SJST

Abdelrahim & Alzarqi / SILPHIUM Journal of Science and Technology. 7(2), 2025

Research Article

SILPHIUM JOURNAL OF SCIENCE AND TECHNOLOGY
(SJST)

The Impact of an Axial Fan Equipped with an Evaporator on the Efficiency of a Refrigeration System

Hamdi F A Abdelrahim[1*], Hamdi Abdurabah Alzarqi[2]

[1]*Mechanical Eng. Department, Tobruk University, Libya*

[2]*Mechancial Eng. Department, College of Technical Sciences, Derna, Libya*

Corresponding email: abdulhamid.fayez@tu.edu.ly

ABSTRACT

The purpose of this study is to improve the performance of a domestic refrigerator by installing an axial fan in the evaporator. A test rig was designed and fabricated, and experiments were conducted using R134a refrigerant to evaluate the refrigerator's performance with and without an axial fan.

Additionally, a refrigeration unit analysis was performed using CoolPack simulation tools version 1.50 to model the system's behavior. The results demonstrated a significant improvement in the coefficient of performance (COP) and refrigeration effect, with the system achieving an 11.2% performance increase when the axial fan was installed. Moreover, compressor work was reduced by 6.8%, indicating decreased energy consumption.

Overall, this study demonstrated that equipping the evaporator with an axial fan can significantly enhance the performance of domestic refrigerators. These findings contribute to the ongoing research efforts aimed at improving the efficiency of refrigeration systems.

***Keywords**: Vapor compression, Coefficient of performance, Refrigerant-134a, CoolPack software.*

تحسين أداء وحدة التبريد بتزويد المبخر بمروحة محورية

حمدي فائزعلي عبدالرحيم[1*]، حمدي عبدربه الزرقي[2]

قسم الهندسة الميكانيكية، جامعة طبرق، ليبيا[1*]

قسم الهندسة الميكانيكية، كلية العلوم التقنية درنة. ليبيا[2]

abdulhamid.fayez@tu.edu.ly للمراسلة

الملخص

الغرض من هذه الدراسة هو تحسين أداء الثلاجة المنزلية عن طريق تركيب مروحة محورية على المبخر. تم تصميم وتصنيع جهاز اختبار، وتم إجراء التجارب باستخدام مادة التبريد R134a. تم تقييم أداء الثلاجة باستخدام وبدون مروحة محورية.

بالإضافة إلى ذلك، تم إجراء تحليل وحدة التبريد باستخدام أدوات محاكاة وأظهرت النتائج أن معامل الأداء والتبريد للنظام تحسن مع تركيب مروحة محورية. حقق النظام تحسنًا مثاليًا في الأداء بنسبة 11.2%. علاوة على ذلك، كان عمل الضاغط أقل بنسبة 6.8% عند استخدام المروحة المحورية عما كان عليه عند عدم استخدامها، مما يشير إلى انخفاض في استهلاك الطاقة.

أظهرت هذه الدراسة أن تجهيز المبخر بمروحة محورية يمكن أن يعزز بشكل كبير أداء الثلاجة المنزلية. تساهم هذه النتائج في الجهود البحثية المستمرة التي تهدف إلى تحسين كفاءة أنظمة التبريد.

الكلمات المفتاحية : دورة ضغط البخار, معامل الاداء لدورة التبريد, مائع التبريد134أ, برنامج كولباك

INTRODUCTION

Air conditioning and refrigeration are essential components of human life. A third of the high-grade energy used globally for residential, commercial, and industrial cooling, heating, and comfort applications is consumed by the HVACR (heating, ventilation, air conditioning, and refrigeration) sectors..

