Evaluation of Various Expansion Devices in Vapor Compression Refrigeration Systems Utilizing Environmentally Friendly Refrigerants

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ABSTRACT
This research outlines a method to evaluate how the capillary tube and thermostatic expansion valve perform in household refrigerators, while also exploring various refrigerants like R134a, R32, and R410a. We have investigated the influence of different refrigerants on the refrigeration cycle and their environmental effects, aiming to minimize the impact on climate change by selecting appropriate refrigerants. R-134a, commonly used in vapor compression refrigeration systems, offers superior thermodynamic properties compared to other refrigerants and has zero ozone depletion potential (ODP). However, it does have a global warming potential (GWP) of 1300. We also considered hydro chlorofluorocarbon (HCFC) refrigerants, composed mainly of carbon, chlorine, fluorine, and hydrogen, as a more eco-friendly option. Therefore, we utilized R-134a alongside R-32, both of which are more environmentally responsible with low GWP and zero ODP. The outcomes of our experiments were compared in a general context. Notably, R-410a showed a 40% (200g) increase in efficiency when using the capillary tube, while its effectiveness dropped by 20% with the thermostatic expansion valve. Additionally, a blend of R-134a and R32 (in a 9:1 ratio) exhibited better performance in both devices, resulting in a 5.9% increase in the coefficient of performance for the thermostatic expansion valve and a 5.6% increase for the capillary tube when compared to other refrigerants.
Keywords:-*Capillarytube,Thermostaticexpansionvalve,ODP,GWP,Alternativerefrigerantand Refrigerant blend.*

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I. INTRODUCTION

Refrigeration involves removing heat from a system, effectively lowering the temperature of a material or a space below what would be typical in its natural environment. The equipment responsible for generating these lower temperatures is known as a refrigeration system. A refrigerant is a substance used to transfer heat through a process of phase change, such as evaporation, which occurs at low temperatures and pressures, although there are exceptions where heat transfer happens through other means. Refrigeration has a wide range of applications, including in the preservation of pharmaceuticals and food, as well as in air conditioning for comfort and various industrial uses.

1.1 Vapor Compression Refrigeration System

The vapor compression refrigeration cycle is commonly used in households. Appliances such as water coolers, refrigerators, and air conditioners operate based on this system. It involves four key processes: evaporation, compression, condensation, and expansion. In this setup, heat is absorbed by the evaporator and released by the condenser. The refrigeration system operates according to the second law of thermodynamics. Figure 1 below illustrates this refrigeration system.

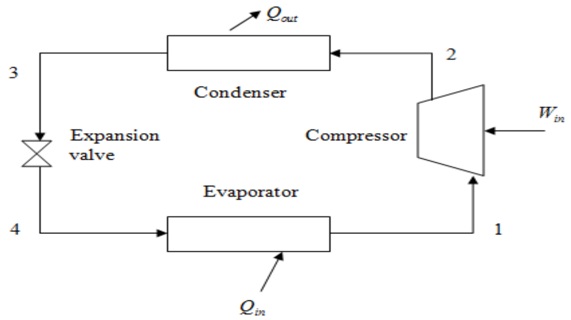

Fig.1-VaporCompressionrefrigerationsystem[1]

The process begins with the refrigerant being pressurized as it moves from point 1 to 2, where it then solidifies in the condenser from point 2 to 3. After that, the refrigerant goes through the expansion valve from point 3 to 4. Finally, it enters the evaporator, where a phase change occurs. This phase change allows the refrigerant to absorb heat from a cooler environment, resulting in its transformation back to point 1, completing the cycle.

1.1 Need for Alternatives

R134a has proven to be an efficient refrigerant and was adopted as a replacement for R12 due to its lower ozone depletion potential. However, in recent years, the demand has shifted toward refrigerants with zero ozone depletion potential and a minimal global warming impact. R134a has a significant global warming potential of 1300, which is concerning. There have been numerous discussions in the refrigeration and cooling industry addressing this issue.

