Sigma J Eng Nat Sci, Vol. 43, No. 1, pp. 107−120, February, 2025

Sigma Journal of Engineering and Natural Sciences
Web page info: https://sigma.yildiz.edu.tr
DOI: 10.14744/sigma.2025.00009

Research Article

Examining the role of nano-sized additives in boosting air conditioner efficiency

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ARTICLE INFO

Article history
Received: 18 December 2023
Revised: 10 February 2024
Accepted: 23 February 2024

Keywords:
Additives; Air Conditioner; Environmental Impact; Nano Fluids

ABSTRACT

This study investigates the critical elements of Global Warming Potential (GWP) and Ozone Depletion Potential (ODP) in refrigerant adoption, with an emphasis on R22, a common refrigerant in household air conditioning with a GWP of 1700 and an ODP of 0.05. Under continuous 30°C testing, hydrocarbon refrigerant mixes (HCM) containing R22 and R152a in various mass ratios were evaluated for their ability to reduce R22 usage in vapor compression air conditioning systems. HCM outperformed R22 in terms of total system performance. The study examined the theoretical and actual performance of R152a, finding greater compressor reliability at lower temperatures and lower emissions due to improved containment and lowered refrigerant charge. To address the demand for R152a replacements, nanomaterials such as nanoCuO, ZnO, and Al2O3 were added into nanofluids to improve heat transmission. The performance of air cooling was investigated using various microfluid volume fractions of R22 and R152a. R152a with 0.5% CuO outperformed other refrigerants in terms of energy efficiency, operational costs, and Coefficient of Performance (COP). Cost research revealed that R152a + 0.5% CuO is a more cost-effective choice than unblended R22 and 13.64% more economical than R152a alone, highlighting its potential as a viable and economically attractive refrigerant solution.

Cite this article as: Javanjal VK, Patil LN, Mahajan KA, Patil AA. Examining the role of nano-sized additives in boosting air conditioner efficiency. Sigma J Eng Nat Sci 2025;43(1):107−120.

INTRODUCTION

Air conditioning is vital for modern living, offering comfort in homes and workplaces. However, its energy use raises concerns about environmental impact and cost. Researchers and industry professionals are exploring ways to improve air conditioning efficiency, including using nano-sized additives in refrigerants. Nano-sized additives, like nanoparticles and nanofluids, can enhance refrigerant thermal properties. They improve heat transfer, reduce energy consumption, and enhance system performance [1-5]. Nanoparticles, with their high surface area-to-volume ratio and tunable properties, are attractive for improving air conditioning efficiency. Despite their potential, integrating nano-sized additives into air conditioning is in early research stages. Challenges include additive

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This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkilic

Published by Yıldız Technical University Press, İstanbul, Turkey

stability, compatibility with existing refrigerants, and long-term effects on system performance. Standardized testing methods are needed to evaluate additives in real-world applications. This article provides an overview of nano-sized additives' role in boosting air conditioner efficiency. It reviews advancements, discusses benefits and challenges, and suggests future research direction [6-12].

The air conditioning system in an automobile has become an essential and indispensable technological component [13-17] that ensures optimal thermal comfort for both the driver and passengers during travel. The assessment of the impact of cooling the passenger compartment on the energy consumption and emissions of the vehicle is contingent upon the consideration of thermal comfort in real-world scenarios [18-25]. The present car air conditioning (AAC) system exhibits excessive fuel consumption relative to its ability to effectively regulate the interior temperature [3, 26,27]. To begin with, the protracted use of the air conditioning system when the vehicle is stationary diminishes its operational effectiveness [28-31]. The existing automotive air-conditioning (AAC) system has some limitations, including excessive fuel consumption in relation to the necessary amount required to sustain the desired thermal comfort level inside the vehicle [32, 33, 34]. To begin, the protracted use of the air conditioning system during vehicular idleness diminishes its operational effectiveness [35]. Consequently, in order to sustain the operation of the AAC system, there is a need for an increase in the workload, power, and fuel consumption of autos. One further concern is the escalation of noxious gasoline emissions originating from mobile cars in situations characterised by frequent stops and slow-moving traffic [36, 37]. Carbon dioxide (CO_2), hydrocarbons (HC), nitrogen oxides (NO_x), and carbon monoxide (CO) are among the gases under question. The emission of gases will contribute to the exacerbation of air pollution and the phenomenon of global warming [38]. Efforts are being made to solve these concerns with the aim of enhancing the existing AAC system, reducing fuel usage, and augmenting overall operational efficiency. The selection of the working fluid for a refrigeration system may significantly influence its performance. When choosing lubricants and refrigerants for AAC systems, it is important to exercise caution [39–43]. Several researchers have conducted experiments involving the utilisation of nanoparticles [44–48] that are disseminated inside lubricants, often referred to as nanolubricants, in order to enhance the coefficient of performance (COP) and cooling capacity of refrigeration systems. The use of nanoparticles enhances the thermal properties [49, 50] and system performance [51, 52] of base fluids or lubricant blends. Ohunakin et al. [53] conducted a study on the utilisation of nanoparticles of TiO_2, SiO_2, and Al_2O_3, which were suspended in mineral oil lubricant, in home freezers powered by liquid propane gas. The study demonstrated that the incorporation of titanium dioxide (TiO_2) and silicon dioxide (SiO_2) nanoparticles resulted in a significant improvement in the coefficient of performance (COP), with an increase of up to 2.06%. The study conducted by Senthilkumar and Anderson [54] examined the behaviour of a suspension of SiO_2 nanoparticles in polyolester (POE) oil within the context of the R410A cooling system. The researchers made a significant finding that the use of lubricant nanoparticles resulted in enhanced performance of the refrigeration system. The highest coefficient of performance (COP) recorded was 1.7, while the lowest value for compressor work was 80 W. The maximum cooling capacity achieved was 160 W, using a refrigerant mass charge of 40 g and including 0.4 g/L of SiO_2 nanolubricants. The use of R134a in cooling and heating systems has been improved by several studies [57–60].

REFRIGERANTS

R22 Refrigerant

Chlorodifluoromethane, sometimes known as R22, is a hydrochlorofluorocarbon (HCFC) refrigerant that was widely used in HVAC and refrigeration systems for a long time. Because of its chemical makeup—$CHClF_2$—it was able to effectively absorb and dissipate heat. Although R22 has a low ozone depletion potential (ODP) of 0.05, it has a high global warming potential (GWP) of around 1,810–1,880 over a 100-year period, which is a major environmental negative. R22 has been phased out of use in many countries due to its detrimental effects on the ozone layer and its contribution to greenhouse gas emissions, and more environmentally friendly alternatives such as hydrofluorocarbons (HFCs) and hydrofluoroolefins (HFOs) have been adopted in its place. Physical Properties for R22 Refrigerant are shown in Table 1.

Table 1. Physical properties for R22 refrigerant

Property	Value
Chemical formula	$CHClF_2$
Molecular weight	86.47 g/mol
Boiling point at 1 atm (°C)	-40.8°C
Boiling point at 1 atm (°F)	-41.4°F
Critical temperature (°C)	96.2°C
Critical temperature (°F)	205.2°F
Critical pressure (MPa)	4.99 MPa
Critical pressure (psia)	724.5 psia
Liquid density at boiling point	1.197 g/cm^3
Gas density at 1 atm and 0°C	4.062 kg/m^3 (0.253 lb/ft^3)
Specific heat of liquid at 25°C	1.47 kJ/kg•K (0.351 Btu/lb•°F)
Specific heat of vapor at 25°C	0.783 kJ/kg•K (0.187 Btu/lb•°F)
Thermal conductivity at 25°C	0.0877 W/m•K (0.051 Btu/h•ft•°F)
GWP (100-year)	Approximately 1,810-1,880
ODP	0.05

R152A Refrigerant

Hydrofluorocarbon (HFC) R-152A, commonly known as 1,1-difluoroethane, is a refrigerant used in a wide range of cooling and refrigeration systems. It has various distinguishing characteristics despite being a tasteless, odourless gas. R-152A is a low-temperature cooling agent with a molecular weight of 66.05 g/mol and a boiling point of -24.7°C (-12.5°F) at atmospheric pressure. Since its global warming potential (GWP) over a 100-year period is only around 124, it is a greener option than some other refrigerants with greater GWP values. Due to its low toxicity and inflammability under normal settings, R-152A has replaced more conventional refrigerants like R-12 and R-134A in systems with an eye towards minimising their ecological footprint. R-152A has no dangers in normal settings; however, there are some scenarios in which it might cause harm if not handled properly. Table 2 shows Physical Properties for R152A Refrigerant.

