

REFERENCES

[1] Seyam, Shaimaa. (2018). Types of HVAC Systems. 10.5772/intechopen.78942.

[2] Sharma, Aniket. (2019). Automotive HVAC Market Size, Global Industry Trends and Forecast to 2025.

[3] Sundaresan, Rajamanickam & Palani, Karthikeyan & Samuel, Anand. (2016). Influence of refrigerant (R134a/R1234yf) properties on cooling performance of an automobile Hvac. 11. 3703-3707.

[4] Vaghela, Jignesh. (2017). Comparative Evaluation of an Automobile Air - Conditioning System Using R134a and Its Alternative

Refrigerants. Energy Procedia. 109. 153-160. 10.1016/j.egypro.2017.03.083.

[5] Sundaresan, Rajamanickam & Tamilselvan, P. & Samuel, Anand. (2018). CHALLENGES OF EXPERIMENTING R1234YF REFRIGERANT FOR AUTOMOBILE HVAC SYSTEM-A REVIEW.

[6] Lee, Yohan & Jung, Dongsoo. (2012). A brief performance comparison of R1234yf and R134a in a bench tester for automobile applications. Applied Thermal Engineering - APPL THERM ENG. 35. 10.1016/j.applthermaleng.2011.09.004.

[7] Shin, & Kim, Jungsun & Lee, Kunwoo & Cho, Honghyun. (2019). Performance Characteristics of Automobile Air Conditioning Using the R134a/R1234yf Mixture. Entropy. 22. 4. 10.3390/e22010004.

[8] Zilio, Claudio & Brown, J. & Schiochet, Giovanni & Cavallini, Alberto. (2011). The refrigerant R1234yf in air conditioning systems. Fuel and Energy Abstracts. 36. 6110-6120. 10.1016/j.energy.2011.08.002.

[9] Cho, Honghyun & Lee, Hoseong & Park, Chasik. (2013). Study on the Performance Improvement for an Automobile Air Conditioning System Using Alternative Refrigerant R1234yf. Korean Journal of Air-Conditioning and Refrigeration Engineering. 25. 10.6110/KJACR.2013.25.4.201.

[10] Navarro-Esbrí, Joaquín & Mendoza-Miranda, J.M. & Mota-Babiloni, Adrián & Barragán, Ángel & Belman-Flores, Juan. (2013). Experimental analysis of R1234yf as a drop-in replacement for R134a in a vapor compression system. International Journal of Refrigeration. 36. 870–880. 10.1016/j.ijrefrig.2012.12.014.

[11] Banakar, Shivakumar & Limperich, Dirk & Asapu, Ramesh & Panneerselvam, Vaishnavi & Singh, Madhu. (2014). Performance Evaluation of Automotive HVAC System with the Use of Liquid Cooled Condenser. SAE Technical Papers. 1. 10.4271/2014-01-0681.

[12] Kang, Byung & Lee, Hyunjin. (2017). A Review of Recent Research on Automotive HVAC Systems for EVs. International Journal of Air-Conditioning and Refrigeration. 25. 10.1142/S2010132517300038.

[13] Kang, B.H. & Kim, H.B. & Kim, S.J.. (2014). Recent R&D trends on HVAC system for xEV. ACRA 2014 - Proceedings of the 7th Asian Conference on Refrigeration and Air Conditioning.

[14] Guo, Bao & Yan, Guo & Sheng, Xiong & Wang, Ying & Dai, Ming & Ye, Jun. (2015). The Development Status and Trends of Air Conditioning on New Energy Vehicles. Applied Mechanics and Materials. 737. 123-127. 10.4028/www.scientific.net/AMM.737.123.

[15] Direk, Mehmet & Keleşoğlu, Alper. (2017). Performance analysis of automotive air conditioning system with an internal heat exchanger using R1234yf under different evaporation and condensation temperatures. Thermal Science. 23. 10.2298/TSCI170125215D.