1.1.1 Environmental alert

The fundamental most basic reserve is exhaustion ofthe ozone layer. The ozone layer is a layer which shields the earth from splendid columns beginningfrom sun. Ozone use potential is assessed on a scale that utilizations R11 as a norm. The various parts depend upon how stinging to the ozone they are in relationship with R-11.The second generation concern is an unnatural environmental change. An unnatural environmental change is increase the earth surface temperature because of the repairs of infrared flood on earth surface. A harmful global warming potential is assessed on a scale that utilizes CO_2as the norm for occasion $CO_2$is transferred a worth and different parts are separated from CO_2. The main requirement for a suitable refrigerant before the establishment of chlorofluorocarbons refrigerants was as follows: must haveastandardboilingpointinthefileforrange-40°C to 0°C. It should be stable, not dangerous, which is not hot. No refrigerants available around the same time, including sulfur dioxide, carbon dioxide, and aromatic salt, methyl chloride, and ethyl chloride, can meet any requirements. The refrigerants chlorofluorocarbons (CFCs) satisfy everything important requirements and declared otherwise transformation in the refrigeration and cooling industry. WAJES all rights Reserved 20 currently include zero ozone depletion potential and zero global warming. Ozone-related environmental concernsfatigueandglobalwarmingdidnotneedtoThe primary environmental concern is the depletion of the ozone layer, which protects the Earth from harmful solar radiation. The potential for ozone depletion is measured compared to a standard refrigerant, R-11. The second major issue is climate change, specifically the rise in Earth's surface temperature due to the trapping of infrared radiation. Global warming potential is also measured relative to carbon dioxide (CO_2), which serves as a baseline for assessing other substances.

Before chlorofluorocarbon (CFC) refrigerants were introduced, the essential criteria for a suitable refrigerant included a boiling point in the range of -40°C to 0°C, along with characteristics such as stability, safety, and non-flammability. At that time, no available refrigerants like sulfur dioxide, carbon dioxide, ammonia, methyl chloride, or ethyl chloride met these requirements. CFCs addressed all these key requirements, leading to a significant transformation in the refrigeration and air conditioning sectors.

Currently, the focus has shifted to ensuring that new refrigerants have zero ozone depletion potential (ODP) and zero global warming potential (GWP). Environmental issues related to ozone depletion and climate change have decreased since the use of CFCs, which were previously indispensable but are now recognized for their negative environmental impact.

1.2 Expansion Devices

An expansion device regulates the refrigerant flow based on the evaporator's load. Known as a metering or throttling device, it's a crucial component of steam compression refrigeration systems, situated between the receiver and the evaporator. Its primary function is to transform high-pressure liquid refrigerant into low-pressure liquid refrigerant before it enters the evaporator.

1.2.1. Capillary Tube

The capillary tube serves as an expansion device for small-capacity hermetically sealed refrigeration units, such as those used in household refrigerators. This device consists of a narrow copper tube, with an internal diameter typically ranging from 0.5 mm to 2.25 mm and lengths varying from 0.5 m to 5 m, depending on the specific application.

1.2.2. Thermostatic Expansion Valve

This type of expansion device features a variable opening and is most commonly used in commercial and industrial refrigeration systems. Referred to as a stable superheat valve, it maintains a consistent superheat level of the vapor refrigerant at the evaporator's outlet by regulating the flow of liquid refrigerant through the evaporator. It includes a feeler bulb connected to the evaporator exit tube, allowing it to monitor the temperature at the outlet.

II. LITERATUREREVIEW

In recent studies on air conditioning and refrigeration systems, there's been a growing recognition of the importance of developing skills related to these devices to decrease energy consumption and minimize pollution. The Montreal Protocol mandates the phased-out use of CFC-12 (R-12), and while manufacturing countries have recently produced these substances, developing nations need to take measures to eliminate CFCs by 2030. Many innovative nations have moved to completely eliminate chlorofluorocarbons, necessitating the search for viable alternatives to R-12 for redesigning current systems.