SELECTION OF NANO MATERIALS

Nanomaterials research and utilization are attractive and dynamic fields of materials science and nanotechnology. Nanomaterials, which are created or handled at the nanoscale, are typically smaller than 100 nanometers (one nanometer is one billionth of a meter). This extraordinary size gives nanoparticles new properties and opens up new possibilities in many sectors. Size-dependent behavior distinguishes nanomaterials. Nanoscale materials typically have different characteristics than bulk materials. Reactivity, optical quality, electrical conductivity, and mechanical strength may be enhanced. Thus, nanomaterials are employed in electronics, medicine, energy, environmental studies, and materials engineering. Nanoparticles, nanotubes, nanowires, and nanosheets are natural nanomaterials. They may be synthesized in a lab using chemical, physical, or biological methods to customize their size, shape, and chemical makeup. Nanomaterials may be used in drug delivery, renewable energy, environmental remediation, and cutting-edge material production. However, their unique traits raise safety, moral, and environmental problems, requiring responsible research and regulation to maximize their benefits and minimize their risks. Nanomaterials are cutting-edge research and development that will transform numerous industries and the planet.

Table 2. Physical properties for R152A refrigerant

Property	Value
Chemical formula	CH3CHF2
Molecular weight	66.05 g/mol
Boiling point at 1 atm (°C)	-24.7°C
Boiling point at 1 atm (°F)	-12.5°F
Critical temperature (°C)	113.7°C
Critical temperature (°F)	236.7°F
Critical pressure (MPa)	4.96 MPa
Critical pressure (psia)	719.2 psia
Liquid density at boiling point	0.49 g/cm³
Gas density at 1 atm and 0°C	3.64 kg/m³ (0.227 lb/ft³)
Specific heat of liquid at 25°C	1.36 kJ/kg·K (0.325 Btu/lb·°F)
Specific heat of vapor at 25°C	0.76 kJ/kg·K (0.182 Btu/lb·°F)
Thermal conductivity at 25°C	0.086 W/m·K (0.050 Btu/h·ft·°F)
Global warming potential (GWP)	Approximately 124
Ozone depletion potential (ODP)	0

Methods for Synthesizing Nanomaterials

Nanomaterials may be synthesised using a wide variety of techniques that allow for precise manipulation of their size, shape, and chemical make-up. Nanoparticles and thin films may be manufactured with high accuracy using chemical procedures like chemical vapour deposition and sol-gel technologies. Physical processes, such as ball milling and laser ablation, reduce materials from their bulk form to nanoscale particles. Nanomaterials may be manufactured via biological processes like biomineralization and biofabrication, which use live creatures or biomolecules. Additional new approaches to nanomaterial design include nanolithography and molecular self-assembly. Researchers now have access to a wider range of techniques than ever before, allowing them to create nanomaterials with precisely tuned characteristics for use in fields as diverse as electronics and medicine. Nanomaterials used in the present study are Alumina Al2O3, Zinc Oxide ZnO, Copper Oxide CuO.

Selection of Parameter Affecting Air Conditioning System

A subjective response to a number of intervening factors determines thermal comfort. Satisfaction with the thermal environment is highly dependent on the design, construction, and usage of the inhabited space, as well as the design, construction, and operation of the HVAC systems. Occupants of a particular place have varying degrees of tolerance for the ambient temperature. Physical state, heat exchange with the environment, and physiological traits all has a role in how comfortable someone feels in their environment. Several factors affect the amount of heat transferred between a person and their environment.

1. Dry-bulb temperature
2. Relative humidity (RH)
3. thermal radiation (solar and mean radiant)
4. Air movement
5. Extent of clothing
6. Activity level
7. Direct contact with non-body surfaces

Standard 55 provides circumstances anticipated to be thermally acceptable to at least 80% of the adult inhabitants of a space, even if optimal thermal conditions for any one individual in a given location are difficult to define owing to personal preferences. Most significantly influencing the performance of the AC are

1. Factors from the outside, such as

1. Climate or weather condition
2. The longitude, latitude, and altitude
3. The position of the building regarding the four directions

2. Inside factors include

1. Area and height of spaces
2. Amount of heat dissipation from people, lighting, and equipment
3. Type of material of the walls, doors, and windows
4. Either the space is adjacent to an air-conditioned space or not.
5. The amount of fresh air required for each space.

Charging and Leak Proof System in Air Conditioning System

The best performance and dependability of air conditioning systems depend on charging and leak-proof mechanisms. For optimal cooling and heating performance, it is essential that air conditioning systems be properly charged with the appropriate quantity of refrigerant. If the system is overcharged or undercharged, the compressor might be damaged, and the system's efficiency and cooling capacity will suffer. Technicians employ precise measurements of refrigerant levels to properly charge an air conditioning system. Depending on the size of the system, the ambient temperature, and the presence or absence of leaks, the required amount of refrigerant must be added or removed. Long-term efficiency and environmental considerations make leak-proofing an AC system as important as charging it. Leaks in refrigeration systems not only reduce their ability to chill but also emit toxic chemicals into the atmosphere, adding to issues like ozone depletion and climate change. Regular checks are undertaken to detect and fix any leaks in the system as soon as possible. In order to find and repair leaks in refrigerant lines, coils, or other components, technicians employ leak detection equipment, such as UV dyes or electronic leak detectors. The effectiveness and longevity of the air conditioning system, as well as the system's reduced environmental impact, depend on the prevention and repair of refrigerant leaks.

INVESTIGATION ON THE PERFORMANCE OF R22 AND R152A REFRIGERANT

This examines the performance of an R22/R52a air conditioning system. Performance parameters, including suction pressure, suction temperature, discharge pressure, discharge temperature, and coefficient of performance, are studied to determine the best air conditioning refrigerant. R22 and R152A are tested individually, without a combination. A typical vapour compression refrigeration system has two pressures. High- and low-side pressures condense and evaporate. The compressor discharge valve and measurement equipment separate these pressures. Condensing pressure includes high-side, head, and discharge pressure, whereas evaporating pressure includes low-side, suction, and back pressure.

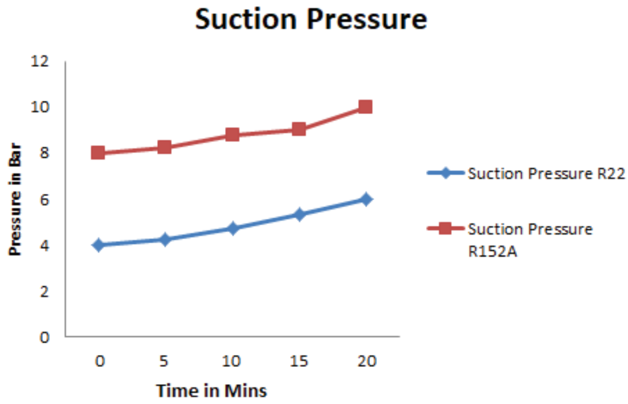

Figure 1. Comparison of suction pressure between R22 and R152A.