[16] Li, Huguang & Tong, Lin & Xu, Ming & Wei, Wangrui & Zhao, Meng & Wang, Long. (2018). Study on energy saving effect of IHX on vehicle air conditioning system. IOP Conference Series: Earth and Environmental Science. 121. 052036. 10.1088/1755-1315/121/5/052036.

[17] Murat, H.; Kaplan, K.; Celil Aral, M.; Mukhamad, S.; Metin Ertunc, H. Support vector regression modeling of the performance of an R1234yf automotive air conditioning system. Energy Procedia 2018, 153, 309–314.

[18] Yuan, Z.; Peng, T.; Ou, X. Scenario Analysis on CO2-equivalent Emissions from Alternative Mobile Air Conditioning Refrigerants in China. Energy Procedia 2017, 142, 2617–2623.

[19] Yadav, A.K.; Neeraj, S. Performance Analysis of Refrigerants R1234yf, R1234ze and R134a in Ejector-Based Refrigeration Cycle. Int. J. Air-Cond. Ref. 2018, 26, 1850026.

[20] Pérez-García, V.; Belman-Flores, J.M.; Rodríguez-Muñoz, J.L.; Rangel-Hernández, V.H.; Gallegos-Muñoz, A. Second Law Analysis of a Mobile Air Conditioning System with Internal Heat Exchanger Using Low GWP Refrigerants. Entropy 2017, 19, 175.

[21] Jignesh, K.V. Comparative Evaluation of an Automobile Air-Conditioning System Using R134a and Its Alternative Refrigerants. Energy Procedia 2017, 109, 153–160.

[22] El-Sayed, A.R.; El-Morsi, M.; Mahmoud, N.A. A Review of the Potential Replacements of HCFC, HFCs Using Environment-Friendly Refrigerants. Int. J. Air-Cond. Ref. 2018, 26, 1850002.

[23] Samaneh, D.; Alibakhsh, K.; Soudabeh, G.; Omid, M.; Shahin, N.; Somchai, W. A comparative study on the performance of HFO-1234yf and HFC-134a as an alternative in automotive air conditioning systems. Appl. Therm. Eng. 2017, 110, 1091–1100.

[24] Devecioğlu, A.G.; Oruç, V. An analysis on the comparison of low-GWP refrigerants to alternatively use in mobile air-conditioning systems. Therm. Sci. Eng. Prog. 2017, 1, 1–5.

[25] Yu, B.; Wang, D.; Liu, C.; Jiang, F.; Shi, J.; Chen, J. Performance improvements evaluation of an automobile air conditioning system using CO2-propane mixture as a refrigerant. Int. J. Refrig. 2018, 88, 172–181.

[26] Yu, B., Yang, J., Wang, D., Shi, J., and Chen, J. (2019) Energy consumption and increased EV range evaluation through heat pump scenarios and low GWP refrigerants in the new test procedure WLTP. International Journal of Refrigeration, 100, 284–294.

[27] Mastrowski, M., Smolka, J., Hafner, A., Haida, M., Palacz, M., and Banasiak, K. (2019) Experimental study of the heat transfer problem in expansion devices in CO2 refrigeration systems. Energy, 173, 586–597.

[28] Gaurav, and Kumar, R. (2018) Computational energy and exergy analysis of R134a R1234yf, R1234ze and their mixtures in vapour compression system. Ain Shams Engineering Journal, 9 (4), 3229–3237.

[29] Jan Grygierzec ∗ , Sebastian Werle † (2020) Critical evaluation of R134a, R1234yf and R744 in passenger car cooling systems. Journal of Power Technologies 100 (3),232–239

[30] Y Liu, Y Li, D Zhao, H Dong (2020), Effect of initial pressure on explosion characteristics of 2, 3, 3, 3–tetrafluoropropene. Journal of Loss Prevention in the Process industries, https://doi.org/10.1016/j.jlp. 2020.104320