

**Performance Enhancement of R600a Vapour
Compression Refrigeration System using $\text{Al}_2\text{O}_3/\text{TiO}_2$
Hybrid Nano lubricants**

Submitted in partial fulfilment of the requirements for the award of Bachelor of
Engineering degree in Mechanical Engineering

By

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SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade "A" by NAAC

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APRIL 2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of PRASANNA VENKATESH A (Reg. No. 39150099) and JOTHEESWARAN S (Reg. No. 39150058) who carried out the Project entitled "**Performance Enhancement of R600a Vapour Compression Refrigeration System using $\text{Al}_2\text{O}_3/\text{TiO}_2$ Hybrid Nano lubricants**" under our supervision from December 2022 to April 2023.

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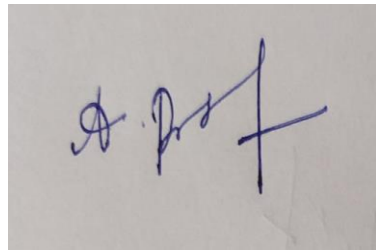
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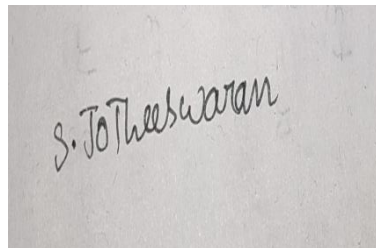
DECLARATION

We, PRASANNA VENKATESH A (Reg.No. 39150099) and JOTHEESWARAN S (Reg.No. 39150058) hereby declare that the Project Report entitled “**Performance Enhancement of R600a Vapour Compression Refrigeration System using $\text{Al}_2\text{O}_3/\text{TiO}_2$ Hybrid Nano lubricants**” done by us under the guidance of **Dr. M. PURUSOTHAMAN, M.E., Ph.D.**, Associate Professor, Dept. of Mechanical Engineering is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering in Mechanical Engineering.

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ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to the Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr. S. Prakash, M.E., Ph.D.**, Dean, School of Mechanical Engineering and **Dr. G. Arun Kumar, M.E., Ph.D.**, Head of the Department, Dept. of Mechanical Engineering for providing us necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Dr. M. Purusothaman, M.E., Ph.D.**, Associate Professor, Dept. of Mechanical Engineering for his valuable guidance, suggestions and constant encouragement, which paved the way for the successful completion of our project work.

We wish to express our thanks to all Teaching and Non-teaching staff members of the Department of Mechanical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

Consumption of energy serves as one of the primary problems with vapor compression refrigeration systems. For the purpose to fix this issue and consume less energy, this system implements a new approach. The performance of R600a refrigerant combined with hybrid $\text{Al}_2\text{O}_3/\text{TiO}_2$ nanoparticles is experimentally evaluated in this paper to produce nano refrigerant. This study used 70 g of R600a and three distinct hybrid nanoparticle concentrations of 0, 0.2, and 0.4 g/L of $\text{Al}_2\text{O}_3/\text{TiO}_2$. The experiment was conducted to explore a variety of significant variables, including Coefficient of Performance, compressor power consumption, and the Cooling effect. R600a refrigerant was used in the research along with $\text{Al}_2\text{O}_3/\text{TiO}_2$ hybrid nanoparticles, and it can be used as a more effective replacement for refrigeration systems that use pure R600a refrigerants. The VCRS in this study that contained 0.4 g/L of the hybrid $\text{Al}_2\text{O}_3/\text{TiO}_2$ nano refrigerant performed most effectively, with a 25.01% increase in Coefficient of Performance, a 20.83% increase in refrigeration effect, and a reduced compressor power requirement. It is determined that blended nanoparticles and hydrocarbon refrigerants offer an environmentally friendly refrigerant that not only has low GWP and ODP but also raises the overall COP of the VCRS. They also have a wide potential for use in refrigeration systems.

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LIST OF SYMBOLS AND ABBEREVIATIONS

VCRS	Vapour Compression Refrigeration System
COP	Coefficient of Performance
HC	Hydrocarbons
CFC	Chlorofluorocarbons
HCFC	Hydrochlorofluorocarbons
ODP	Ozone Depletion Potential
GWP	Global Warming Potential
POE	Polyol Ester Oil
MWCNT	Multi Walled Carbon Nanotube
SWCNT	Single Walled Carbon Nanotube
PAG	Poly Alkylene Glycol
MO	Mineral Oil
RTD	Resistance Temperature Detector
HFO	Hydrofluoroolefins

CHAPTER – 1

INTRODUCTION

The refrigerant used in a refrigeration system largely determines its performance, and conventional refrigerants have considerably higher GWP and ODP. Therefore, for both optimal performance and environmental sustainability, an ideal refrigerant should be used as the working fluid in household refrigerators. The use of refrigerants significantly harms the ecosystem in two different ways. The compressor of a refrigerator uses energy, increasing CO₂ emissions and contributing to global warming, which are all indirect causes. The ozone layer may be destroyed, and global warming may be accelerated by direct factors like the discharge of refrigerant gases or leaks into the atmosphere. Nano-refrigerants may contribute to a healthy economy by reducing energy consumption. The most used refrigerants in residential refrigeration systems today are HFC refrigerants like R134a, R32, and R410a. These refrigerants have a high GWP despite having a modest ODP. Because of these drawbacks, these refrigerants won't be used in the upcoming years. Some businesses have already shifted to HC like R290, R600a, etc. because of their zero ODP and minimal GWP. These pure refrigerants, when blended along with nanoparticles like Polyaniline Tubes, Titanium dioxide, Silicon dioxide, Copper oxide, and Aluminium oxide, can improve the overall Thermo-Physical characteristics and heat transfer coefficient, improving refrigeration system efficiency and consuming less energy. The ratio of thermal energy removed from the evaporator space to the work utilized by the compressor is known as the Coefficient of Performance (COP) of a refrigeration system. There are generally two ways to increase this COP: first, by raising the evaporator's heat extraction, and second, by reducing the power consumption by the compressor (B. P. Krishnan et al., 2019). Many experts have investigated the feasibility of incorporating nanoparticles into refrigerants to develop a new category of refrigerants known as Nano Refrigerants. By accelerating the heat transfer characteristics using nanoparticles, it will increase the system's cooling efficiency (Haque et al., 2016). Heat exchangers, heavy-duty vehicles, centrifugal pumps, oil pumps, military and medical applications, energy storage, military and aerospace use, automobiles,

electronic cooling, and medical applications are just a few of the many sectors that use nano-fluids (D. Sendil Kumar & R. Elansezhian, 2012).

1.1 PREPARATION METHODS OF NANOFLUIDS

Nanoparticles can be made of metals like copper, nickel, or aluminium as well as oxides like silicon dioxide, aluminum oxide, titanium dioxide, and copper oxide mixed with a base fluid, such as engine oil, water, Propylene Glycol (PG), Ethylene Glycol (EG), and refrigerants. The first phase in the experimental studies on nano-refrigerants is the preparation of nanofluids. Nano-fluids are not merely combinations of solid and liquid. The main requirements for an ideal Nanofluid are stability, resistance to agglomeration, long-lasting suspension, and no need for the fluid to undergo any chemical changes. There are generally two methods adopted for the nanofluid preparation. They are one step and two step methods.

A two-step process is adopted in the current investigation. For the creation of the nano lubricant, Sigma Aldrich utilized the commercially available aluminum oxide particles which were having an appropriate size of 50 nm and a density of 0.26 grams per cubic centimeter. The mixture of nanoparticles and lubricant have 0.06% mass of nanoparticles. The nanoparticles were uniformly dispersed using an ultrasonic vibrator and this required agitation for roughly 24 hours (Subramani & Prakash, 1970).

Nanoparticles must initially be generated and then dispersed throughout the base fluid in order to form nano-fluids. The nano fluids can be prepared using either a one step process or a two-step method. The two-step method prepares the nanoparticles first before dispersing them into the base fluid, in contrast to the one step method's simultaneous dispersion and production of nanoparticles (Mohan & PrakashM, 2007).

The most often utilized technical methods for dispersing nanoparticles in a two-step process includes stabilization, magnetic stirring, homogenizing, ultrasonic agitation, etc., (Bhattad et al., 2019). The different methods for Nanofluids preparation are shown in Fig 1.1