Effect on Suction Pressure

At a certain pressure, the refrigerant begins to evaporate. Evaporation, often known as vaporising pressure, is the name given to this phase change. The compressor and any point in between are suitable locations for measuring evaporating pressure. Changes in suction pressure have a greater impact on compressor capacity than changes in the overhead residual condensate, gas density, or compressor head. The compressor can compress more gas without modification if the sucrose pressure or discharge pressure is increased. The amount of refrigerant needed is calculated using the system's suction pressure, suction temperature, and discharge air wet bulb temperature. Using R22 and R152A as refrigerants, Figure 1 displays the 20-minute variation in suction pressure. Both refrigerants see an increase in suction pressure when the air conditioner operates. The suction pressure of R152A refrigerant is greater than that of R22. The flow of refrigerant is impeded by decreasing suction pressures. This research demonstrates that an increase in suction pressure results in a free flow of refrigerant into the system.

Effect On Suction Temperature

Suction temperature changes for R22 and R152A throughout a 20-minute experimental period are shown in Figure 2. It has been observed that the suction temperature decreases for both refrigerants as the system runs longer. When compared to R22, R152A refrigerant has a greater suction pressure. Since the pressure ratio rises with increasing suction temperature, more horsepower from the compressor is needed to cool a given tonnage of air. However, the compressor in this setup requires less horsepower.

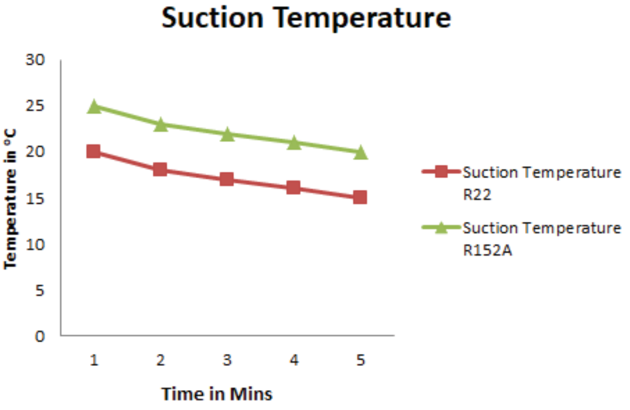

Figure 2. Comparison of suction temperature between R22 and R152A.

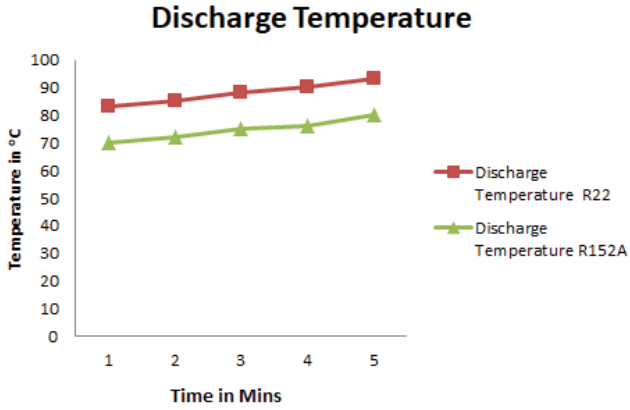

Figure 4. Comparison of Discharge Temperature between R22 and R152A.

Effects in Discharge Pressure

That's why we call it "condensing pressure" when it happens. A pressure gauge placed anywhere between the compressor's discharge valve and the metering device's inlet will provide an accurate reading of this pressure. Figure 3 depicts the fluctuation in discharge pressure for R22 and R152A, two common refrigerants. It is seen that the discharge pressure decreases while the system keeps running. Refrigerant R-I 52a is characterised by a lower discharge pressure. The discharge pressure generated by R22 is greater than that generated by R152A.

Effect on Discharge Temperature

Figure 4 displays the discharge temperatures measured experimentally for the refrigerants R22 and R152A while the air conditioning system ran for a 20-minute period of time. The results reveal that the discharge temperature is rising, whereas for R22 it is rising at first, then fluctuating, and then stabilising at a higher value. This might be because refrigerant is a better heat transmission medium.

Effect on Coefficient of Performance

The coefficient of performance (COP) is a metric used to evaluate the effectiveness of a heat pump or other refrigeration system. The coefficient of performance (COP) for a refrigerator is calculated by dividing the energy required to complete the job of the compressor by the beneficial effect or intended energy transfer done by the evaporator (RE). In Figure 5 we can see how the coefficient of performance varies for the two refrigerants in this investigation, R22 and R152A. As the system runs longer, the coefficient of performance rises for both refrigerants, although the R152A refrigerant has a greater coefficient of performance than the R22 refrigerant. The COP for R152A jumps significantly upon system start up before levelling down. This might have been caused by the original greater refrigerant compression ratio.

The use of refrigerant R152A has been seen to improve the efficiency of air conditioning systems. When compared to R152A's efficiency, R22's performance pales in comparison. With R152A, the suction pressure and temperature may be increased while the discharge temperature and

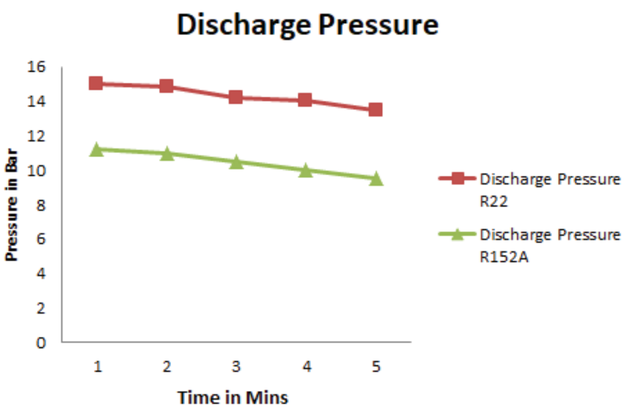

Figure 3. Comparison of Discharge Pressure between R22 and R152A.

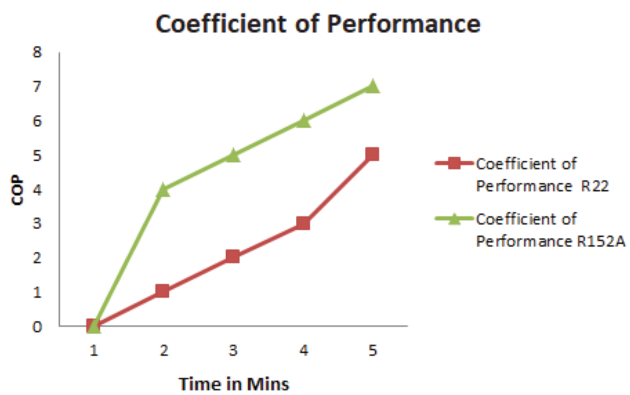

Figure 5. Comparison of Coefficient of Performance between R22 and R152A.

pressure are decreased, resulting in a more effective air conditioning system. Over time, the R152A system's performance coefficient is much higher than that of the R22 system, indicating a greater refrigerant ion impact.

Investigation on the Performance of Blended R22 and R152A Refrigerants

Data collected from testing air conditioning systems charged with pure R22 and R152A are used as a benchmark against which the performance of other refrigerant blends may be evaluated. Air conditioning systems benefit from blended refrigerants because of their enhanced performance and efficiency. The compressor was charged with a combination of R22 and R152A, with mass fractions of 30:70, 50:50, and 70:30, and the results were compared to those produced with pure R22 and pure R152A. The early experimental findings using various ratios of R22 and R152A are used to determine the blending ratio.

Effect on Suction Pressure

Both suction pressure and suction temperature will be reduced if the compartment being cooled is already at a low temperature. Compressor efficiency drops with an increasing compression ratio and decreasing suction pressure due to losses in volumetric efficiency and cooling. The leftover gas expands in response to a decrease in suction pressure, leaving less room for new vapour to enter. So, the mass flow rate decreases because the compressor pumps less refrigerant at a certain compression ratio.