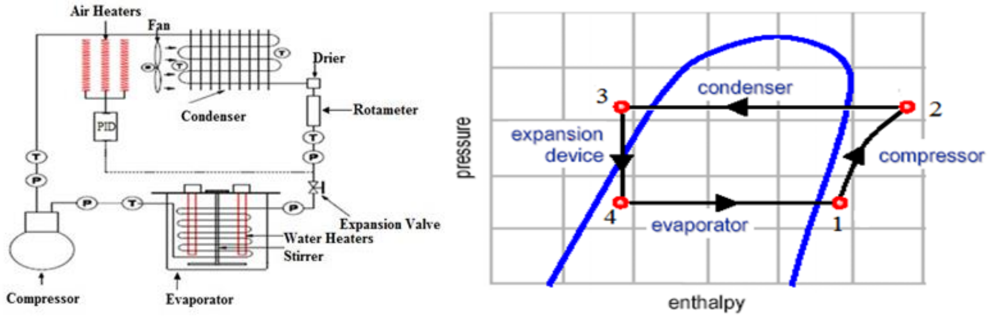
The vapor compression refrigeration system (VCR) is used mainly worldwide for HVACR applications in vapor absorption and adsorption refrigeration systems (V. W. Bhatkar. et al., 2013). In this system, the refrigerant undergoes four phases in a closed cycle: compression, condensation, expansion, and evaporation.

The condenser rejects heat to the environment during the condensation process, and the compressor is used to compress the low-pressure, low-temperature refrigerant from the evaporator to a high-pressure, high-temperature refrigerant.

Following the condensation process, the condensed refrigerant entered the expansion device, where the lowering pressure caused the refrigerant's temperature to drop below the ambient temperature. Resistant vapor expands when pressure decreases. The vapor produces a cooling effect on its surroundings when it expands, drawing energy from the surrounding area or the material in touch with it. Following this procedure, the refrigerant is prepared to absorb heat from the area that has to be cooled. The evaporator served as the site of the heat-absorption process. The term "evaporation" refers to the process of heat absorption. When the refrigerant evaporatively returned to the compressor's suction line, the cycle was finished.

Furthermore, the pressure–enthalpy [log(p)-h] diagram illustrates the fluid's liquid and vapor phases during the cycle (lines 1–4) and provides a precise measurement of the energy transfer in each stage.

The p-h diagram and schematic of the VCR system are displayed in Figures. 1(a) and (b).



(a) (b)

Figure 1. (a) Schematic diagram (b) p-h diagram for VCR system.

(Bhatkar et al., 2022)

(Mann et al., 2017) concluded that axial fans offer a cost-effective method to enhance the performance of refrigeration systems, particularly by improving COP and reducing energy consumption. Their findings suggest that axial fans should be considered an essential component in the design of efficient refrigeration systems.

(Meyer et al., 2020) discusses the different heat transfer mechanisms involved, including conduction, convection, and phase change, emphasizing how these affect evaporator efficiency. The study highlights critical design factors for evaporators, such as surface area, flow arrangement, and refrigerant selection, which can significantly impact their performance. Overall, the paper underscores the critical importance of evaporators in refrigeration systems and provides insights into optimizing their design and operation for improved efficiency.

(Zhang, Y., et al., 2019) compared the energy efficiency of refrigeration systems using various fan types, specifically axial and centrifugal fans. Their findings indicate that axial fans generally provided higher airflow rates with lower energy consumption than centrifugal fans, making them more suitable for specific refrigeration applications.

The fan structure and motor technology in the evaporator and condenser enable the system to effectively reduce the temperature and generate waste heat. The waste heat from the evaporator fan usually leads to a reduction in compressor runs, thus saving more energy. Therefore, the fan structures and technologies used in the evaporator and condenser are crucial for the energy efficiency of the cooling system (S. Erten et al., 2020).

The effect of condensing fan speed on steam compression refrigeration systems was explored by (Acharya et al. 2021). The results revealed that as the CFM speed increases, the pressure head decreases, and the heat loss in the system decreases. Space cooling efficiency is a key factor, which enables the high CFM speed to reduce the space temperature faster. (Elsayed et al., 2020) Evaluated the performance of split air conditioning systems driven by frequency converter, and studied the influence of compressor speed, condenser fan speed, evaporator fan speed, and the effect of electronic expansion valve. The study found that a 7 °C increase in the air inlet temperature of the condenser led to an 18% increase in the power consumption of the system and a 15% decrease in the energy efficiency ratio (COP).

(Dang et al. 2019) analyzed the thermal performance of S-NDWCT equipped with an axial flow fan at different fan diameters and fan power levels to evaluate its impact. The study found that when the diameter of the fan exceeds 15.0 meters, the air velocity in the central area of the tower increases significantly, leading to a more uniform temperature distribution.