Rasti et al. [1] explored the potential of using two hydrocarbon refrigerants as replacements for R-134a in home refrigerators. They examined various factors such as refrigerant type, charge amount, and compressor type in their analysis. Their study utilized R-436A (a mix of 46% iso-butane and 54% propane) and pure iso-butane as hydrocarbon refrigerants, along with compressors designed for both R-134a and hydrocarbons.

In a similar vein, Rashid et al. [2] conducted research to evaluate the performance of R-600a (isobutene), R-290 (propane), R-134a, R-22, R-410A, and R-32. They specifically focused on a modern finned-tube evaporator and studied its effects on the system's coefficient of performance (COP). Their findings revealed that while an increase in oil flow enhanced the system's performance, it was not feasible to optimize both COP and evaporator performance simultaneously.

Wongwises et al. [3] carried out an experimental analysis of hydrocarbon mixtures intended to replace HFC-134a in domestic refrigeration. They compared the refrigerant mixtures, including blends based on R-134a, R-152a, and R-32, with traditional refrigerants like R-12, R-22, and R-134a. Interestingly, their results showed that specific blends were the most effective alternatives based on performance metrics and environmental considerations regarding ozone depletion and global warming.

Sattar et al. [4] investigated the performance of domestic refrigeration systems utilizing isobutene and blends of propane and butane. They designed a refrigeration system that initially used R-134a and used it as a benchmark for testing hydrocarbon options. Their experiments looked at how condenser and evaporator temperatures influenced performance metrics such as COP and energy consumption. Their findings indicated that hydrocarbon blends could perform comparably to R-134a.

Lastly, Austin et al. [5] focused on optimizing thermodynamic efficiency in domestic refrigerants using a mixture of propane and butane. Their experiments compared these blends to R-134a and assessed the impact of condenser and evaporator temperatures. They determined that the energy usage of the mixed refrigerants was lower than that of R-134a, underscoring the potential advantages of using hydrocarbon mixtures in refrigeration applications.In recent studies on air conditioning and refrigeration systems, there's been a growing recognition of the importance of developing skills related to these devices to decrease energy consumption and minimize pollution. The Montreal Protocol mandates the phased-out use of CFC-12 (R-12), and while manufacturing countries have recently produced these substances, developing nations need to take measures to eliminate CFCs by 2030. Many innovative nations have moved to completely eliminate chlorofluorocarbons, necessitating the search for viable alternatives to R-12 for redesigning current systems.

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Yudhveer et al. [6] conducted a study investigating how different extension devices, such as capillary tubes and thermostatic extension valves, affect the performance of alternative refrigerants in domestic applications. Their research focused on enhancing efficiency while minimizing losses, analyzing the global warming potential (GWP) and ozone depletion potential (ODP) associated with R290 and R600a.

M.S. Kim et al. [7] explored the development of new adiabatic capillary tubes for R22 and its substitutes, including R407C (a mix of R32, R125, and R134a at 23/25/52 wt%) and R410A (a 50/50 wt% mix of R32 and R125). They found that the mass flow rate for R407 was about 40% higher, and the R-410A mixture showed a 23% improvement on average compared to R22. The flow rates in tubes with a twisted diameter of 40mm were approximately 11% lower than those in straight capillary tubes.

Rao et al. [8] reported that the energy consumption in thermostatic expansion valve systems was lower compared to that of capillary tube systems, particularly under higher cooling loads and lower cooling limits. They noted that the Carnot coefficient of performance (COP) was greater than the hypothetical COP, which in turn was higher than the actual COP, aligning with theoretical expectations.

Lee et al. [9] studied the performance of a small refrigerator using a refrigerant blend of R-290 and R-600a in a 55:45 ratio as an alternative to R-134a. They adjusted the compressor displacement volume of the new R-290/R-600a system to match the refrigeration capacity of the original R-134a system.