Suction pressure shifts for unmixed R22 and R152A, as well as the three blended mixtures, are shown in Figure 6. As the system continues to run, it is seen that the suction pressure rises for all refrigerants. The suction pressure for R22 refrigerant is the lowest, and the suction pressure for R152A refrigerant is the greatest. Blended refrigerants provide an efficiency level between those of these two options. Suction pressure tends to rise as the R152A content of a mixture rises.

Effect on Suction Temperature

When operating circumstances change, the evaporator and compressor capabilities are influenced in various ways. Suction temperature is one component that affects their performance as shown in Figure 7. As the evaporator temperature changes, the compressor capacity responds in the exact opposite way. When the temperature at the point of suction drops, the evaporator's capacity rises while the compressor's falls, and vice versa when the suction temperature rises. Figure 8 depicts the difference in suction temperature between a system using pure R22 and one using a combination of R22 and R152A. R22 has a lower suction temperature, whereas R152A has a greater one. When the air conditioner is put into operation with the mixed refrigerant, the suction temperature drops.

Effect on Discharge Pressure

Lowering the discharge pressure helps the air conditioner's compressor run more efficiently. Discharge pressure is shown to vary for different R22/R152A mixtures in Figure 8. Discharge pressures range from very low for R152A to very high for R22 refrigerant. Discharge pressure is observed to decrease with refrigerant mixture, with 70:30 combinations of R152A and R22 having the lowest discharge pressure. This demonstrates that under blending conditions, R152A has a greater impact than R22.

Effect on Discharge Temperature

The compression ratio and the discharge temperature both increase when the condensing temperature (pressure) increases for a certain suction temperature. The discharge port is the hottest part of the system, so when the discharge temperature rises, the oil and even the refrigerant might break down there. Greater compression ratios, due to high

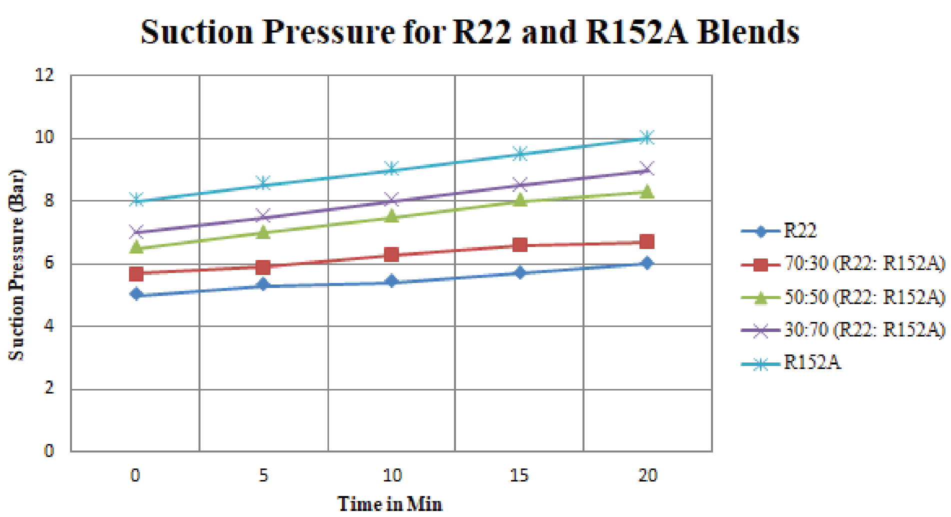

Figure 6. Suction pressure for various blends of R22 and R152A.

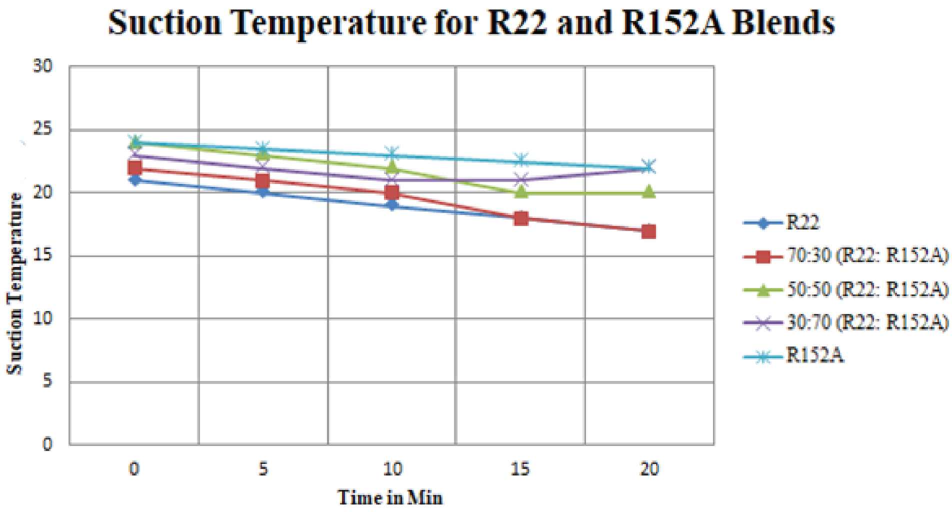

Figure 7. Suction temperature for various blends of R22 and R152A.

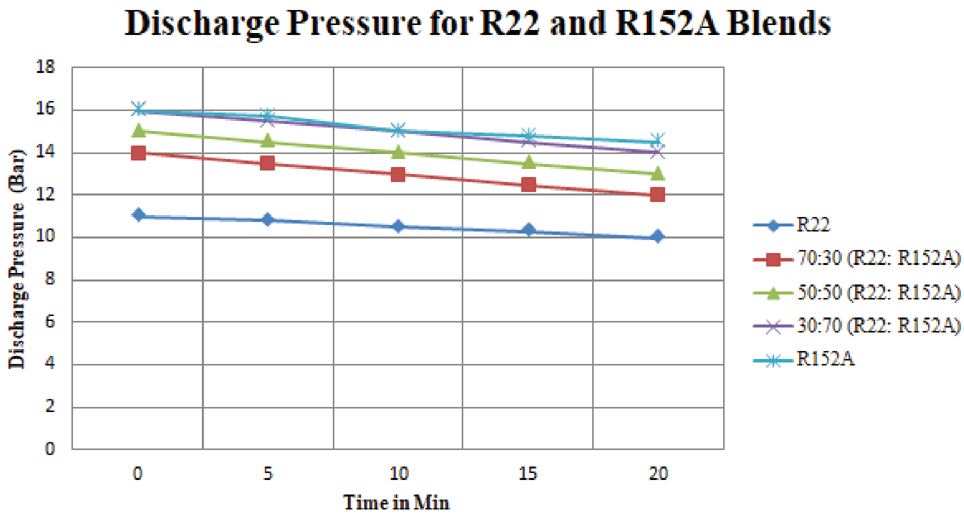

Figure 8. Discharge pressure for various blends of R22 and R152A.

condensing and low evaporating temperatures, likely account for the greater discharge temperature at lower loads.

Discharge temperatures are shown to vary for both pure R22 and combined R22 and R152A refrigerant in Figure 9. The R22 discharge temperature is the highest, and the R152A refrigerant discharge temperature is the lowest. Discharge temperatures for blended refrigerants fall somewhere in this range. The blend of R152A and R22 (70:30) had the lowest discharge temperature of any gas tested, even lower than pure R152A.

Effect on Coefficient of Performance

The "Coefficient of Performance" (COP) is a common metric for describing the effectiveness of cooling solutions. The coefficient of performance (COP) for cooling systems is defined as the ratio of cooling power delivered to cooling power consumed. A higher COP indicates a more efficient cooling system.