(Amin et al. 2020) compared the application of traditional (on-off) control with variable speed drive (VSD) control for split air conditioning evaporator fan motors, aiming to reduce cooling time and power consumption. The study found that the VSD controls improved the energy efficiency ratio (COP) by 32% and reduced energy consumption by up to 11% compared to the on-off controls.

This study experimentally evaluates the performance of a refrigerator by incorporating an axial fan to enhance its efficiency. The research focuses on calculating the Coefficient of Performance (COP) and identifying optimal parameter measurement locations for accurate performance assessment. The experiment was conducted using a developed test rig, which was upgraded and modified as needed, to achieve maximum system performance.

Real refrigeration cycle (M. Mohanraj, et al., 2008)

Real refrigeration cycle consists of the following state changes as illustrated in Figure 2:

1 – 2 polytropic compression to the condensation pressure

1 – 2' isentropic compression

2 – 3 isobaric cooling, deheating of the superheated steam

3 – 4 isobaric condensation

4 – 4 'isobaric cooling, supercooling of the liquid

4’–5’ isenthalpic expansion to the evaporation pressure

5’ – 1’ isobaric evaporation

1’ – 1 isobaric heating, superheating of the steam

The liquid exiting the condenser is subcooled and the vapor exiting the evaporator is most likely slightly superheated in a functional circuit. The liquid was subcooled to 4' and the gas from the evaporator was superheated to point 1.

Subcooling is defined as the difference between the condensing temperature and liquid temperature at the expansion valve inlet.

As the refrigerant passes through the evaporator, its capacity to absorb heat will diminish since it will be a mixture of liquid and gaseous (flash gas) when it reaches the expansion device. Although this circumstance is not unusual, it negatively impacts the system's functionality. To get the most cooling capacity, the refrigerant entering the expansion valve needs to be

subcooled liquid, or pure liquid without flash gas. The product is cooled when the low-pressure liquid passes through the evaporator and absorbs heat. The capacity and efficiency of the system will be reduced if the refrigerant at the valve input is not a subcooled liquid and instead consists of a mixture of liquid and flash gas. This is because gas has a far lower density than liquid, which means, less refrigerant can pass through the expansion valve, lowering its cooling capability.

Significantly more flash gas will enter the evaporator, which will further impair performance and need more effort and time from the system to attain the proper temperature.

Super-heating (SH) is the amount of heat we provide to the refrigerant after it has fully evaporated. Taking this definition into account, reheating means a contribution of heat sensitivity to the refrigerant and, therefore, an increase in temperature. To calculate it, we need to know two temperatures; the suction of the compressor and the evaporation temperature at a given pressure. Superheat ensures total evaporation of the liquid refrigerant before it goes into the compressor Figure 2 depicts the refrigeration cycle with state modifications.

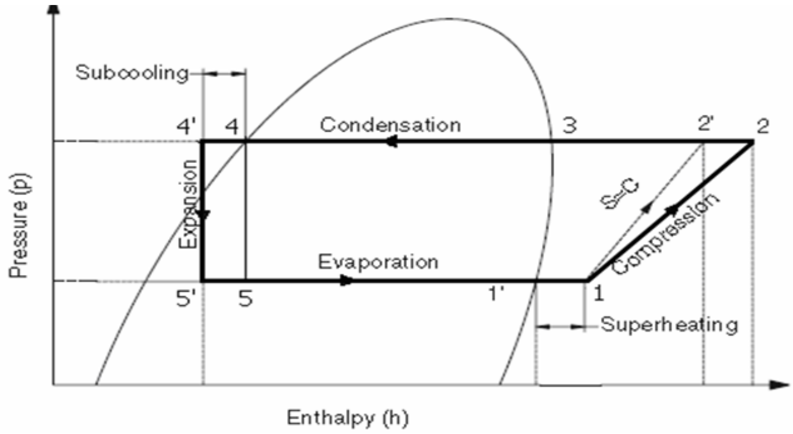


Fig.2: refrigeration cycle with state changes

(Lucia et al., 2012)

The main parameters of the refrigeration system are:

¬ Cooling capacity (heat absorbed in the evaporator)

$qi = h1 – h5$ (kJ/kg) (1)

The cooling load of 1 ton of refrigeration is equivalent to (3.6 kW)