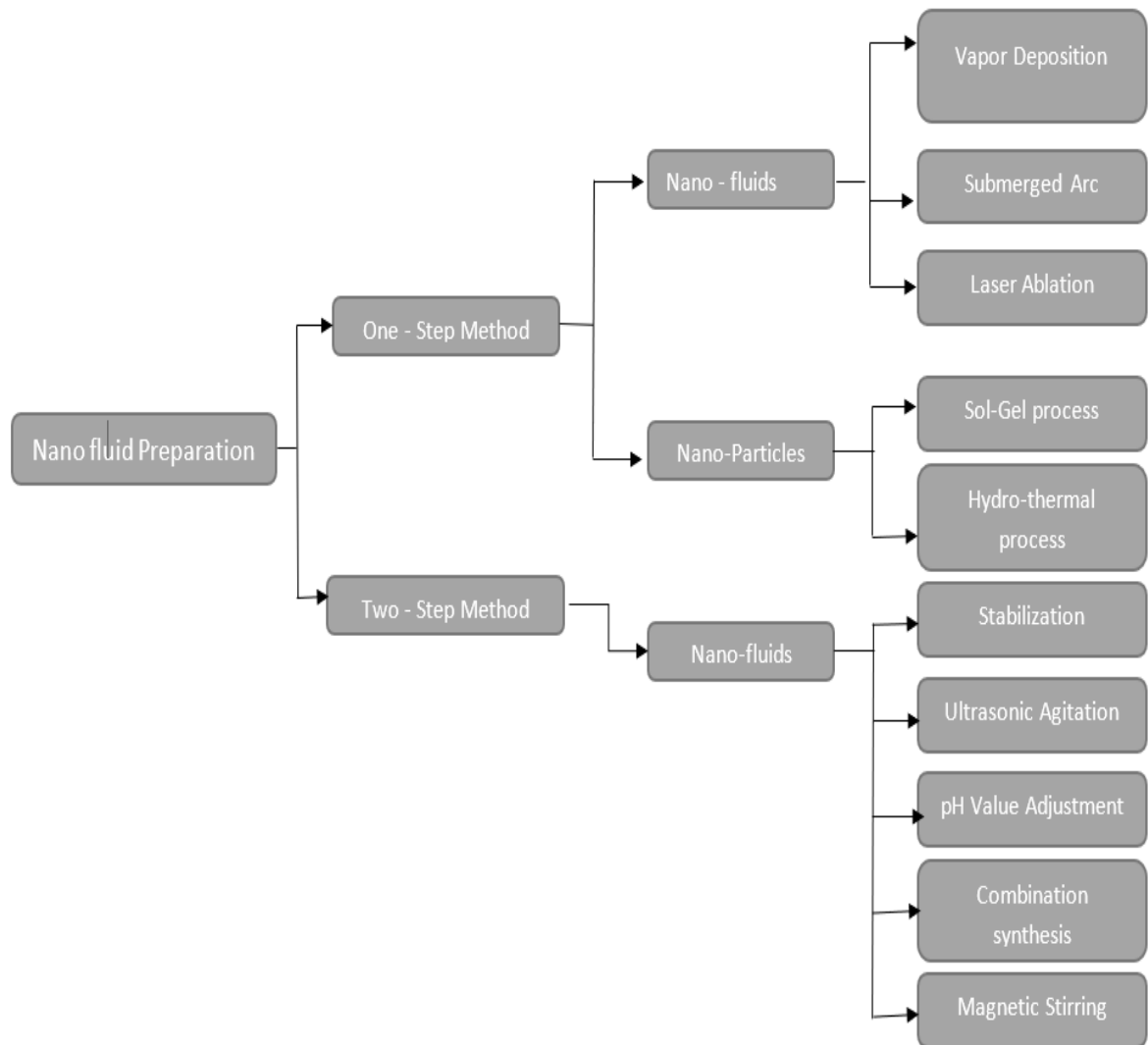


Figure 1.1: Different techniques for preparing nanofluids

1.1.1 Two - step methodology

The two-step process is the one that is most frequently used to make nanofluids. In this methodology, nanofibers, nanotubes, or any other nanomaterials are employed to create dry powders via chemical or physical means first. The prepared nano-sized dry powder will next be dispersed into the base liquid using various methods such as magnetic force agitation, homogenizing, ultrasonic agitation, etc.

The two-step method is the most economical way to produce nanofluids on a wide scale, as commercial production levels of nano powder synthesis techniques have already been attained. Because of their high surface area and surface features, nanoparticles frequently agglomerate. A common technique for improving the durability of nanoparticles in fluids is the application of surfactants. Numerous cutting-edge solutions, including the one-step method, have been developed as a result of the challenges associated with creating stable nanofluids using the two-step method (Rathodiya et al., 2017).

S. Venkatachalapathy used a two-step method to mix CuO nanoparticles along with the de-mineralized water without the addition of any surfactants to create homogeneous and stable suspensions. After that, the suspension was placed an hour in an ultrasonic homogenizer and so using this method, nanoparticles were generated (Venkatachalapathy et al., 2015).

By utilizing TiO₂ nanoparticles into a solution of cetyltrimethylammonium bromide (CTAB) and de-mineralized water, Ehsan Ebrahimnia-Bajestan created nanofluids. After that, the mixture was constantly sonicated for three to five hours within an ultrasonic bath. Without any visible sedimentation, the suspensions were found to be stable for around three months (Ebrahimnia-Bajestan et al., 2016). Titanium dioxide (TiO₂) nanofluids were made using an ultrasonic approach by Paisarn Naphon without the use of a surfactant (Naphon et al., 2008).

By directly combining Al₂O₃ and CuO nanoparticles along with the diesel fuel as the base fluid and then ultrasonically processing it for an hour at a 40 Hz frequency, Soner Gumus et al. created Nano diesels. In order to create the Nanoparticles enhanced Phase Change Materials (NEPCMs), they used the traditional two-step approach with erythritol and nano-titania as the PCM (Luo et al., 2015).

B. Pitchia Krishnan et al. blended Al₂O₃ nanoparticles which are in the size of approximately 40 nm along with the PAG base fluid to incorporate nano lubricant in a recognized technique for nanofluid preparation. The mixture of Al₂O₃ nanoparticles which was dispersed in its base fluid PAG was set up for two hours under the direction of an appealing stirrer. The mixture is then continued vibrating for an additional four hours using an ultrasonic vibrator for thoroughly separating the

nanoparticles and to maintain any groupings of particles in the mixture for proper homogenization and thus discarding the aggregation of particles (P. B. Krishnan et al., 2017). The nanofluid prepared by B. Pitchia et al. is shown in Fig 1.2. The preparation of nanofluid by two step method is shown in Fig 1.3.



Figure 1.2: Prepared Nanofluid using Magnetic Stirring Method

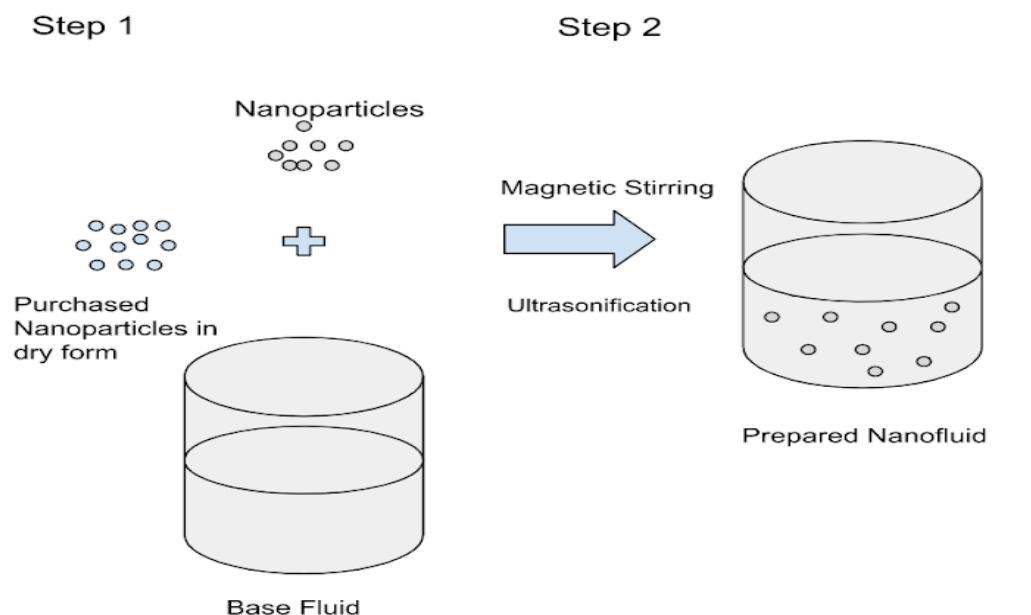


Figure 1.3: Nano fluid preparation utilizing a two-step methodology

1.1.2. One - step methodology

The vacuum evaporation onto a running oil substrate, or VEROS technique, was created by Akoh et al. in 1978. Although the initial goal of this technique was to

create nanoparticles, it is challenging to afterwards separate the particles from the fluids to create dry nanoparticles (Akoh et al., 1978).

In an adapted VEROS technique developed by Eastman et al. (1997), the vapors of copper nanoparticles are rapidly condensed to nanoparticles by interaction with a flowing low-vapor-pressure liquid. In order to reduce the agglomeration of nanoparticles, Eastman et al. developed this vapor condensation method to create Cu/EG concurrently preparing and dispersing the nanoparticles in the fluid. This technology reduces nanoparticle agglomeration and improves fluid stability by doing away with the operations of drying, storing, transporting, and dispersing nanoparticles (Eastman et al., n.d.).

One-step processes can be used to produce evenly distributed nanoparticles that can be kept consistently in the base fluid. The suction submerged arc nanoparticle synthesis system is another effective technique for creating nanofluids with various insulating liquids (Fuskele & Sarviya, 2017). M.A. Akhavan et al., utilized multi walled carbon nanotubes or MWCNT to produce the nanofluids using the Chemical Vapor Deposition (CVD) technique with deionized water (Akhavan-Behabadi et al., 2015). The synthesis of nanofluid by one step method is shown in Fig 1.4.