Figure 10 shows the performance coefficients for several refrigerants in both blended and unblended conditions. It has been found that the COP of R152A is greater than that of unblended R22 and that the COP of R22 blended with a greater mass percentage of R152A is greater than that of unblended R22. Blending two distinct refrigerants might increase the COP.

The COP might go up, down, or stay about the same. Superheating improves COP in Freon 12 systems but worsens it in Freon 22 systems. Light superheat has a positive influence on the volumetric efficiency and COP of reciprocating compressors because it causes any liquid refrigerant

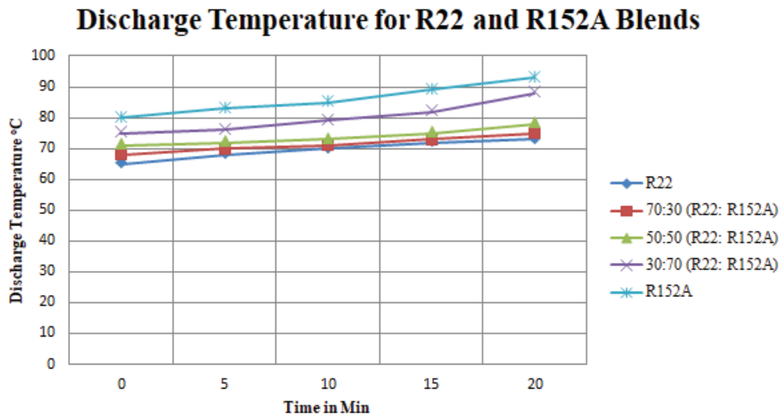

Figure 9. Discharge temperature for various blends of R22 and R152A.

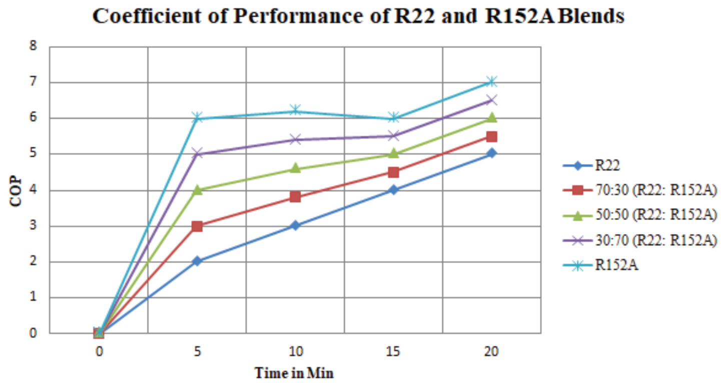

Figure 10. Coefficient of performance for various blends of R22 and R152A.

droplets suspended in the suction vapour to completely aphorize. It's important to keep in mind that superheating outside the evaporator or cold area causes a loss in the air conditioning system. Blends of the common refrigerants R22 and R152A, with volumetric ratios of 30:70, 50:50, and 70:30, were found to make air conditioning work better. The 70:30 blends had the lowest discharge temperature. Additionally, the COP value increased with increasing blend volume, indicating that the mixtures were safe to use in the systems without any modifications. The COP might go up, down, or stay about the same. Superheating improves COP in Freon 12 systems but worsens it in Freon 22 systems. Light superheat has a positive influence on the volumetric efficiency and COP of reciprocating compressors because it causes any liquid refrigerant droplets suspended in the suction vapour to completely aphorize. It's important to keep in mind that superheating outside the evaporator or cold area causes a loss in the air conditioning system. Blends of the common refrigerants R22 and R152A, with volumetric ratios of 30:70, 50:50, and 70:30, were found to make air conditioning work better. The 70:30 blends had the lowest discharge temperature. Additionally, the COP value increased with increasing blend volume, indicating that the mixtures were safe to use in the systems without any modifications.

Table 3. ANOVA table for Grey relational grade

Source	DF	Seq. SS	Adj MS	F	p	% Contribution
Type of Refrigerant	1	0.3150	0.3112	187.022	0.000	79.12
Type of Nanoparticle	2	0.0356	0.0187	11.55	0.011	9.46
Volume fraction	2	0.0256	0.0112	6.745	0.012	5.86
Error	12	0.0186	0.0015	1.012		5.13
Total	17	0.3901	0.0229			100.00

Table 4. Results of confirmation experiment

Suction pressure	Discharge pressure	Suction temperature	Discharge temperature	COP
14.98	12.86	23	66	6.843

Confirmation Experiment with Optımum Condition

An experimental validation is performed with the same experimental setup to determine the performance of Rl 52a refrigerant with a 0.5 volume percentage of CuO nanoparticles, and the results are tabulated in Table 4. Comparing the results of the confirmation experiment to the mean of the experimental outputs reveals an improvement of 53.69% in suction pressure, a decrease of 18.99% in discharge pressure, an increase of 34.85% in suction temperature, a decrease of 15.44% in discharge temperature, and an increase of 23% in the coefficient of performance.

Power Analysis

Table 5 compares the output of pure R22 and R152A, blended R22 and R152A, pure R22 plus Nano additives, and pure R152A plus various Nano additives. Hourly power usage rates are taken into account. Take R22's 2 u/h energy consumption as an example. The daily cost of using the air conditioner at full blast is 16 units of electricity. This is a monthly consumption of 480 units during a period of 30 days. According to the findings, R152A is a more effective refrigerant than R22. Blending R22 with R152A, however, improves upon both of the separate refrigerants' performances while still falling short of that of R152A alone. When compared to pure R22 and R152A, the performance of R22 combined with nanoparticles yields superior results.

Cost Analysis

Using the air conditioner's monthly electricity bill, we can calculate the total cost of operation. Take R22's 2 u/h energy consumption as an example. Let's pretend that the AC uses 16 units of energy each day, operating for 8 hours each day. This is a monthly consumption of 480 units during a period of 30 days. The monthly operating cost of an air conditioning unit using R22 is almost similar to Rs. 4800/-, assuming a unit cost of Rs. The running costs of alternative refrigerants are determined in the same way. Table 6 compares the prices of pure R22 and R152A, R22 and R152A blends, R22 with nano additions, and R152A with various nano additives. When comparing the percentile increase

Table 5. Power consumed by different refrigerants used in the work

Sr. No.	Refrigerant	Power (W/Hr.)	% improvement wrt R22	% improvement wrt R152A
1	R22	2.1	1	-11.5
2	R152A	1.85	15.29	1
3	30 R22:70 R152A	1.91	11.5	-2.31
4	50 R22:50 R152A	1.98	7.38	-5.91
5	70 R22:30 R152A	2.05	3.56	-9.26
6	R22: 0.1 Al2O3	2.04	4.09	-8.79
	R22: 0.3 Al2O3	1.99	6.82	-6.41
	R22: 0.5 Al2O3	1.95	9.11	-4.41
7	R22: 0.1 ZnO	2.03	4.63	-8.33
	R22: 0.3 ZnO	1.97	7.95	-5.42
	R22: 0.5 ZnO	1.9	12.11	-1.78
8	R22: 0.1 CuO	1.94	9.7	-3.89
	R22: 0.3 CuO	1.86	14.64	0.43
	R22: 0.5 CuO	1.74	22.95	7.71
9	R152A: 0.1 Al2O3	1.82	17.28	2.74
	R152A: 0.3 Al2O3	1.78	20.05	5.17
	R152A: 0.5 Al2O3	1.72	24.46	9.02
10	R152A: 0.1 ZnO	1.78	20.05	5.17
	R152A: 0.3 ZnO	1.73	23.7	8.36
	R152A: 0.5 ZnO	1.67	28.39	12.46
11	R152A: 0.1 CuO	1.74	22.95	7.71
	R152A: 0.3 CuO	1.71	25.22	9.7
	R152A: 0.5 CuO	1.64	30.87	14.64