Therefore, the cooling capacity of the system (Qi) which presents the heat absorbed by the refrigerant in time

$Qi = m.qi$ (kW) (2)

Where m is the flow rate (kg/sec)

¬ Amount of heat rejected in the condenser (absolute value)

$qo = h2 – h4$ (kJ/kg) (3)

¬ The absolute value of work consumed by the system

WC = m (h2 – h1) + (the power of equipped fan) (4)

Refrigeration Effect (RE)=qi

RE= m (h1-h5) (5)

¬ The refrigeration efficiency is defined as the following equation

COP = RE/WC (6)

Where,

h1, h2, h4, and h5 are the enthalpies at specified points (kJ/kg), and COP is the performance coefficient.

Methodology

The refrigerator's performance is evaluated using an experimental method and attempts to upgrade and achieve the maximum performance for a refrigerator unit by incorporating an axial fan installation. To obtain more accurate results for interpreting the refrigerator's performance, it is crucial to identify the suitable locations of the parameters to be recorded. The experiment was conducted using the developed test rig, which was upgraded and modified when required.

A compressor (0.5 hp) and evaporator axial fan with a power of 30 watts were installed. A load of 18 liters of water at a 35 °C temperature was placed inside a cooling chamber measuring 420 × 520 × 440 mm for cooling. After the integration of the components, the system was charged with 856 g of refrigerant (R134A), The line and electrical connections were thoroughly inspected for leaks, The absence of any pressure gauge readings indicated a possible refrigerant leak in the pipeline or gas loss.

A schematic diagram of the experimental apparatus and a view of the test rig are shown in Figures 3 and 4, respectively).

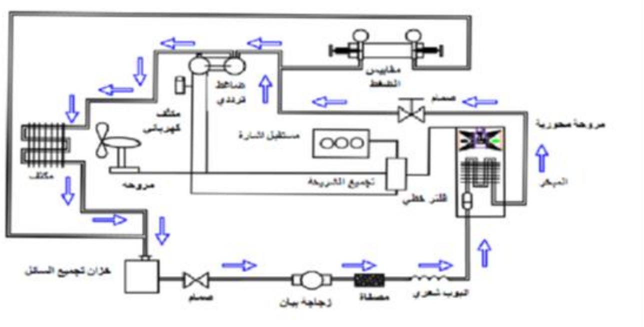


Fig. 3: Diagram of the experimental apparatus

Fig. 4: View of test rig

Results and Discussion

To assess the performance of the VCR system in terms of the refrigeration effect, compressor work consumption, and coefficient of performance, pressure, temperature, and enthalpy values were measured at several key locations throughout the compressor, condenser, expansion valve, and evaporator. The results are presented in Table (1).

Parameters	Fan Turn off	Fan Turn on
High pressure (bar)	10.9	10.3
Low pressure (bar)	48.	.47
Compressor temp in (°C)	16.8	16.5
Compressor temp out (°C)	45.2	44
Expansion valve temp in (°C)	37.7	34.2
Condensation (°C)	43.4	41
Evaporator temp out(°C)	14.8	14
Condenser temp out(°C)	43.6	40.5
Equilibrium pressure (bar)	7.4	7.4

Table 1. Experimental data observed

The p-h chart is drawn accordingly, and the Refrigeration Effect (RE) and C.O.P are calculated using Eq. (5 and 6), respectively. For this study, all refrigeration cycle components were analysed based on the following assumptions:

Steady-state, steady-flow cycle.

negligible kinetic and potential energy changes across each component.

No heat transfer (gain or loss) in the connecting pipes.

A thermodynamic cycle was traced by the authors in the log (p)-h chart using CoolPack software. CoolPack is a comprehensive suite of simulation tools that may be used for refrigeration system design, dimensioning, analysis, and optimization. CoolPack's programs are categorized into three primary groups: Dynamic, EESCoolTools, and Refrigeration Utilities.

Four subgroups have been created from the primary group EESCoolTools: Cycle analysis, Design, Evaluation, and Auxiliary.

The three refrigerant-focused applications that make up the group Refrigeration Utilities are mostly, used to calculate the properties of primary and secondary refrigerants and to create property plots for primary refrigerants (such as p-h diagrams).