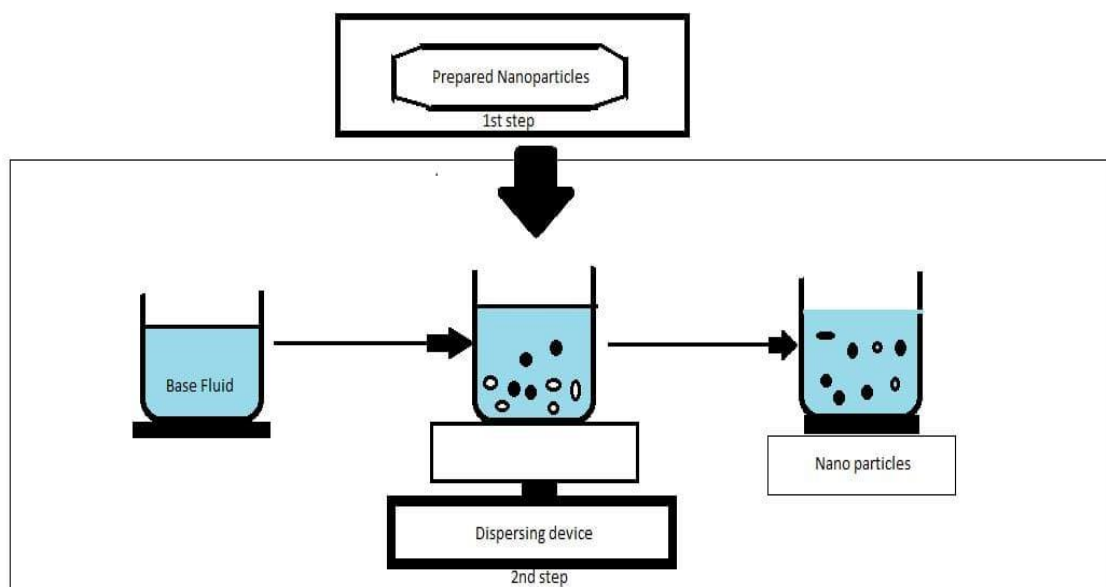


Figure 1.4: Nanofluids preparation by one step method

1.2. STABILITY OF NANOFLUID

Due to their propensity to coagulate, nanofluids may lose their ability to transport heat. As a result, investigating stability is a crucial subject that might alter the thermal characteristics of the nanofluids, which is used in wide applications. Examining the underlying factors that have an impact on the stability of such suspensions is equally essential. Methodologies for stability development and improvements to stability are covered in this section (Sandhu et al., 2016).

1.2.1 Basic Methods for Stability Evaluation

1.2.1.1. Centrifugal and Sedimentation Method

The most straightforward and simple method for assessing the sustainability of nanofluids is sedimentation. An indicator of the stability of nanofluids is the mass or quantity of sediment when subjected to external forces. When the proportion or size of the particles are consistent over both time and space, a nanofluid is said to be constant. Images of the dirt at the bottom of the liquid can be captured by cameras. The sedimented particles were evaluated. At a specific time, the volume percentage of the particulate solution was computed. Using this methodology, we can see how sediments and fractions have changed throughout time. However, the longer the observation time in this method causes errors. As a result, a method for measuring the hardness of nanofluids using centrifugation was created (Sandhu et al., 2016).

1.2.1.2. Zeta Potential Measurement

The electric potential is significant because the sustainability of nano-fluid is correlated with its value. A physical characteristic displayed by any suspended particle, material surface, or macromolecule is called zeta potential. It can be employed to estimate interactions with surfaces, improve the production of films and coatings, and improve the compositions of suspensions, protein solutions and emulsions. And it can also be helpful in making long-term sustainability predictions. It is well recognized that greater the zeta potential, nanofluids have more stability, whereas lower the zeta potential, nanofluids have poorer stability. It is generally

noted that when the Zeta potential values lying between the range of 40mV and 60mV are typically regarded as stable nanofluids, whereas, for zeta potential values of 60mV and higher are regarded as highly stable nanofluids. The zeta potential method is used to determine the voltage between a static layer of fluid particles and a dispersed phase. A value of 25 mV is arbitrarily selected to distinguish between low and high charge surfaces which separates poorly stable from highly stable nanofluids (Mukherjee & Paria, n.d.).

1.2.1.3 Spectral Absorbance Measurement

It is yet another useful technique for assessing the durability of nanofluids. Typically, the concentration of nanofluids and intensity of absorbent are directly correlated. By measuring the absorption of UV by nanofluids, one may determine how the supernatant particles in the solution change over time. One advantage of this technology is that it provides a comparative measurement of the sustainability of nanofluids throughout time. The amount of UV spectral absorption by nanofluids is used to calculate their concentration, the greater their absorption, the more stable the nanofluids are (Sandhu et al., 2016).

1.2.2. Stability enhancement methods

The three most effective methods for creating stable nanoparticle suspensions include adjusting the pH of the suspensions, adding surfactants, and using ultrasonic vibration. All of these methods work to stabilize suspensions by modifying the surface characteristics of suspended nanoparticles and preventing the development of clustered particles (Mukherjee & Paria, n.d.).

1.2.2.1. Surfactants

Surfactants of small amounts have an immense impact on the surface properties of nanofluids and another name for surfactants is Dispersants. Dispersants are composed of two parts: the head and the tail. The hydro-philic head and hydro-phobic tail of the dispersion are its two main components. Surfactants help the liquid and solid phases make better contact with one another. Dispersants are substances that are positioned between the interfaces of particles and fluids in nanofluids. They create continuity between the two phases and bind the particles to

the base fluid medium, enhancing the nanofluid's stability. Surfactants, according to Yu and Xie, can be divided into four classes based on the composition of the head: Alcohol and other nonionic surfactants have no charge on their heads. Alkyl sulphates are an anionic surfactant that has a negatively charged head. The head of cationic surfactants is positively charged. The zwitterionic head has amphoteric surfactants (Chen & Xie, 2010).

1.2.2.2. Techniques for Surface Modification

This method, which uses no surfactants, intends to improve stability while minimizing or eliminating compromises to the thermal conductivity of nanofluids. The surface of nanoparticles can be changed using chemicals. The particles in the base fluid solution are more stable. Chen et al., utilized single and double stacked carbon nanotubes using a mechanochemical process (CNTs). Zeta potential and infrared spectroscopy techniques were used to test the stability, and it was discovered that CNTs become stable in the appropriate base fluid when a hydroxyl group is linked to their surface (Chen & Xie, 2010). Diamond's surface was altered by Yu et al., via plasma treatment (Yu et al., 2008).

1.2.2.3. pH Controls of Nanofluids

Because the electro-kinetic properties of nanofluids directly affect their stability, controlling their pH can make them more stable due to strong repulsive forces. In order to stabilize the test Nano fluids, V. Nikkhah et al., used the pH control approach, controlling the pH of the nanofluids with HCl + NaOH (Nikkhah et al., 2015). The three phases of pH adjustment, stirring, and sonication were used in a novel combinatorial technique. At any proportion of nanofluids, stability may be attained for around 1080 hours (Sandhu et al., 2016).

1.3. DIFFERENT TYPES OF REFRIGERANTS

A refrigerant is a substance which is used to absorb the heat from the refrigerator compartment (Evaporator) and transfer it to the atmosphere. In their optimum state, all refrigerants are liquid. It moves through several components of a refrigerator. During the circulation process, it transforms from a liquid to a gas, then

back to a liquid. The refrigerants are mainly from CFC, HCFC and HC. CFCs are among the primary contributors to the greenhouse gas effect and the destruction of the ozone layer. The most popular CFC, also known as Freon, was R12. HCFC is slightly better than CFCs because of its reduced chlorine content in its molecule although it has adverse effects in GWP. HFCs have no chlorine content in their molecules. So, it has less ODP but high GWP. The most used HFCs are R22, R32, R134a, R410a. HC have less ODP and GWP values. So, it is considered as an Eco-friendly refrigerant (R-600a, R290, etc.,). Numerous studies have been conducted in recent years to utilize HC mixed with Nano-Particles to enhance the functionality of refrigeration systems (Mclinden et al., n.d.). The history of various refrigerants used since 1990 is shown in Fig 1.5.