Table 6. Cost associated with different refrigerants used in the work

Sl. No	Refrigerant	Cost/Month	% improvement wrt R22	% improvement wrt R152A
1	R22	4801.256	1.256	-11.244
2	R152A	4201.256	15.546	1.256
3	30 R22:70 R152A	4345.256	11.756	-2.054
4	50 R22:50 R152A	4513.256	7.636	-5.654
5	70 R22:30 R152A	4681.256	3.816	-9.004
6	R22: 0.1 Al2O3	4657.256	4.346	-8.534
	R22: 0.3 Al2O3	4537.256	7.076	-6.154
	R22: 0.5 Al2O3	4441.256	9.366	-4.154
7	R22: 0.1 ZnO	4633.256	4.886	-8.074
	R22: 0.3 ZnO	4489.256	8.206	-5.164
	R22: 0.5 ZnO	4321.256	12.366	-1.524
8	R22: 0.1 CuO	4417.256	9.956	-3.634
	R22: 0.3 CuO	4225.256	14.896	0.686
	R22: 0.5 CuO	3937.256	23.206	7.966
9	R152A: 0.1 Al2O3	4129.256	17.536	2.996
	R152A: 0.3 Al2O3	4033.256	20.306	5.426
	R152A: 0.5 Al2O3	3889.256	24.716	9.276
10	R152A: 0.1 ZnO	4033.256	20.306	5.426
	R152A: 0.3 ZnO	3913.256	23.956	8.616
	R152A: 0.5 ZnO	3769.256	28.646	12.716
11	R152A: 0.1 CuO	3937.256	23.206	7.966
	R152A: 0.3 CuO	3865.256	25.476	9.956
	R152A: 0.5 CuO	3697.256	31.126	14.896

and decrease in operating cost using different refrigerant with R22 and R152A, we find that adding 0.5% of nanoparticles to R152A results in a decrease in operating cost, while adding R152A to a blend of CuO as a refrigerant results in the highest percentage increase, at 13.64%. Compared to using pure R22 refrigerant, R152A has the lowest operating costs; however, using R152A combined with 0.5% nanofluid reduces those costs by an additional 29.87%.

Comparıson of Different Refrigerants Performance

Table 7 also includes information on how the performance of various refrigerants improves in comparison to that of unblended R22 and R152A. When compared to unblended R152A, blended R152A, and R152A mixed with nanofluids, it is clear that the performance of R22 refrigerant is worse. Blending R152A with 0.5% CuO nanofluid yields optimal performance. When comparing R152A with 0.5% CuO to R22 refrigerant, the discharge temperature is reduced by 32.35% and the coefficient of performance (COP) is increased by 31.045; when comparing R152A with R22 refrigerant, the discharge temperature is reduced by 14.71% and the COP is increased by 14.8%.

RESULTS AND DISCUSSION

Both R22 and R152A are used in the experiments. Using R152A as a refrigerant in an air conditioner may boost its efficiency. R152A allows for increased suction pressure and temperature while reducing discharge temperature and pressure, leading to more effective air conditioning. Over time, the R152A system's performance coefficient is much greater than that of the R22 system, indicating a more powerful refrigeration effect. Blends of the common refrigerants R22 and R152A, in the volumes of 30:70, 50:50, and 70:30, are found to improve air conditioning performance. It is safe to use a combination of R152A and R22 in the system without making any further adjustments. It has been discovered that the discharge pressure and temperature decrease with the refrigerant combination, with the lowest values being obtained for 70:30 blends of R152A and R22. It has been shown that 70:30 mixes of R152A and R22 provide the maximum suction pressure and suction temperature. Mixtures of R152A and R22 with a 70:30 ratio provide the highest COP values (5.427). Al2O3, ZnO, and CuO nanoparticles were introduced to the refrigerant at concentrations of 0.1%, 0.3%, and 0.5% by volume, respectively. Adding nanoparticles to the refrigerant in an air conditioner

Table 7. Performance comparison of different refrigerants used in the work

Sl. No	Refrigerant	Measured/ Computed response		% improvement wrt R22		% improvement wrt R152A	
		Temp.	COP	Tempt	COP	Temp.	COP
1	R22	92	6.376	1.86	1.86	-11.47	-22.43
2	R152A	80	7.474	17.24	21.40	1.86	1.86
3	30 R22:70 R152A	83	7.283	12.97	18.57	-1.84	-1.66
4	50 R22:50 R152A	86	7.038	9.00	14.63	-5.28	-6.55
5	70 R22:30 R152A	88	6.62	6.51	6.98	-7.44	-16.07
6	R22: 0.1 Al2O3	89	6.469	5.31	3.88	-8.48	-19.93
	R22: 0.3 Al2O3	86	6.74	9.00	9.31	-5.28	-13.17
	R22: 0.5 Al2O3	84	6.998	11.62	13.96	-3.02	-7.40
7	R22: 0.1 ZnO	88	6.621	6.51	7.00	-7.44	-16.04
	R22: 0.3 ZnO	85	6.841	10.29	11.19	-4.16	-10.84
	R22: 0.5 ZnO	83	7.105	12.97	15.75	-1.84	-5.17
8	R22: 0.1 CuO	87	6.698	7.74	8.51	-6.38	-14.17
	R22: 0.3 CuO	83	6.983	12.97	13.70	-1.84	-7.72
	R22: 0.5 CuO	80	7.308	17.24	18.95	1.86	-1.18
9	R152A: 0.1 Al2O3	79	7.577	18.74	22.85	3.16	3.66
	R152A: 0.3 Al2O3	77	7.835	21.86	26.26	5.86	7.90
	R152A: 0.5 Al2O3	74	7.987	26.86	28.14	10.19	10.23
10	R152A: 0.1 ZnO	78	7.675	20.28	24.18	4.49	5.31
	R152A: 0.3 ZnO	76	7.929	23.48	27.43	7.27	9.35
	R152A: 0.5 ZnO	72	8.148	30.43	30.02	13.29	12.57
11	R152A: 0.1 CuO	76	7.95	23.48	27.69	7.27	9.67
	R152A: 0.3 CuO	74	8.234	26.86	30.99	10.19	13.78
	R152A: 0.5 CuO	70	8.45	34.21	33.31	16.57	16.66

significantly alters the system's performance. ZnO has the greatest suction pressure, followed by CuO and alumina. The temperatures at which suction occurs are shown to be lowest for CuO, ZnO, and alumina, in that order. The suction temperature drops as the process advances.

When utilising R152A as a refrigerant, adding 0.5% of CuO nanoparticles to create low GWP and zero ODP greatly boosts the efficiency of the air conditioning system. Due to the increased density of the nano-refrigerant, the pressure at the suction head rises when nano-particles are added to the refrigerant. Depending on the concentration of CuO nanoparticles, the suction pressure ranges from 14.1 bar for 0.5% to 10.21 bar for 0.1%. As the number of nanoparticles in a discharge grows, so does the associated pressure. However, as the process continues, the discharge pressure often drops. Adding 0.5% CuO results in the lowest discharge pressure. The temperatures at which vacuums draw in ZnO, Al2O3, and CuO are, in order, the highest. The suction temperature decreases as the system develops, indicating a maximum input of nanofluids. The suction temperature is measured to be highest at 0.5% nanoparticle addition and lowest at 0.1%. The discharge temperature drops as the nanoparticle volume fraction rises in the cooling medium. The inclusion of nanoparticles in the refrigerant boosts the efficiency of the system by enhancing the rate of heat transfer in the condenser. At a nanoparticle composition of 0.5%, the maximum value of the coefficient of performance was found. Maximum COP is achieved by adding 0.5% Al2O3, ZnO, and CuO; lowest COP is achieved by adding 0.1% Al2O3, ZnO, and CuO; and the values are 6.131, 6.292, and 6.594, respectively.