The parameters determined by the software are depicted in Fig. 6. (With the evaporator fan turned off) and Fig. 7, (With the evaporator fan turned on)

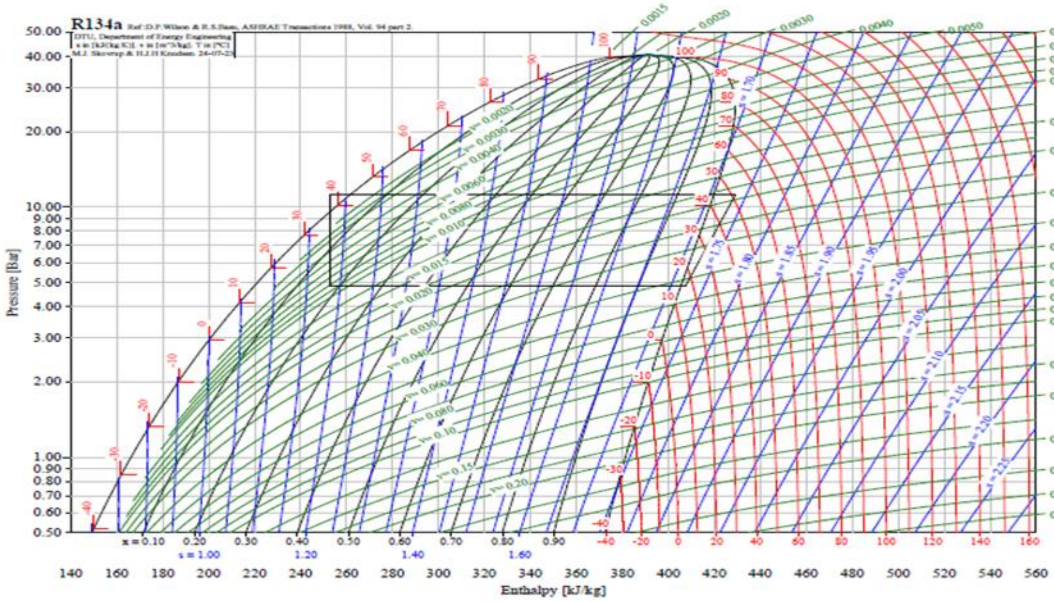


Fig. 5 The thermodynamic cycle of a refrigerating system obtained using CoolPack software

(Axial Fan Off)

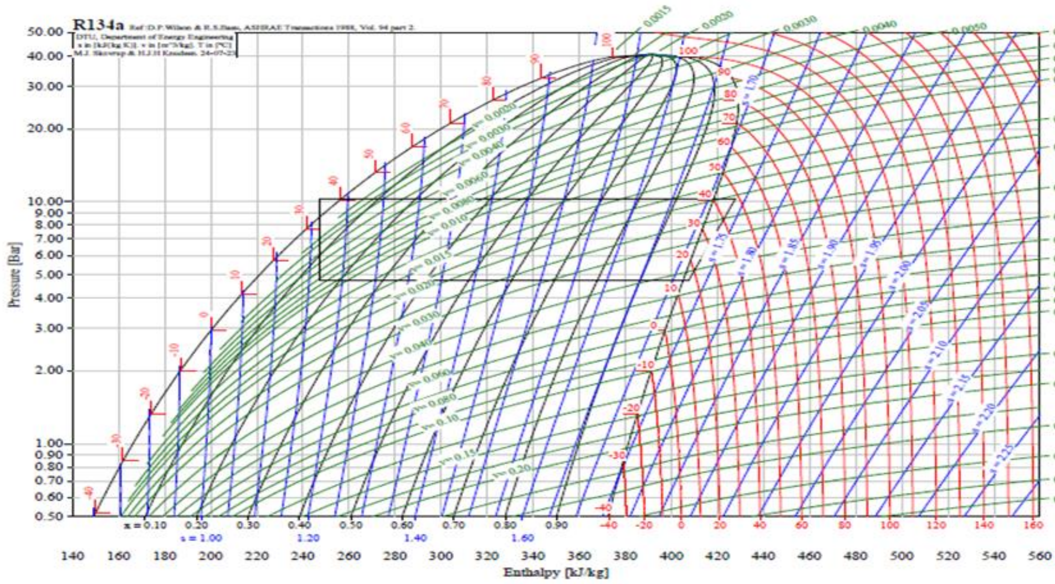


Fig.6 The thermodynamic cycle of a refrigerating system obtained using CoolPack software

(Axial Fan On)

It can be noticed that both the superheating and subcooling degrees increased when the axial fan was incorporated into the cooling system.