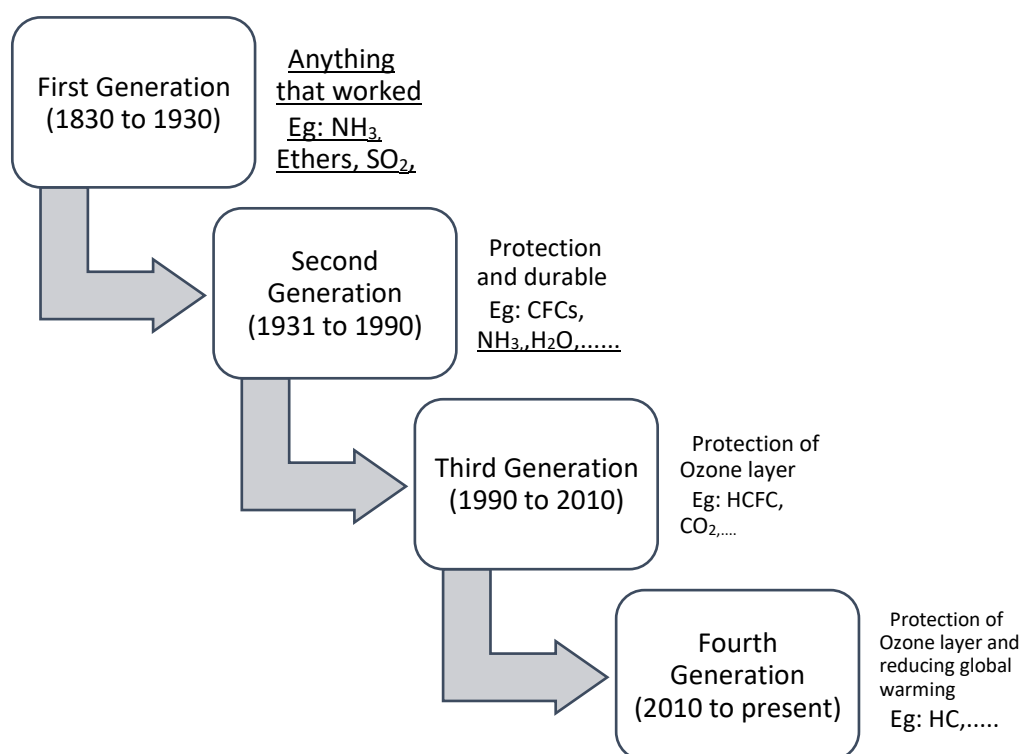


Figure 1.5: History of usage of different Refrigerants

1.3.1 Refrigerants of first generation

These refrigerants are initially utilized for the purpose of abstracting heat from the evaporator. The only requirements for a refrigerant throughout this period were that it be easily accessible and that it function in the system that was in use at the time. However, a few of the refrigerants discovered in such initial periods included both fluids, such as sulphur, which also had outstanding thermodynamic properties but were extremely toxic, in addition to fluids with decent thermodynamic properties but are still excellent refrigerants today (such as ammonia, propane, and CO₂, H₂O). The major concerning factor for our environmental concerns in these categories of refrigerants were flammable, toxic and highly reactive. According to the table shown below, the 1st generation of refrigerants have low ODP and GWP values, which means they are not dangerous to the environment. However, as technology and demand grew, they were unable to provide the desired level of cooling effect, and the 2nd generation of refrigerants entered the market (Narute et al., 2021). The characteristics of first-generation refrigerants is tabulated in Table 1.1.

Table 1.1: Characteristics of first-generation refrigerants

Refrigerant Name	Chemical formula	Designation of refrigerants	ODP	GWP	Applications
Carbon dioxide	CO ₂	R - 744	0	1	Used for preserving food products.
Sulphur dioxide	SO ₂	R - 764	0	0	Used in cold storage plants
Ammonia	NH ₃	R – 717	0	0	Used in Heat pump systems,

					Hvac chillers, Thermal storage systems.
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1.3.2. Refrigerants of second generation

The transition to chlorofluoro compounds for safety and durability, as opposed to first generation refrigerants, is a key component of second-generation refrigerant. The variations in chlorofluorocarbons have a significant impact on the reduction of flammability and toxicity of the refrigerant. CFC is non-toxic, less reactive, and combustible. It is suitable for a variety of applications due to its great stability and minimal reactivity (Narute et al., 2021). Examples of second-generation refrigerants include R-11, R-12, and others. The air conditioning and refrigeration industries largely use the excellent refrigerant R-11. It is also non-explosive, non-flammable, and non-toxic. The only problem with 2nd generation refrigerants, as seen in the Table, is that they greatly contribute to the ozone layer's thinning and increase the rate of global warming. Third generation refrigerants, which are second generation refrigerants that have been changed, are therefore necessary (Calm, 2008). The characteristics of second-generation refrigerants is tabulated in Table 1.2.

Table 1.2: Characteristics of second-generation refrigerants

Refrigerant Name	Chemical formula	Designation of refrigerants	ODP	GWP	Applications
Trichlorofluoro methane	CCl_3F	R - 11	1	4000	Used in ACs of small rooms, factories.

Dichlorodifluoromethane	CCl_2F_2	R – 12	1	8400	Used in Liquid chillers, Transportation refrigerants.
Chlorodifluoromethane	CHClF_2	R – 22	0.055	1800	Used in mini splits.

1.3.3. Refrigerants of third generation

The goal of 3rd generation refrigerants is to have lower potential for ozone depletion and global warming. This is a brand-new class of refrigerants made from the chemicals HFC and HFC. These 2nd refrigerants that have been changed provide HFO refrigerators, a different new class of fluorocarbon refrigerators with reduced GWP capacity, have been enhanced. In addition to having a low GWP, their key benefit is that they can be integrated into current refrigeration system designs. This is advantageous for the sector and its clients, although fluorine vapour would still be available. The 3rd generation refrigerants although having zero ODP, it has high GWP which will result in the rise of global warming. Thus, fourth generation refrigerants came for usage with improved characteristics (Calm, 2008). The characteristics of third-generation refrigerants is tabulated in Table 1.3.

Table 1.3: Characteristics of third-generation refrigerants

Refrigerant Name	Chemical formula	Designation of refrigerants	ODP	GWP	Applications

Difluoro methane	CH ₂ F ₂	R - 32	0	600	Used as a replacement of R410a
Tetraflouro ethane	CF ₃ CH ₂ F	R -134a	0	1200	Used as a replacement of R12
Azeotropic refrigerant	R32+R125	R 410a	0	1900	Used in AC's.

1.3.4. Refrigerants of fourth generation

The only thing that this new generation of refrigerants are is more environmentally conscious. The refrigerants used in this period were from the category of HC. The main improvement seen in this refrigerant is that it has zero ODP and low GWP, which will cause no harm to the environment (Sruthi Emani et al., 2017). The characteristics of fourth-generation refrigerants is tabulated in Table 1.4.

Table 1.4: Characteristics of fourth-generation refrigerants

Refrigerant Name	Chemical formula	Designation of refrigerants	ODP	GWP	Applications
Isobutane	C ₄ H ₁₀	R – 600a	0	3	Used in refrigeration and AC's.
Opteon	-	R – 513	0	573	Used in centrifugal chillers.

CHAPTER – 2

LITERATURE SURVEY

2.1 PROPERTIES OF NANO-PARTICLES AND ITS EFFECT ON VCRS

Because of the small dimensions and high surface-to-volume ratio, nanoparticles display a variety of unique characteristics that set them apart from those found in bulk. In multiple fields of technology and science, the following characteristics of nanoparticles are especially important:

- Thermal Conductivity.
- Viscosity.
- Heat Transfer.
- Optical Properties.
- Chemical Reactivity.
- Magnetic Properties.

2.1.1. Thermal Conductivity of Nanofluid

Selvam et al., conducted a study utilizing silver Nano fluids in a solution of water and EG. Using a thermophysical properties analyzer, parameters including viscosity, thermal transfer capacity, specific heat, density were measured (kd2 Pro). With a rise in temperature and nanoparticle concentration, the thermal conductivity got better. As the concentration of nanoparticles increased, so did the viscosity and density, which fell as the temperature increased. With an increase in temperature and a drop in nanoparticle concentration, the specific heat increased (Selvam et al., 2016).

Akilu et al. examined CuO and TiO₂ nanoparticles using EG as the base fluid. In relation to their volume concentration and temperature, the viscosity and thermal conductivity of nanoparticles were assessed. The outcome revealed that the concentration of temperature and volume of nanoparticles had a significant impact on the viscosity and thermal conductivity (Akilu et al., 2017).

Vasconcelos et al., investigated the application of SWCNT Nanofluid as a secondary fluid in a refrigeration system. The SWCNT Nano fluid was assessed as a secondary fluid and has a 4 to 9 kW cooling power range. The test rig was an R22 VCRS with an air-cooled condenser type and an electronic expansion valve. The experiment made use of various volumetric concentrations of Nanofluid. The output demonstrated that Nanofluid, used as a secondary refrigerant, has increased thermal conductivity and refrigerating capacity (Vasconcelos et al., 2017).

Maheshwary et al., investigation looked at how ZnO/R134a Nano refrigerant's heat transfer and thermal properties were impacted by the nanoparticles' shape. ZnO nanoparticles with a cubic and spherical shape were considered for the test. The findings showed that compared to pure R134a refrigerant, cubic ZnO Nanoparticles in R134a had a 42.5% increase in thermal conductivity. The author suggested using cubic-shaped ZnO nanoparticles in R134a in VCRS (Maheshwary et al., 2018).

2.1.2. Viscosity of nanofluid

According to O. A. Alawi, as the addition of nanoparticles increases, the viscosity also increases along with it and at the same time as the temperature increases the viscosity of the material decreases. When the Nano lubricant flowing inside of the smooth tube was investigated, the viscosity increased due to the increase in Nanoparticle concentration (Alawi & Sidik, 2014).

M. Anish et al. claim that the thermal conductivity and viscosity are estimated at temperatures between 30 and 60 °C using a kd₂ analyzer and a Fenske viscometer utilizing MgO-Therminol 55 as a nanofluid. According to data gathered from their experimental findings, viscosity and density at various temperatures decrease as volume concentration rises, while thermal conductivity rises (Arunkumar et al., 2019).

The viscosity of the Al₂O₃ nanoparticle that was combined with R141-b refrigerant was determined using the Brinkman Model. The viscosity of the nanofluid was found to increase with the addition of nanoparticles on a volume basis, but to decrease with increasing temperature (Veera Raghavalu & Govindha Rasu, 2018).

2.1.3. Heat transfer performance of nanofluid

Arunkumar et al. had used two distinct nanoparticle compositions. The base fluid used for dissolving the nanoparticle is a mixture of 20% ethylene glycol and 80% water. Assuming the ideal pH level for having lower agglomeration and high stability, MgO is added to the base fluid in 0.12% volume concentration and Al₂O₃ nanoparticles is added to the base fluid in 0.4% volume concentration. A second mixture is made using the exact same amount of 0.12% volume concentration of Al₂O₃ and 0.4% volume concentration of TiO₂ in the base fluid. The use of 0.12 and 0.40% Al₂TiO₅ nanoparticles increased the heat transfer efficiency by 19.81% and 27.91%, respectively, when compared to water. Additionally, using 0.12 and 0.40% of Mg-Al₂O₄ nanoparticles increased the rate of transfer of heat by 25.24% and 33.20%, respectively, when compared to water (Arunkumar et al., 2019).