At a nanoparticle composition of 0.5%, the maximum value of the coefficient of performance was found. In terms of energy efficiency, the addition of 0.5% CuO to R152A makes it the most power-efficient refrigerant available. R152A+0.5% CuO has a lower operating cost than both unblended R22 and R152A, by a margin of 29.87% and 13.64%, respectively. R152A+0.5%Cuo have a lower discharge temperature than either R22 or R152A in their unblended states by 32.35 and 14.71 degrees Celsius, respectively. As the proportion of nanoparticles in the refrigerant rises, so does the efficiency coefficient. Compared to R22 and R152A, the COP for R152A+0.5%CuO is 31.45% and 14.80%, respectively.

CONCLUSION

The study focused on refrigerant adoption, emphasizing the importance of GWP and ODP environmental factors. R22, a common air conditioning refrigerant, has a GWP of 1700 and an ODP of 0.05. Hydrocarbon refrigerant mixtures (HCM) with R22 and R152a showed promise in reducing R22 consumption. Following points are highlighted from the present study.

- Hydrocarbon refrigerant mixtures (HCM) with R22 and R152a reduce R22 consumption.
- Continuous 30°C testing showed HCM outperformed R22 in system performance.
- R152A demonstrated improved compressor reliability at lower operating temperatures, reducing emissions.
- Nanomaterials (nanoCuO, ZnO, Al2O3) explored for enhanced heat transfer in air cooling.
- Nanofluids with varying microfluid volume fractions of R22 and R152a tested for air conditioning performance.
- R152a with 0.5% CuO showed higher energy efficiency, lower operating costs, and a higher COP.
- Cost analysis revealed R152a + 0.5% CuO to be more economical than unblended R22 and R152a alone.
- Study suggests R152a + 0.5% CuO as a promising and cost-effective alternative for air conditioning refrigeration.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Atik K, Aktaş A. An experimental investigation of the effect of refr igerant charge level on an automotive air conditioningsystem. J Therm Sci Technol 2011;31:11–17.

[2] Moon JH, Lee JW, Jeong CH, Lee SH. Thermal comfort analysis in a passenger compartment considering the solar radia-tion effect. Int J Therm Sci 2016;107:77–88. [CrossRef]

[3] Mansour C, Nader WB, Breque F, Haddad M, Nemer M. Assessing additional fuel consumption from cabin thermal com-fort and auxiliary needs on the worldwide harmonized light vehicles test cycle. Transp Res Part D Transp Environ 2018;62:139–151. [CrossRef]

[4] Danca P, Vartires A, Dogeanu A. An overview of current methods for thermal comfort assessment in vehicle cabin. Energy Proced 2016;85,:162–169. [CrossRef]

[5] Lee J, Kim J, Park J, Bae C. Effect of the air-conditioning system on the fuel economy in a gasoline engine vehicle. Proc Inst Mech Eng Part D J Automob Eng 2012;227:66–77. [CrossRef]

[6] Barth M, Boriboonsomsin K. Traffic congestion and greenhouse gases. Access Mag 2009;1:2–9.

[7] Najjar YSH. Gaseous pollutants formation and their harmful effects on health and environment. Innov Energy Polic 2011;1:1–9. [CrossRef]

[8] McNabola A, Broderick BM, Gill LW. The impacts of inter-vehicle spacing on in-vehicle air pollution concentrations inidling urban traffic conditions. Transp Res Part D Transp Environ 2009;14:567–575. [CrossRef]

[9] Hundy GF, Trott AR, Welch TC. Refrigeration, Air Conditioning and Heat Pumps, 5th ed.; Butterworth-Heinemann: Oxford, UK, 2016. pp. 488. [CrossRef]

[10] Rejvani M, Saedodin S, Vahedi SM, Wongwises S, Chamkha AJ. Experimental investigation of hybrid nano-lubricant forrheological and thermal engineering applications. J Therm Anal Calorim 2019;138:1823–1839. [CrossRef]

[11] Ben Said L, Kolsi L, Ghachem K, Almeshaal M, Maatki C. Advancement of nanofluids in automotive applications duringthe last few years-A comprehensive review. J Therm Anal Calorim 2021;147:7603–7630. [CrossRef]

[12] Mohanraj M, Jayaraj S, Muraleedharan C, Chandrasekar P. Experimental investigation of R290/R600a mixture as an alter-native to R134a in a domestic refrigerator. Int J Therm Sci 2009;48:1036–1042. [CrossRef]

[13] Ahmadpour M, Akhavan-Behabadi M, Sajadi B, Salehi-Kohestani A. Effect of lubricating oil on condensation characteristicsof R600a inside a horizontal U-shaped tube: Experimental study. Int J Therm Sci 2019;145:106007. [CrossRef]

[14] Saleh B. Parametric and working fluid analysis of a combined organic Rankine-vapor compression refrigeration system acti-vated by low-grade thermal energy. J Adv Res 2016;7:651–660. [CrossRef]

[15] Afshari F, Comakli O, Lesani A, Karagoz S. Characterization of lubricating oil effects on the performance of reciprocatingcompressors in air-water heat pumps. Int J Refrig 2017;74:503–514. [CrossRef]