III. COMPONENTOFTHEEXPERIMENTAL SETUP

In the experiment depicted in figure 4, the test setup utilizes water as the working liquid, which is placed on the evaporator. Initially, the refrigerant circuit is filled with R-134a refrigerant following the established procedures to eliminate moisture and create a vacuum in the system. Once the refrigerant is in place, the handheld thermostatic valve is closed, and the capillary valve on the cylinder is opened. Data is collected after this step, and once the information is gathered, the capillary valve is closed, allowing the thermostatic expansion valve to be opened under the same operational conditions. The system reaches a stable state after running for 30 minutes, at which point the testing begins. Various parameters related to the refrigerant, such as its efficiency, airflow, and distribution performance, are recorded.

Sr.NO	Parameters	Description
1	Type	RefrigerationTestRig
2	Refrigerant	R-134a, blend refrigerant(R-134a&R-32)(9.5%/0.5%,90%/10%, 8.5%/1.5%)andR-410a
3	Capacity	0.3TR
4	Compressor	HermeticallySealed,single cylinderreciprocating
5	Condenser	FinnedCoils,aircooled
6	Expansion device	Capillary tube and thermostatic Expansion Valve (TXV)
7	Evaporator	Shell & tube type evaporator

Table1:Componentsintheexperimentalsetup[1]

In the next phase, the refrigerant mixture includes R-134a and R-32 in ratios of 9.5:0.5, 9:1, and 8:2. The system is vacuumed again to remove moisture. After adding the refrigerants, the previous steps are repeated to gather comprehensive data. Lastly, the refrigerant configuration is adjusted to include 40% R-410a, and the vacuuming process is performed again to eliminate any moisture. Following the charging of the refrigerants, the entire procedure is revisited to collect all relevant information.

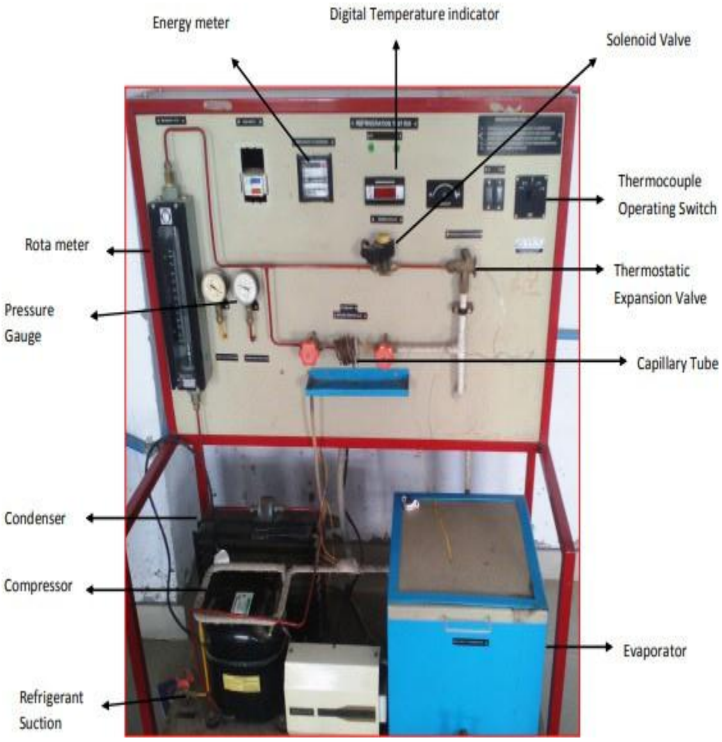

Fig2--PhotographicViewofExperimentalSetup[2]

IV. RESULTS & DISCUSSIONS

This part discusses how the coefficient of performance is affected, along with the influence of refrigerants and the blower operation in a system that incorporates two types of expansion devices: a capillary tube and a thermostatic expansion valve. We also experimented with three different refrigerants: R-134a, R-410a (using a mix of 40% and 200g), and a combination of R-134a with R-32 in various ratios (95/5%, 90/10%, and 85/15%).

4.1 EffectofDifferentRefrigerantsonRefrigerating Effect

The cooling effect of the system has demonstrated the critical point at which the refrigerant enters the evaporator. The refrigerant absorbs this heat, causing the evaporator to become cool. This cooling effect is determined through experimental results.