Peng et al., carried out experimental evaluations for various combinations of CuO nanoparticles and stated that the properties of heat transfer have been enhanced. They also looked into different mass combinations and varied vapor qualities and discovered that for a mass concentration flux of 80 kg.m²/sec and 0.1 wt.% of CuO Nanoparticle concentration, the improvement in heat transfer is found to be approximately 70% when compared to the pure refrigerant (Xuan et al., 2013).

Mahbulul et al. found that the volume of the combination of nanoparticles enhanced the heat transfer coefficients and thermal conductivity of the nanofluid in a horizontal smooth tube filled with R141-b blended with Al₂O₃ nanoparticles. They determined that at 0.2 vapour quality and 5% volume particle concentration, the highest heat transmission coefficient was 1755820 W/m²K (Mahbubul et al., 2013).

2.1.4. Improved performance of the VCRS using Nanoparticles

Haque et al. performed tests in a domestic refrigerator using hybrid Al₂O₃/TiO₂ nanoparticles in POE oil. The results showed adding Al₂O₃/TiO₂ hybrid nanoparticles to the POE oil in amounts of 0.05 percent and 0.1 percent by weight had increased the COP by 19% and 22%, respectively. Additionally, using Al₂O₃/TiO₂ hybrid nanoparticle concentrations of 0.1 percent by weight had reduced

the compressor power usage by 27.73% in comparison to the results obtained with pure refrigerant (Haque et al., 2016).

Babarinde et al. used MWCNT in the R600a cooling system with a variable mass charge of 0.4 and 0.6 g/L of MWCNT; as a result, the value of COP increased from 2.6 to 2.8 and 2.6 to 2.9 for the 0.4 and 0.6 grammes per liter, respectively, and the power usage of the compressor decreases to 0.0639 kW, a lower value (Babarinde et al., 2020).

Ghorbani et al. conducted a study on the efficacy of the VCRS by combining CuO nanoparticles with R600a refrigerant in a Polyol ester oil base fluid. Additionally, pure R600a, R600a and POE, and three various combinations of R-600a refrigerant blended with CuO nanoparticles and submerged in POE oil with 0.5, 1.0, and 1.5 mass percentages are all experimental factors. The findings revealed that by incorporating nanoparticles had improved the condensing Film Coefficient by an average of 4.1%, 8.11%, and 13.7% for three different mass combinations of nanoparticles compared to that of the system using R600a refrigerant without the inclusion of nanoparticles. Furthermore, the film coefficient increased to the highest value by using 1.5 mass percentage (Ghorbani et al., 2017).

Reji Kumar et al. conducted an experiment on the R600a VCRS using Al_2O_3 nanoparticles. With the addition of nanoparticles employed in the VCRS, the system's COP increased by 19.6% and the energy consumption of the compressor decreased by 11.6% (Reji Kumar et al., n.d.).

Yang et al. used graphene nanosheets in the SUNISO 3GS refrigerant oil to make three different nanofluids with mass concentrations of 10, 20, and 30 mg/L. Energy consumption for a 24-hour time was reduced by 15.40%, 19.21%, and 20.30%, respectively, when refrigerating lubricant was combined with nanosheets containing graphene at amounts of 10, 20, and 30 mg/L (Yang et al., 2020).

Suresh et al. used R134a and R152a refrigerants as circulating refrigerant fluid to evaluate the efficacy of a VCRS with ZrO_2 nanoparticles. The ZrO_2 nanoparticle quantity used ranges between 0.01 and 0.06% by volume with nanoparticle dimensions up to 20 nm and R134a and R152a refrigerant gas. When R152a refrigerant was used with a ZrO_2 at volumetric concentration of 0.06%, the

system's coefficient of performance significantly improved with a value of 33.45%. The ZrO₂ nanoparticles with R152a refrigerant's discharge temperature were very similar to that of R134a (Suresh Kumar et al., 2016).

Yogesh Joshi et al., utilized aluminum oxide nanoparticles and assessed the performance of a VCRS. In this experiment, varied portions of 0.02, 0.04, 0.07 and 0.1 weight percent of Al₂O₃ nanoparticles were synthesized in the nanofluid. For this investigation, R600a and R134a refrigerants were analyzed separately. The experimental test apparatus incorporates MO as a base component for R600a refrigerant and POE for R134a refrigerant. Power consumption of the compressor, discharge pressure, COP, and pull-down time were considered as variables affecting performance for the assessment of VCRS. The experimental results showed that using 0.1 percent by weight of the Al₂O₃ nanoparticle in MO with R600a refrigerant improved COP by 37.21%, reduced compressor electrical consumption by 28.71%, increased discharge pressure by 8.91%, and decreased pull-down time by 17.61% when compared to an R134a refrigeration system (Yogesh Joshi et al., 2021).

Amey Majgaonkar tabulated the thermal conductivity of several materials as given in the Table 2.1, and it is important to consider that the most popular nanoparticles, including, CuO, Al₂O₃, TiO₂ and ZnO, have thermal conductivities that range from 0.4 to 50 W/mK (Majgaonkar & Sharad Majgaonkar, n.d.). The overview of few experimental results is tabulated in Table 2.2. Some of the previously carried out experimental research with their conclusions are tabulated in Table 2.3.

Table 2.1: Various Nano-Particles and its Thermal Conductivity

Various Materials	Thermal Conductivity (W/m.K)
Common Refrigerants	0.01 – 0.09
Oil	0.1 – 0.2
TiO ₂ (Titanium Dioxide)	0.4 – 11.8

Al ₂ O ₃ (Aluminium Oxide)	30 - 40
ZnO (Zinc Oxide)	10 - 50
CuO (Copper Oxide)	20 - 40
Si (Silicon)	100 - 150
Ni (Nickel)	90 - 240
Pure Al	200 - 240
Pure Cu	350 - 400
Diamond	2200 - 4000
MWCNT	1800 - 6600

Table 2.2: Overview obtained from few experimental Results

Author	Nano-Refrigerant used	Base fluid used	Enhanced Thermal Conductivity	Usage
Zawawi et al., (2018) (Zawawi et al., 2018)	Al ₂ O ₃ -TiO ₂	PAG	2.42%	Hybrid Electric Vehicle (HEV)
Rahman et al., (2019) (Rahman et al., 2019)	SWCNT-R407C	Polyolefin-Oil	15.62%	RAC

Sanukrishna et al., (2018a) (Sanukrishna et al., 2019)	R134a-SiO ₂	PAG	1.31 times compared to pure refrigerant	Mini - channel heat exchanger
Mahbubul et al., (2013) (Mahbubul et al., 2013)	R134a - Al ₂ O ₃	Automatic Transmission fluid (ATF)	28.582%	Heat Reduction in automobile parts
Sidik and Alawi et al., (2014) (Alawi & Sidik, 2014)	CuO	EG	43.2%	Heat Reduction in automobile parts
Prakash et al., (2018a) (Sanukrishna & Jose Prakash, 2018)	TiO ₂	PAG	1.38 times compared to pure refrigerant	RAC
Gill et al., (2019) (Jatinder et al., 2019)	TiO ₂	MO	Between 14.72% and 41.20%	Automobile Parts heat reduction

Table 2.3: A Summary of previously carried out works for enhancing the COP of VCRS

Author and Year	Refrigerant used	Lubricant used	Nano-Particle used	General Conclusions
Sanukrishna et al. (2018) (Sanukrishna et al., 2018)	R-134 a	PAG	SiO ₂	The use of nanoparticles at a particle concentration of 0.40% raised the heat transfer coefficient to 163% (approx.).
Jatinder et al., (2019) (Adelekan et al., 2019)	R-600 a	Mineral-oil	TiO ₂	In compared to an LPG system, the COP and cooling effect were enhanced to 62.50% and 17.40%, respectively when the pure refrigerant is blended along with TiO ₂ nanoparticle. The compressor also used less energy.
Babarinde et al., (2020a) (Babarinde et al., 2020)	R-600a	Polyester Oil	MWCNT	When MWCNT is used, the COP value rises from 2.6 to 2.8 and 2.6 to 2.9 for 0.4 and 0.6 grams per liter, respectively, and the compressor's power consumption,

				was 0.0639 kW which is a decreased value.
Adelekan et al., (2019b) (Jatinder et al., 2019)	R-600a	Mineral-Oil	Graphene	With R-600a/70 g and 0 g/L nanorefrigerant, the maximum coefficient of performance value of 0.76 was achieved, and the compressor's power consumption was reduced by around 0.065 kW.
Yang et al., (2020) (Yang et al., 2020)	R-600a	SUNISO 3GS	Graphene Nanosheets	Energy usage for 24 hours dropped by 15.40%, 19.21%, and 20.30% when the refrigerant oil was combined with nanosheets comprising graphene at concentrations of 10, 20, and 30 mg/L.
Elansezhian et al., (2012) (D. Sendil Kumar & R. Elansezhian, 2012)	R-134a	Mineral Oil	CuO	The results implied that by processing CuO along with the pure refrigerant, it enhances the COP of the System.
O.A. Alawi, et al., (2015)	R-1225	Mineral Oil	TiO ₄	Utilization of TiO ₄ along with the

(Alawi et al., 2015)				refrigerant R-1225 immersed in the base fluid of Mineral oil had decreased the Energy power consumption and increased the Heat transfer coefficient [27].
Rezaeianjouybari et al., (2019) (Sheikholeslami et al., 2019)	R-600a	POE oil	CuO	The coefficient of heat transfer was raised by 1.5% to 2% by using the R-600a refrigerant and CuO nanoparticles in a variety of particle concentrations.
Kumar et al., (2019) (Kumar & Tiwari, 2019)	R-134a	PAG	Al ₂ O ₃	The COP increases by 10.30% when nanoparticle concentrations of 0.2% are employed, and there is also a reduction in energy usage.