The increased subcooling degree improves the cooling capacity by increasing the latent heat of vaporization of the refrigerant, which directly affects the enthalpy difference in the evaporator, leading to an improvement in cooling capacity. An increase in COP was observed after the axial fan was incorporated, with the COP rising by 11.2%. In addition, the compressor work decreased by 6.8% after the axial fan was integrated.

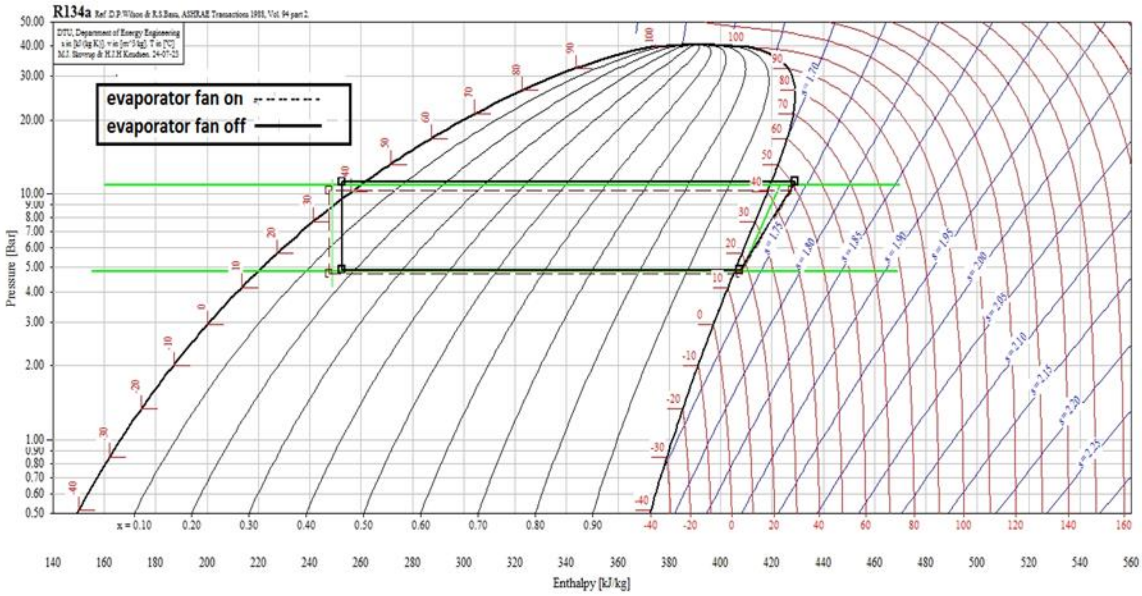


Figure 7. Comparative performance of VCR system with and without evaporator axial fan

Based on the simulated results for the selected refrigerant, the following performance parameters, such as COP, Cooling capacity, and Compressor Work were analysed and compared. Tables (2) and (3) illustrate the theoretical performance and superheating and supercooling comparisons of the evaporator axial fan in both the off and on states.

Evaporator fan	Enthalpy h1 (kJ/kg)	Enthalpy h2 (kJ/kg)	Enthalpy h3=h4 (kJ/kg)	Compressor Work (kJ/kg)	Refrigerating Effect (kJ/kg)	heat rejected (kJ/kg)	COP	Power consumption (kW)
OFF	408	429	252	21.7	155	177	7.1	0.49
ON	407	428	248	20.3	160	180	7.9	0.44

Table 2. Experimental Results: Performance Comparison with Evaporator Fan On and Off

Fan State	Subcooling (°C)	Superheating (°C)
Off	5.9	2
On	6.3	2.5

Table 3. Superheating and subcooling comparison

When the system is running, the pressure and temperature conditions may change slightly due to the continuous flow of the medium, which may result in a small change in the enthalpy. When the system is off, a temporary thermal stabilization may occur, resulting in a small difference in the values.