4.1.1 Variation of different refrigerants on refrigerating effect when operating system is capillary tube

When testing with a capillary tube, we observed that replacing R-134a refrigerant with 40% R-410a led to a decrease in refrigerant performance by 21.9%. In contrast, using a mixture of R134a and R-32 in a 9.5:0.5 ratio resulted in a 21% increase in cooling efficiency. Alternatively, a different blend of R-134a and R-32 at a 9:1 ratio showed an increase of 10.9%. However, when the ratio was adjusted to 8.5:1.5, there was a slight decline of 0.23% in refrigerant performance.
This indicates that the actual cooling efficiency of R-410a is lower than that of R-134a, likely due to the lower quantities of R-410a used. Overall, the combination of R-134a and R-32 appears to provide better performance, particularly in the 9:1 mixture due to the characteristics of both HCFC and HFC components

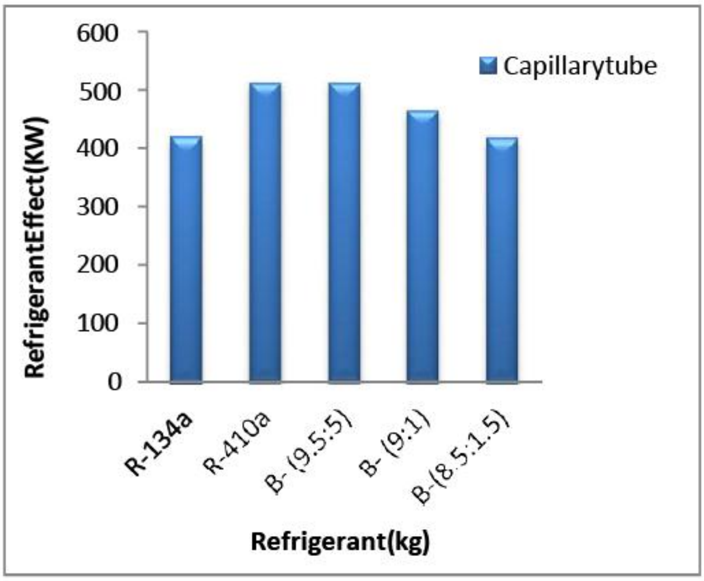

Fig-3Refrigeratingeffectforcapillarytube

4.1.2 Variation of different refrigerants on refrigerating effect when operating system is thermostatic expansion valve

During our testing with a capillary tube, we found that substituting R-134a refrigerant with a blend containing 40% R-410a resulted in a 21.9% drop in performance. Conversely, a mixture of R-134a and R-32 in a 9.5:0.5 ratio improved cooling efficiency by 21%. Additionally, a different combination of R-134a and R-32 in a 9:1 ratio led to a 10.9% increase in performance. However, adjusting this blend to an 8.5:1.5 ratio caused a slight decrease of 0.23%. This suggests that R-410a's cooling efficiency is not as good as R-134a's, possibly due to the lower amounts of R-410a used. Overall, it seems that R-134a combined with R-32 delivers superior performance, especially in the 9:1 mixture, benefiting from the properties of both HCFC and HFC components.