CHAPTER – 3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

3.1. AIM

The purpose of this research is to improve the performance of a VCRS employing a mixture of R600a refrigerant and $\text{Al}_2\text{O}_3/\text{TiO}_2$ hybrid nanoparticles in MO lubricant. By doing pull-down experiments and examining the generated data, the goal is to determine how different nanoparticle concentrations affect the functioning of the refrigeration system.

3.2. OBJECTIVE

- To prepare three different mass concentrations of 0, 0.2 and 0.4 g/L of $\text{Al}_2\text{O}_3/\text{TiO}_2$ hybrid nanoparticles in MO lubricant.
- To conduct Pull-down test on VCRS using those three mass concentrations with 70 g charge of R600a refrigerant gas.
- To evaluate and compare the COP, Evaporator temperature, Cooling effect, Compressor energy consumption, and pull-down time of three different mass concentrations of nano-lubricants.
- The R600a refrigerant which we use for our VCRS will have low ODP and GWP.
- Thus, it decreases the power consumption of the system thereby reducing the cost and also it does not affect the environment.

3.3. SCOPE OF THE PROJECT

- Hybrid nanoparticles used in the process of the refrigeration system will be having improved thermal conductivities, thereby it can be used for several cooling applications.
- The refrigerant from the category of hydrocarbons is having less ODP and GWP, so it does not affect the environment.

- Thus, by improving the COP of the overall system, the power consumption can be reduced.

CHAPTER – 4

MATERIALS AND METHODOLOGY

4.1. EXPERIMENTAL SETUP

The experimental test apparatus consists of a Kirloskar hermetic-sealed type compressor, a water-filled coil-enclosed evaporator tank, and a stirrer to ensure that the temperature that exists inside the tank is dispersed evenly. Resistance Temperature Detector (RTD) sensor is provided at several locations in the experimental test rig, and it is used for measuring the temperature of refrigerant at various locations. To record the suction and discharge pressures of the refrigerant gas, two dial-type pressure gauges are provided. Fig 4.1 depicts the experimental test apparatus that was used for this research. The specifications of the refrigeration test rig are shown in the Table 4.1.



Figure 4.1: R600a experimental test rig

Table 4.1: Description of R600a VCRS

Sl.No.	Parameter	Values
1	Refrigerant	R600a
2	Base fluid used	Mineral oil (250 mL)
3	Refrigerant mass charge	70g
4	Concentrations of Nano lubricant	0, 0.2, and 0.4 g/L
5	Condenser	Air cooled
6	Capillary Valves	0.036, 0.040, 0.044 inches
7	Evaporator capacity	7 liters
8	Temperature of Ambient space	26 – 32°C
9	Nanoparticles used	Al ₂ O ₃ and TiO ₂
10	Heater used	230 V
11	Compressor	Kirloskar Hermetic – Sealed type compressor

4.2. METHODOLOGY USED FOR HYBRID NANO LUBRICANT PREPARATION

The process used for generating the hybrid nano lubricant is explained briefly in this part. The two nanoparticles (Al₂O₃ and TiO₂) are initially taken in dry powder form for the creation of the hybrid nano lubricant and are synthesized using the appropriate techniques and it is shown in Fig 4.2. According to Lab Chemicals, the nanoparticles used in this investigation fall between the sizes of 5 and 20 nm. Al₂O₃ and TiO₂ nanoparticles used in this study have thermal conductivities of 40 W/mK

and 8.4 W/mK, respectively (Majgaonkar & Sharad Majgaonkar, n.d.). Thus, by using nanoparticles of high thermal conductivities, it can improve the heat transfer characteristics of the VCRS and resulting in improved COP. The grammes of nanoparticles used to make the hybrid nanoparticles, which were made by combining 60% aluminium oxide and 40% titanium dioxide nanoparticles, were measured using a microbalance.



Figure 4.2: Hybrid nanoparticles and Micro-balance Machine.

Next, two-step methods are used to prepare hybrid nanofluids. This technique involves dispersing hybrid $\text{Al}_2\text{O}_3/\text{TiO}_2$ nanoparticles in 250 mL of mineral oil that is kept in a glass beaker. To attain stability and ensure the correct blending of two nanoparticles in the MO base fluid, the mixture is then kept in a magnetic stirrer for roughly 6 to 8 hours. Fig 4.3 depicts the mixture that was maintained in the magnetic stirrer. To reduce particle agglomeration in the created combination, it is also placed in an ultrasonic chamber for the sonification process, as shown in Fig 4.4. The flow chart for the preparation of hybrid nano lubricants is depicted in the below Fig 4.5.

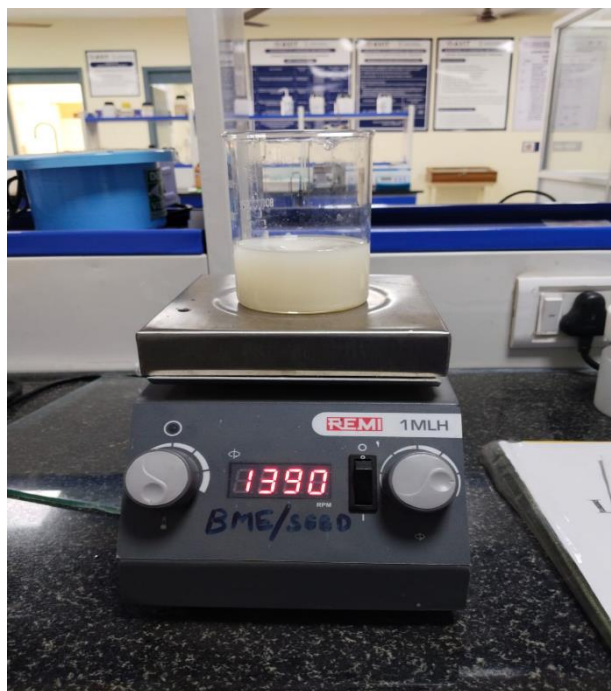


Figure 4.3: Magnetic Stirrer containing nano lubricant



Figure 4.4: Nano lubricants undergoing sonification process

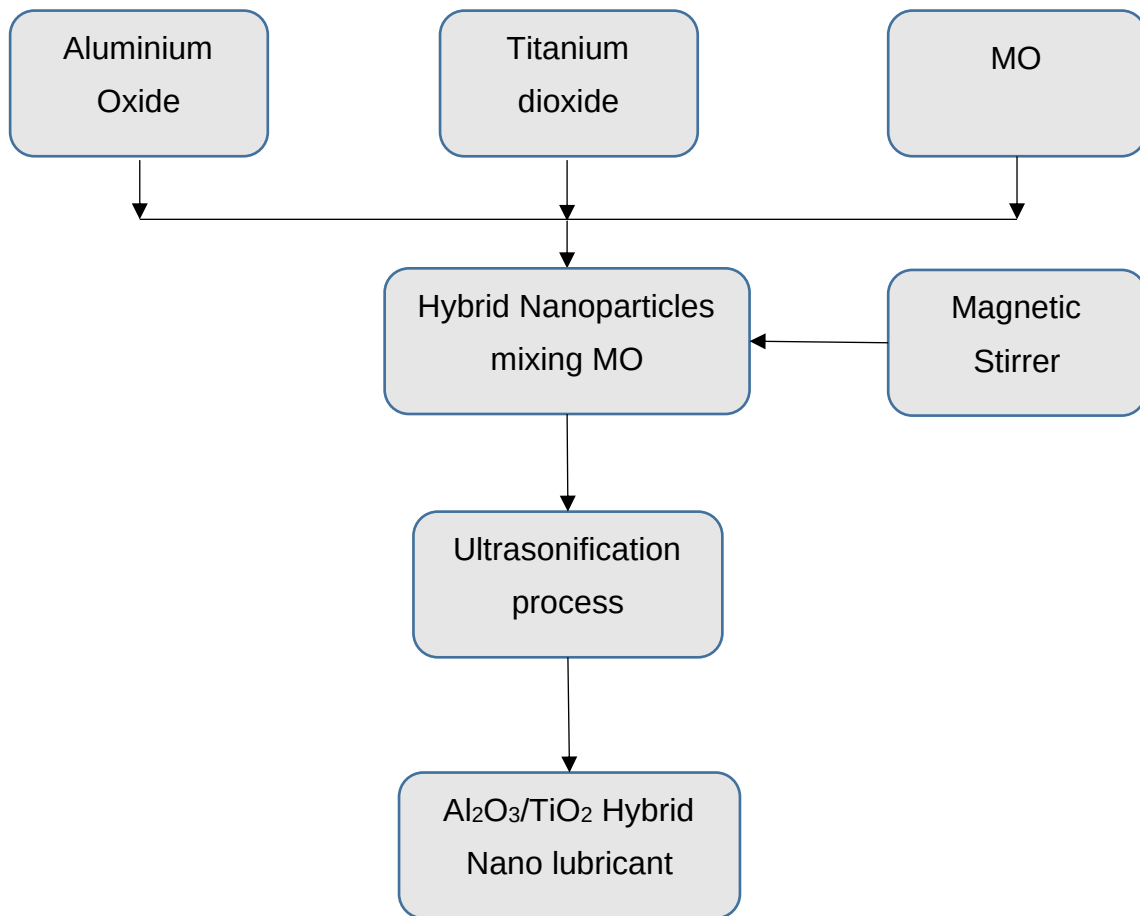


Figure 4.5: Flow chart for the Preparation of hybrid nano lubricants

The thermophysical characteristics of MO will be enhanced by adding hybrid nanoparticles. Compared to conventional lubricants, hybrid nano lubricants offer many advantages. These features will reduce the compressor's need for energy, which will enhance the vapour compression refrigeration device's COP and refrigeration impact.