[16] Tashtoush BM, Al-Nimr MDA, Khasawneh MA. Investigation of the use of nano-refrigerants to enhance the performanceof an ejector refrigeration system. Appl. Energy 2017;206:1446−1463. [CrossRef]
[17] Murshed SMS, Leong KC, Yang C. Investigations of thermal conductivity and viscosity of nanofluids. Int J Therm Sci 2008;47:560−568. [CrossRef]
[18] Rashid I, Zubair T, Asjad MI, Tag-ElDin EM. The Influence of Aligned MHD on Engine Oil-Based Casson Nanofluid withCarbon Nanotubes (Single and Multi-Wall) Passing through a Shrinking Sheet with Thermal Radiation and Wall Mass Ex-change. Micromachines 2022;13:1501. [CrossRef]
[19] Gokdemir G, Doner N, Sert Z, Sen F, Ciddi K. Effects of CuO, TiO2 and graphite microparticles on the heat transfer prop-erties of greases. Eng Sci Technol Int J 2022;30:101044. [CrossRef]
[20] Zainal NA, Nazar R, Naganthran K, Pop, I. Unsteady MHD stagnation point flow induced by exponentially permeablestretching/shrinking sheet of hybrid nanofluid. Eng Sci Technol Int J 2021;24:1201−1210. [CrossRef]
[21] Yıldız G, Ağbulut Ü, Gürel AE. A review of stability, thermophysical properties and impact of using nanofluids on theperformance of refrigeration systems. Int J Refrig 2021;129:342−364. [CrossRef]
[22] Usri NA, Azmi WH, Mamat R, Hamid KA. Forced convection heat transfer using water-ethylene glycol (60: 40) basednanofluids in automotive cooling system. Int J Automot Mech Eng 2015;11:2747. [CrossRef]
[23] Ohunakin OS, Adelekan DS, Babarinde TO, Leramo RO, Abam FI, Diarra CD. Experimental investigation of TiO2-,SiO2-and Al 2O3-lubricants for a domestic refrigerator system using LPG as working fluid. Appl Therm Eng 2017;127:1469−1477. [CrossRef]
[24] Senthilkumar A, Anderson A. Experimental investigation of SiO2 nanolubricants for R410A vapour compression refrigerationsystem. Mater Today Proc 2021;44:3613−3617. [CrossRef]
[25] Mihai I, Suciu C, Picus CM. Particularities of R134a refrigerant temperatur e variations in a transient convective regimeduring vaporization in rectangular microchannels. Micromachines 2022;13:767. [CrossRef]
[26] Zawawi NNM, Azmi WH, Ghazali MF. Performance of Al2O3-SiO2/PAG composite nanolubricants in automotive air-con-ditioning system. Appl Therm Eng 2022;204:117998. [CrossRef]
[27] Qi Z, Zhao Y, Chen J. Performance enhancement study of mobile air conditioning system using microchannel heat exchang-ers. Int J Refrig 2010;33:301−312. [CrossRef]
[28] Tuo H, Hrnjak P. Flash gas bypass in mobile air conditioning system with R134a. Int J Refrig 2012;35:1869−1877. [CrossRef]
[29] Sharif MZ, Azmi WH, Redhwan AAM, Mamat R, Yusof TM. Performance analysis of SiO2/PAG nanolubricant in auto-motive air conditioning system. Int J Refrig 2017;75:204−216. [CrossRef]
[30] Sharif, MZ, Azmi WH, Redhwan AAM, Mamat R, Najafi G. Energy saving in automotive air conditioning system per-formance using SiO2/PAG nanolubricants. J Therm Anal Calorim 2019;135:1285−1297. [CrossRef]
[31] Atik K, Aktaş A. An experimental investigation of the effect of refrigerant charge level on an automotive air conditioning system. J Therm Sci Technol 2011;31:11−17.
[32] Moon JH, Lee JW, Jeong CH, Lee SH. Thermal comfort analysis in a passenger compartment considering the solar radiation effect. Int J Therm Sci 2016;107:77−88. [CrossRef]
[33] Mansour C, Nader WB, Breque F, Haddad M, Nemer M. Assessing additional fuel consumption from cabin thermal comfort and auxiliary needs on the worldwide harmonized light vehicles test cycle. Transp Res Part D Transp Environ 2018;62:139−151. [CrossRef]
[34] Danca P, Vartires A, Dogeanu A. An overview of current methods for thermal comfort assessment in vehicle cabin. Energy Proced 2016;85:162−169. [CrossRef]
[35] Lee J, Kim J, Park J, Bae C. Effect of the air-conditioning system on the fuel economy in a gasoline engine vehicle. Proc Inst Mech Eng Part D J Automob Eng 2012;227:66−77. [CrossRef]
[36] Barth M, Boriboonsomsin K. Traffic congestion and greenhouse gases. Access Mag 2009;1:2−9.
[37] Najjar YSH. Gaseous pollutants formation and their harmful effects on health and environment. Innov Energy Policies 2011;1:1−9. [CrossRef]
[38] McNabola A, Broderick BM, Gill LW. The impacts of inter-vehicle spacing on in-vehicle air pollution concentrations in idling urban traffic conditions. Transp Res Part D Transp Environ 2009;14:567−575. [CrossRef]
[39] Hundy GF, Trott AR, Welch TC. Refrigeration, Air Conditioning and Heat Pumps. 5th ed. Butterworth-Heinemann; Oxford, UK: 2016. pp. 488. [CrossRef]
[40] Rejvani M, Saedodin S, Vahedi SM, Wongwises S, Chamkha AJ. Experimental investigation of hybrid nano-lubricant for rheological and thermal engineering applications. J Therm Anal Calorim 2019;138:1823−1839. [CrossRef]
[41] Ben Said L, Kolsi L, Ghachem K, Almeshaal M, Maatki C. Advancement of nanofluids in automotive applications during the last few years-A comprehensive review. J Therm Anal Calorim 2021;147:7603−7630. [CrossRef]
[42] Mohanraj M, Jayaraj S, Muraleedharan C, Chandrasekar P. Experimental investigation of R290/R600a mixture as an alternative to R134a in a domestic refrigerator. Int J Therm Sci 2009;48:1036−1042. [CrossRef]

[43] Ahmadpour M, Akhavan-Behabadi M, Sajadi B, Salehi-Kohestani A. Effect of lubricating oil on condensation characteristics of R600a inside a horizontal U-shaped tube: Experimental study. Int J Therm Sci 2019;145:106007. [CrossRef]
[44] Saleh B. Parametric and working fluid analysis of a combined organic Rankine-vapor compression refrigeration system activated by low-grade thermal energy. J Adv Res 2016;7:651−660. [CrossRef]
[45] Afshari F, Comakli O, Lesani A, Karagoz S. Characterization of lubricating oil effects on the performance of reciprocating compressors in air-water heat pumps. Int J Refrig 2017;74:503−514. [CrossRef]
[46] Tashtoush BM, Al-Nimr MDA, Khasawneh MA. Investigation of the use of nano-refrigerants to enhance the performance of an ejector refrigeration system. Appl Energy 2017;206:1446−1463. [CrossRef]
[47] Murshed SMS, Leong KC, Yang C. Investigations of thermal conductivity and viscosity of nanofluids. Int J Therm Sci 2008;47:560−568. [CrossRef]
[48] Rashid I, Zubair T, Asjad MI, Tag-ElDin EM. The ınfluence of aligned MHD on engine oil-based casson nanofluid with carbon nanotubes (single and multi-wall) passing through a shrinking sheet with thermal radiation and wall mass exchange. Micromachines 2022;13:1501. [CrossRef]
[49] Gokdemir G, Doner N, Sert Z, Sen F, Ciddi K. Effects of CuO, TiO2 and graphite microparticles on the heat transfer properties of greases. Eng Sci Technol Int J 2022;30:101044. [CrossRef]
[50] Zainal NA, Nazar R, Naganthran K, Pop I. Unsteady MHD stagnation point flow induced by exponentially permeable stretching/shrinking sheet of hybrid nanofluid. Eng Sci Technol Int J 2021;24:1201−1210. [CrossRef]
[51] Yıldız G, Ağbulut Ü, Gürel AE. A review of stability, thermophysical properties and impact of using nanofluids on the performance of refrigeration systems. Int J Refrig 2021;129:342−364. [CrossRef]
[52] Usri NA, Azmi WH, Mamat R, Hamid KA. Forced convection heat transfer using water-ethylene glycol (60:40) based nanofluids in automotive cooling system. Int J Automot Mech Eng 2015;11:2747. [CrossRef]
[53] Ohunakin OS, Adelekan DS, Babarinde TO, Leramo RO, Abam FI, Diarra CD. Experimental investigation of TiO2-, SiO2-and Al2O3-lubricants for a domestic refrigerator system using LPG as working fluid. Appl Therm Eng 2017;127:1469−1477. [CrossRef]
[54] Senthilkumar A, Anderson A. Experimental investigation of SiO2 nanolubricants for R410A vapour compression refrigeration system. Mater Today Proc 2021;44:3613−3617. [CrossRef]
[55] Mihai I, Suciu C, Picus CM. Particularities of R134a refrigerant temperature variations in a transient convective regime during vaporization in rectangular microchannels. Micromachines 2022;13:767. [CrossRef]
[56] Zawawi NNM, Azmi WH, Ghazali MF. Performance of Al2O3-SiO2/PAG composite nanolubricants in automotive air-conditioning system. Appl Therm Eng 2022;204:117998. [CrossRef]
[57] Qi Z., Zhao Y., Chen J. Performance enhancement study of mobile air conditioning system using microchannel heat exchangers. Int J Refrig 2010;33:301−312. [CrossRef]
[58] Tuo H, Hrnjak P. Flash gas bypass in mobile air conditioning system with R134a. Int J Refrig 2012;35:1869−1877. [CrossRef]
[59] Sharif MZ, Azmi W.H., Redhwan AAM, Mamat R, Yusof TM. Performance analysis of SiO2/PAG nanolubricant in automotive air conditioning system. Int J Refrig 2017;75:204−216. [CrossRef]
[60] Sharif MZ, Azmi WH, Redhwan AAM, Mamat R, Najafi G. Energy saving in automotive air conditioning system performance using SiO2/PAG nanolubricants. J Therm Anal Calorim 2019;135:1285−1297. [CrossRef]