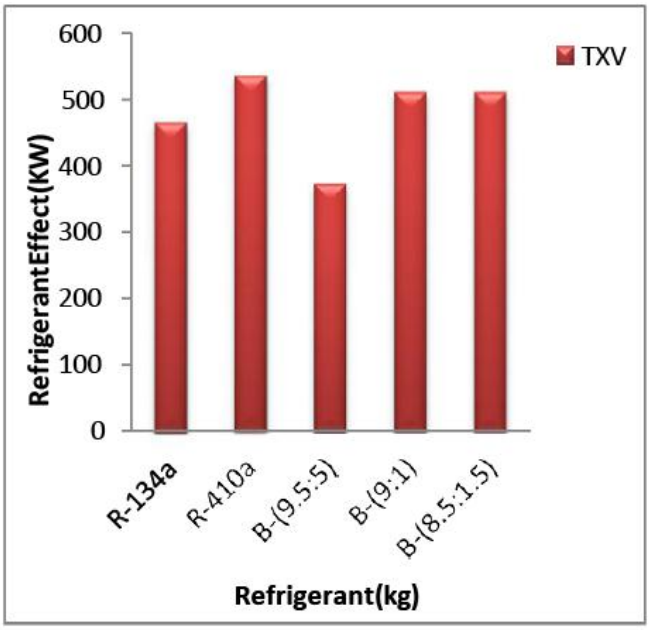

Fig-4Refrigeratingeffectforthermostaticexpansion valve on different refrigerants.

When examining the role of the thermostatic expansion valve, we observed that replacing R-134a with a refrigerator utilizing 40% R-410a resulted in a 15% decrease in performance. Conversely, a mixture of R-134a and R-32 in a 9.5:0.5 ratio led to a 20% decline in efficiency. However, another blend of R-134a and R-32 at a 9:1 ratio actually improved the refrigerator's performance by 9.8%. In summary, the impact of the R-410a refrigerator (40%) is less favorable compared to R-134a due to R-410a's operational limitations. Overall, the combination of R-134a and R-32 provided the best results, particularly in the 9:1 ratio, thanks to the properties of both HCFC and HFC materials.

4.2 Effect of different refrigerants on compressor effort

The compressor function of the system is indicated by the calculation power of the system. The oppressor presses the refrigerant and increases the pressure again refrigeration temperature. The function of the compressoriscalculated withthehelpofthetestresult.

4.2.1. Variation of different refrigerants on compressor effort when operating system is capillary Tube

In the capillary tube, replacing R-134a refrigerant with a blend of 40% R-410a leads to a 19.2% increase in compressor performance. Using a combination of R-134a and R-32 in a 9.5:5 ratio results in a 19% boost in compressor effectiveness.When the ratio is adjusted to 9:1 for R-134a and R-32, the compressor's workload increases by 5.02%. However, when using an 8.5:1.5 ratio of R-134a to R-32, there is a slight decline in compressor performance, with a decrease of 2.9%. This suggests that the compressor operates with less effort when using hydrocarbons and a mixture of HCFC and HFC in a 9:1 ratio.

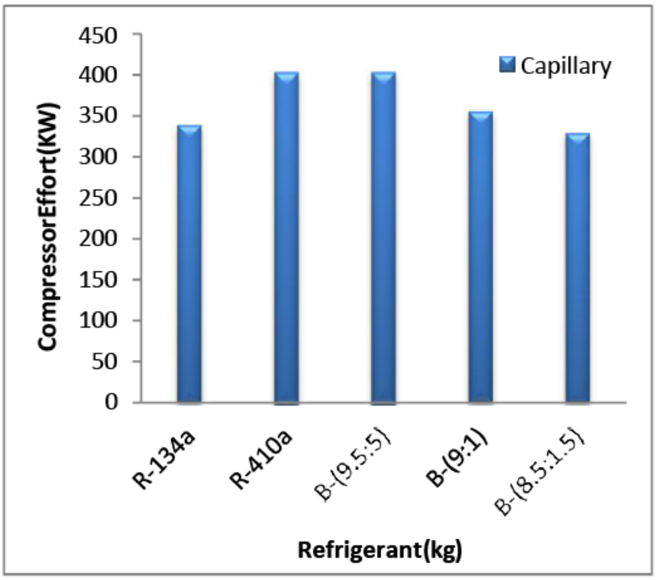

Fig5-Compressorworkforcapillarytubeondifferent refrigerants.