4.3. VAPOUR COMPRESSION REFRIGERATION SYSTEM

For evaluating the performance of the hybrid nano lubricants which is employed in this research, R600a VCRS which works safely with R600a refrigerant gas and mineral oil is used. The Cyclic flow of the R600a refrigerant in the VCRS system is depicted in Figure. 4. In a Vapour Compression Refrigeration Cycle, there are four processes, they are

1. Reversible adiabatic compression.
2. Constant pressure heat Rejection.
3. Iso-enthalpic expansion.
4. Constant pressure heat absorption.

4.3.1. Reversible Adiabatic Compression process (Constant entropy process)

After receiving heat from the surroundings in the evaporator, the cooling fluid enters the compressor unit in a gaseous state. This low pressure as well as temperature refrigerant which is in vapour form is transformed into a higher temperature and pressure vapour refrigerant in the compressor. Power is used by the compressor as it performs compression. An energy meter measures this electricity usage in KWh (Zsembinszki et al., 2017).

4.3.2. Constant-Pressure Heat Rejection process

In this process, the high temperature and pressure vapour refrigerant enters the condenser, and phase change occurs in this phase, and it gets converted into a liquid phase with high temperature. Here, the cooling fluid is permitted to flow through a series of tubes, which reject heat as the refrigerant passes over the cold tubes (Golabhanvi & Navadagi, n.d.).

4.3.3. Iso-enthalpic Expansion process

The devices used in this procedure are throttle valves. By sending the refrigerant liquid through expansion or throttle valves, the process lowers the high pressure and temperature of the liquid and transforms it into a liquid with a low pressure and temperature (Zsembinszki et al., 2017).

4.3.4. Constant-Pressure Heat Absorption process

The low pressure and temperature liquid refrigerant exit the expanding device at this point and enters the evaporator, where the work gets done. This refrigerant undergoes a phase shift and transforms into vapour because of absorbing the latent

heat from its surroundings. For consecutive cycles, this vapour refrigerant is once more put into the compressor (Dongare et al., 2017).

The points shown in Figure 4.5 reflect various conditions of the refrigerant throughout the cycle as well as various conditions of the refrigerant flow in interaction with the heat exchangers. The model makes no assumptions on heat transfer from the connecting pipes because the various system devices are integrated by comparatively short and well-insulated pipes. The various points mentioned in Fig 4.6 are demonstrated in table 4.2.

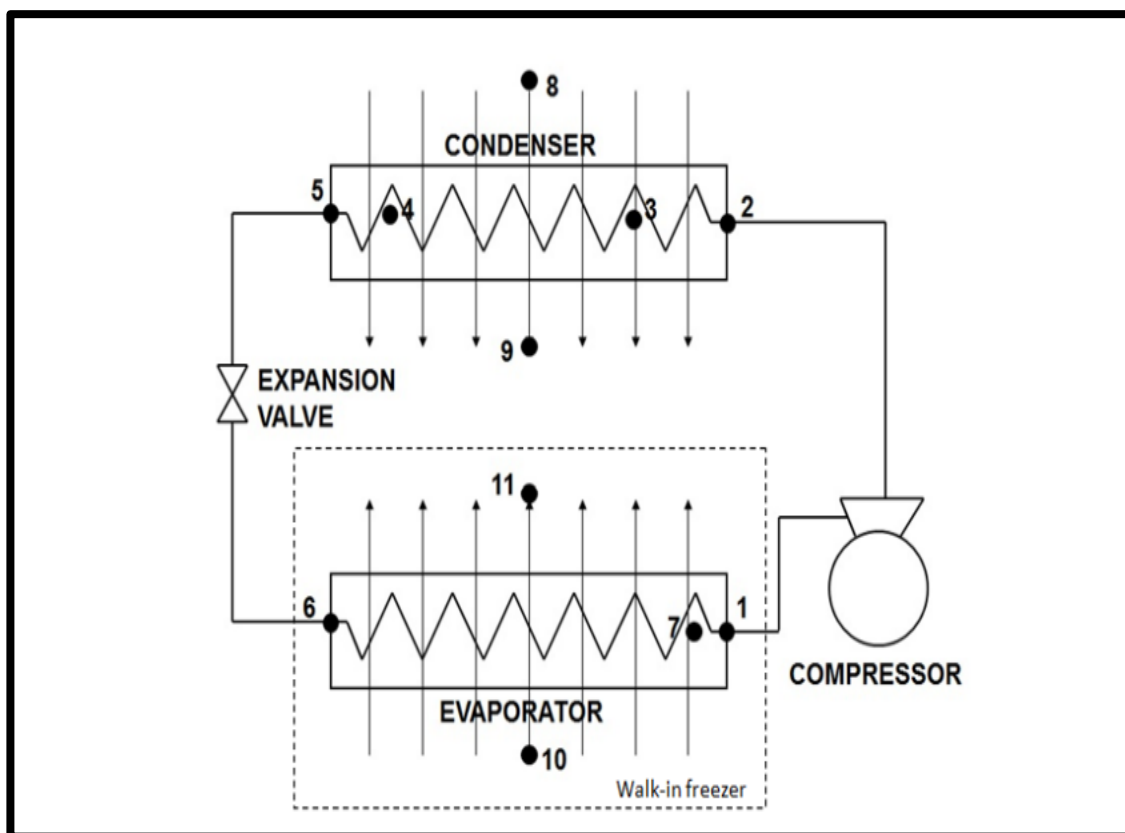


Figure 4.6: Vapor Compression Refrigeration Cycle

Table 4.2: Descriptions of different points

POINTS	MEANING
1	compressor entrance and evaporator exit

2	Condenser entrance and compressor exit
3	Vapour that is saturated within the condenser
4	Liquid that is saturated within the condenser
5	expansion valve entrance and condenser exit
6	Evaporator intake and expansion valve exit
7	Vapour that is saturated within the evaporator
8	Ambient outside air at the condenser inlet
9	Ambient outside air at the condenser outlet
10	Interior air (freezer) entering the evaporator
11	Freezer air coming out of the evaporator interior

4.4. EXPERIMENTAL PROCEDURES

The method which is employed for this research is the pull-down test. Before starting the pull-down test, it is mandatory to all the valves and check for the leakage. And after that, it is also required to evacuate the refrigeration system using a vacuum pump. After evacuating the refrigeration system, a pull-down test is taken three times for this experimental research. Thus, for three different mass quantities of 0 g/L, 0.2 g/L and 0.4 g/L of $\text{Al}_2\text{O}_3/\text{TiO}_2$ hybrid nano lubricant along with 70g of R600a refrigerant, three separate readings are to be taken. The test has been conducted at surrounding temperatures between 26 and 32 °C. Considering that working at various temperatures affects significant parameters like refrigeration effect, COP

and the power required for the compressor, the surrounding temperature should be maintained within this range. Thus, after making the required set up, the following steps are followed for the pull-down test of three different hybrid nano lubricant concentrations:

- Charge the refrigeration test rig with 70g of R600a refrigerant.
- Connect the mineral oil-filled glass beaker containing the hybrid $\text{Al}_2\text{O}_3/\text{TiO}_2$ nanoparticles to the VCRS.
- Up to the system's utmost capacity, fill the evaporator tank with water. The capacity is 7 liters for this test setup.
- Using a temperature sensor, raise the water in the evaporator tank's temperature to 30°C.
- Switch on the main and allow the system to stabilize for approximately 5 minutes.
- Utilizing temperature and pressure sensors, note the refrigerant's initial readings for temperature, pressure and initial compressor power consumption.
- At an interval of 5°C, the temperatures at various locations are noted, and the time taken in minutes is also taken as readings.
- Using a stopwatch, note how long it took to achieve the desired temperature of 20°C.
- Take note of the refrigerant's temperature and pressure end readings using temperature and pressure sensors installed in the system at different points.
- The reading of power consumption by the compressor at the end of 20°C is taken by a power meter in kWh.
- Repeat the experiment for the varying proportions of mass charges and note down the readings.

4.5. CALCULATION OF PERFORMANCE PARAMETERS

The various important parameters for evaluating the system's performance were determined using the formulae below:

The COP of the VCRS is given by the formula:

$$COP = \frac{Q_{R.E.}}{W_{Comp.}}$$

Where, $Q_{R.E.}$ is the Refrigeration effect in kW.

$W_{comp.}$ is the Energy input given to the compressor in kWh.

$$Q_{R.E.} = \frac{m \times C_p \times T_f - T_i}{t}$$

Where, m is Capacity of water in the evaporator in kg.

C_p is the Specific heat of water in kJ/kgK.

T_f is the Final set temperature in the test apparatus in °C.