Although the system with the fan consumes an additional 30 watts, the total energy consumption is less than the system without a fan. This is due to the difference in enthalpy,

(h2-h1) fan on < (h2-h1) fan off

as shown in Figure 7, which leads to a difference in the work done by the compressor.

Conclusion

This study aims to investigate the impact of incorporating an evaporator axial fan into a refrigerator system. The researchers conducted experimental tests and presented the results and evaluations. The key finding was that the coefficient of performance (COP) of the system significantly improved by 11.2% with the installation of an axial fan. Additionally, using the axial fan resulted in a 6.8% reduction in compressor work compared to operating the system without a fan. These findings demonstrate the potential benefits of incorporating an evaporator axial fan into a refrigerator system.

The authors recommended that future research concentrate on the performance of variable-speed axial fans, as they offer greater flexibility for optimizing airflow and energy efficiency. Additionally, they emphasize that the geometry and materials of fan blades play a critical role in improving performance, potentially reducing energy consumption and noise levels.

References

[1] V. W. Bhatkar, V. M. Kriplani and G. K. Awari.(2013). Alternative refrigerants in vapor compression refrigeration cycle for a sustainable environment: A review of recent research. International journal of environmental science. and Tech., vol. 10, pp. 871-880

[2] V. W. Bhatkar, V. M. Kriplani and G. K. Awari,(2013) "Numerical simulations of an aluminum microchannel condenser for household air conditioner," Int. Review of Mech. Engg., vol. 7, no. 1, pp. 181-188,

V. W. Bhatkar, V. M. Kriplani and G. K. Awari, (2015)"Experimental performance of R134a and R152a using microchannel condenser," Journal. of Thermal Engg., vol. 1, no. 7, pp. 575-582,

[4] M. Mohanraj, S. Jayaraj, C. Muraleedharan, (2008), Comparative assessment of environmentally friendly alternatives to R134a in domestic refrigerators, Energy Efficiency1:189–198

[5] Mann, J. & Murtagh, J. (2017). "Performance Analysis of Axial Fans in Refrigeration Applications." Journal of Mechanical Engineering and Automation, 7(3), 45-50.

[6] Meyer, B. J. (2020)"The Role of Evaporators in Refrigeration Systems." International Journal of Refrigeration, 115, 45-55.

[7] Zhang, Y., & Wu, Y.(2019). "Investigation of the Energy Efficiency of Refrigeration Systems with Different Fan Types." Energy Reports, 5,123

[8] S. Erten, C. Ocak and M. Aktaş, (2020)"Experimental analysis of fan performance in industrial cooling systems," in Proceeding of 9th International Conference on Advanced Technologies (ICAT'20), Bolu, Turkey, pp. 551-562

[9] P. Acharya, B.K. Choudhury, S.K. Rout, (2021)"Effect of speed of condenser fan motor on vapor compression refrigeration system," Advances in Air Conditioning and Refrigeration, Singapore: Springer, pp. 395-403.

[10] A.O. Elsayed, T.S. Kayed, "(2020) Dynamic performance analysis of inverter-driven split air conditioner," International Journal of Refrigeration, vol. 118, pp. 443-452

[11] Z. Dang, Z. Zhang, M. Gao, S. He, (2019)"Numerical simulation of thermal performance for super large-scale wet cooling tower equipped with an axial fan," International Journal of Heat and Mass

Transfer, vol. 135, pp. 220-234.

[12] A. Zulkifli and Zulfikri, (2020)"Optimize performance of split AC evaporator using variable speed

drive in motor fan evaporator," in American Institute of Physics (AIP) Conference Proceedings,

vol. 1983, pp. 020010-1 -020010-7.

[13] V. W. Bhatkar1, R. M. Tak,(2022)"Dynamic Simulation of Vapor Compression Refrigeration System with R134a and R1234yf using Dymola Behavior Modeling" Proceedings of the 7th World Congress on Momentum, Heat and Mass Transfer (MHMT'22)

[14] Lucia VÎLCEANU, Mihaela FLORI (2012) "PERFORMANCE CHARACTERISTICS OF VAPOR-COMPRESSION REFRIGERATION SYSTEMS". ANNALS OF FACULTY ENGINEERING HUNEDOARA – International Journal Of Engineering ISSN 1584 – 2665