4.2.2. Variation of different refrigerants on compressor effort when operating system is thermostatic expansion valve

When we tested a thermostatic expansion valve system, we discovered that substituting R-134a refrigerant with 40% R-410a resulted in an 11% improvement in compressor performance. However, using a mixture of R-134a and R-32 in a 9.5:5 ratio led to a 20% drop in compressor efficiency. Interestingly, when we adjusted the ratio to R-134a and R-32 at 9:1, there was a slight 3.5% increase in compressor performance. Similarly, with a ratio of R-134a to R-32 at 8.5:1.5, the compressor performance improved by 8%. This indicates that the compressor has to exert less effort when working with HFC and the HCFC-HFC combination at a 9:1 ratio.

4.3 Effect of different refrigerants on coefficient of performance of the system

The effectiveness of the framework is shown through its execution coefficient. This coefficient is established using both experimental data and theoretical information.

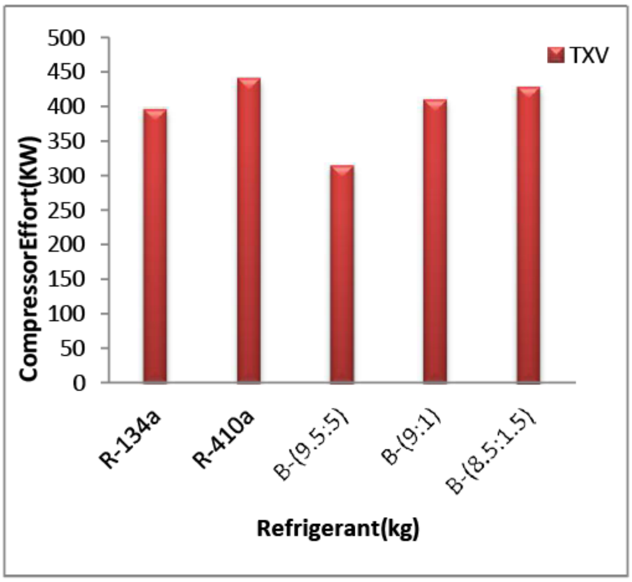

Fig6-CompressoreffortforThermostaticexpansion valves on different refrigerants

4.3.1. Variation of differentrefrigerants on coefficient of performance on the capillary tube

System efficiency can be evaluated in various ways, one of which is by calculating the Coefficient of Performance (COP) through specific testing methods. When we replaced R-134a refrigerant with a mix that contains 40% R-410a, there was a 2.4% increase in performance.

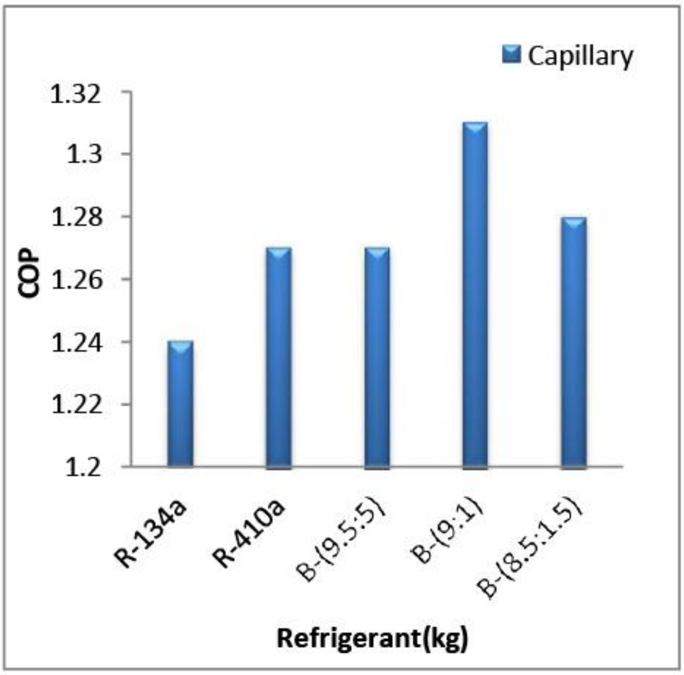

Fig7-CoefficientofPerformanceforcapillarytubeon different refrigerants**.**

In another scenario, using a combination of R-134a and R-32 in a 9.5:5 ratio also resulted in a 2.4% increase in COP. However, when we adjusted the mix to a 9:1 ratio of R-134a to R-32, the COP rose significantly by 8.06%. Even with a slightly different combination of 8.5:1.5, there was a 3.2% increase.
Overall, it's clear that R-134a performs considerably better than a mixture containing 40% R-410a. The combination of R-134a and R-32 provides the most effective performance, particularly in the 9:1 ratio, likely due to the properties of the HCFC and HFC compounds involved.

4.3.2 Variation of different refrigerant oncoefficient of performance for thermostatic expansion valve on different refrigerant

In the thermostatic expansion valve, if we substitute R-134a refrigerant with a blend that includes 40% R-410a, the performance drops by 2.5%. However, when we try mixing R-134a with R-32 in a ratio of 9.5:5, we see an improvement in the coefficient of performance (COP) by 2.5%. Altering that ratio to 9:1 results in an impressive 5.9% increase in COP. Likewise, a mix of R-134a and R-32 at a ratio of 8.5:1.5 leads to a 3.4% boost in COP. This indicates that R-134a performs significantly better, nearly 40% more efficient than HFCs. The mixed refrigerant of R-134a and R-32 achieves a better COP due to the specific ratios and the combination of HCFCs and HFCs.

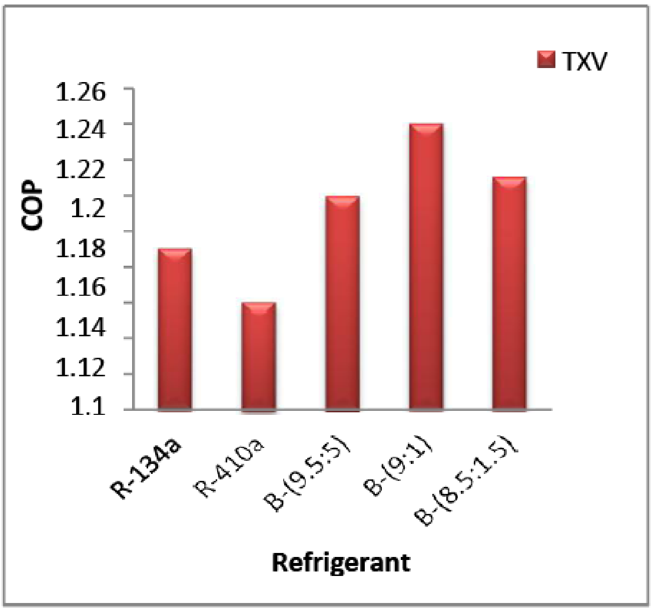

Fig-8Coefficientofperformanceforthermostatic expansion valve on different refrigerants.

V. CONCLUSION

I'm currently working on a new refrigerant that not only focuses on efficiency but also honors nature. For this study, we utilized two expansion devices for each refrigerant to compare their efficiencies. Below are the key results from my research.

(1) When utilizing R-134a, the coefficient of performance (COP) experiences a 5.6% decrease when comparing the thermostatic expansion valve to the capillary tube.

(2) For R-410a, 40% efficiency (200g) results in a 2.4% improvement with the capillary tube, while its COP drops by 20% with the thermostatic expansion valve.

(3) A blend of R-134a and R-32 (90% and 10%) offers improved performance for both types of expansion devices compared to using only R-134a or R-410a. The COP improves by 23.9% for the thermostatic expansion valve and by 16.2% for the capillary tube.

(4) In systems using R-134a, the compressor shows a 17.1% increase in performance with the thermostatic expansion valve compared to the capillary tube.

(5) Looking ahead, we might see the use of various hydro chlorofluorocarbons (HCFCs), hydro fluorocarbons (HFCs), and hydrocarbon refrigerants mixed together. Future applications may incorporate different hydrocarbon refrigerant connectors to lower global warming potential (GWP) and ozone depletion potential (ODP).

(6) Additionally, we could consider using alternative expansion materials to enhance efficiency.

(7) We also have the option to modify the design of the compressor, evaporator, and condenser to boost overall system efficiency.

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