T_i is the Initial set temperature in the test apparatus in °C.

t is the time taken for temperature drop from 30 to 20 °C

4.5.1. Performance parameters of 0 g/L of Hybrid nano lubricant

From the experimental readings, it is found that by using 0.4 g/L of hybrid nano lubricant, the energy consumed by the compressor is 0.040 kWh.

$$Q_{R.E.} = \frac{m \times C_p \times T_f - T_i}{t}$$

$$Q_{R.E.} = \frac{7 \times 4.187 \times (30 - 20)}{580}$$

$$Q_{R.E.} = 0.5053 \text{ kW}$$

$$W_{Comp.} = 0.040 \text{ kWh}$$

To convert kWh to kW,

$$W_{Comp.} = \frac{0.040 \times 3600}{580}$$

$$W_{Comp.} = 0.2482 \text{ kW}$$

$$COP = \frac{Q_{R.E.}}{W_{Comp.}} = \frac{0.5053}{0.2482}$$

$$COP = 2.035$$

4.5.2. Performance parameters of 0.2 g/L of hybrid nano lubricant

From the experimental readings, it is found that by using 0.4 g/L of hybrid nano lubricant, the energy consumed by the compressor is 0.035kWh.

$$Q_{R.E.} = \frac{m \times C_p \times T_f - T_i}{t}$$

$$Q_{R.E.} = \frac{7 \times 4.187 \times (30 - 20)}{540}$$

$$Q_{R.E.} = 0.5427 \text{ kW}$$

$$W_{Comp.} = 0.035 \text{ kWh}$$

To convert kWh to kW,

$$W_{Comp.} = \frac{0.035 \times 3600}{540}$$

$$W_{Comp.} = 0.2334 \text{ kW}$$

$$COP = \frac{Q_{R.E.}}{W_{Comp.}} = \frac{0.5427}{0.2334}$$

$$COP = 2.325$$

4.5.3. Performance parameters of 0.4 g/L of hybrid nano lubricant

From the experimental readings, it is found that by using 0.4 g/L of hybrid nano lubricant, the energy consumed by the compressor is 0.032 kWh.

$$Q_{R.E.} = \frac{m \times C_p \times T_f - T_i}{t}$$

$$Q_{R.E.} = \frac{7 \times 4.187 \times (30 - 20)}{480}$$

$$Q_{R.E.} = 0.6106 \text{ kW}$$

$$W_{Comp.} = 0.032 \text{ kWh}$$

To convert kWh to kW,

$$W_{Comp.} = \frac{0.032 \times 3600}{480}$$

$$W_{Comp.} = 0.240 \text{ kW}$$

$$COP = \frac{Q_{R.E.}}{W_{Comp.}} = \frac{0.6106}{0.240}$$

$$COP = 2.551$$

CHAPTER – 5

RESULTS AND DISCUSSION

5.1. EXPERIMENTAL RESULTS

The readings from the R600a VCRS experimental test rig for the Pull-down test of three different mass concentrations of 0, 0.2, and 0.4 g/L of $\text{Al}_2\text{O}_3/\text{TiO}_2$ hybrid nano lubricant and 70 g of R600a refrigerant are tabulated individually.

Table 5.1: Pull-down test of 0 g/L of hybrid nano lubricants

S. I. No.	Temperature	Evaporator Inlet temp in °C	Evaporator Outlet temp in °C	Condenser Inlet temp in °C	Condenser outlet temp in °C	Time in s	Energy Consumed in kWh	Suction Pressure in Psi	Discharge Pressure in Psi
1.	30	40.3	33	14	31.1	0	0.512	20	70
2.	25	43	31.8	12.6	27.5	360	0.540	20	70
3.	20	44.5	31.6	12.4	23.1	580	0.552	20	70

Table 5.2: Pull-down test of 0.2 g/L of hybrid nano lubricants

S. I. No.	Temperature	Evaporator Inlet temp in °C	Evaporator Outlet temp in °C	Condenser Inlet temp in °C	Condenser outlet temp in °C	Time in s	Energy Consumed in kWh	Suction Pressure in Psi	Discharge Pressure in Psi

1.	30	44.5	35.2	26.8	27.3	0	0.635	30	80
2.	25	42.6	35.9	23.3	29.8	24 0	0.654	30	80
3.	20	40.7	35.2	16.2	19.6	54 0	0.670	30	80

Table 5.3: Pull-down test of 0.4 g/L of hybrid nano lubricants

S. I. N o.	Temper ature	Evapo rator Inlet temp in °C	Evapo rator Outlet temp in °C	Conde nser Inlet temp in °C	Conde nser outlet temp in °C	Ti m e in s	Energ y Consu med in kWh	Sucti on Pres sure in Psi	Disch arge Press ure in Psi
1.	30	64.4	33.1	26	26	0	0.874	35	130
2.	25	59.2	32.8	23.1	23.8	23 0	0.884	35	130
3.	20	56.6	32	13.6	21.5	48 0	0.906	35	130

5.2. DISCUSSION OF THE OBTAINED RESULTS

5.2.1. Comparison of cooling effect with different mass concentrations of nano lubricants

The quantity of heat removed from the evaporator space per unit of time is the cooling effect. According to Senthilkumar et al., using 60g of pure R600a refrigerant, the cooling effect was 158 W; however, using a mass concentration of 0.6 g/L of ZnO/SiO₂ hybrid nano lubricant, the cooling effect was increased by 14% to 180 W (Senthilkumar et al., 2020). Initially, the pull-down test for a temperature

decreases of 30 to 20°C is carried out for a mass charge of 70g of R600a without the inclusion of nanoparticles, and the result for cooling effect is obtained as 0.5053 KW. Then, using two distinct hybrid nano lubricant mass concentrations of 0.2 g/L and 0.4 g/L independently, the pull-down test is carried out at the same temperature reduction. The results indicate that the KW values are 0.5427 and 0.6106 for 0.2 and 0.4 g/L, respectively. According to the above findings, using 0.4 g/L of hybrid nano lubricant can produce 20.83% more cooling impact than using pure R600a refrigerant. The variation in the cooling effect for different hybrid nano lubricant concentrations are depicted in Fig 5.1.

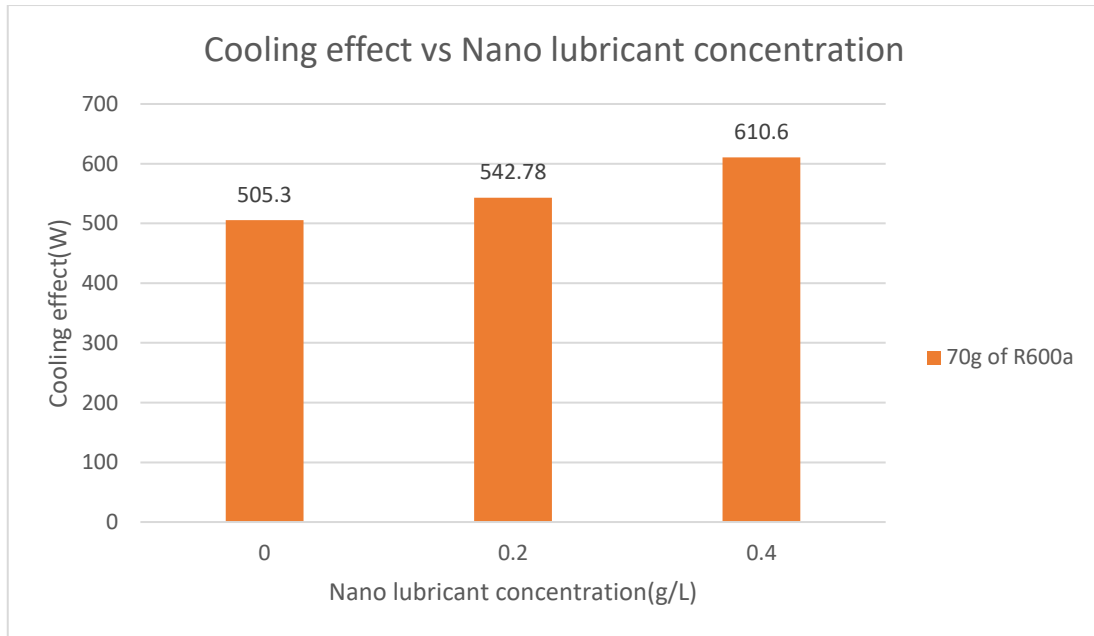


Figure 5.1: Cooling effect vs Nano lubricant concentration

5.2.2. Comparison of COP with different mass concentrations of nano lubricants

The COP of the VCRS is the ratio of cooling effect to compressor energy consumption. Initially a mass charge of 70g of R600a is subjected to a pull-down test for a temperature decrease of 30 to 20°C without the addition of nanoparticles, and the result for COP is found to be 2.035. Then, using two distinct hybrid nano lubricant mass concentrations of 0.2 and 0.4 g/L of Al₂O₃/TiO₂ independently, the pull-down test is carried out at the same temperature reduction. The results show that for 0.2 and 0.4 g/L, respectively, the COP values are 2.325 and 2.5441.

According to the above findings, using 0.4 g/L of blended nano lubricant can produce 25% more COP than using pure R600a refrigerant. Similarly, Senthilkumar et al. found that 0.2 g/L of the hybrid nano lubricant increased COP of 1.6 by 36.7% when compared to the results of using pure R600a refrigerant. They conducted performance tests on four different mass concentrations of CuO/Al₂O₃ hybrid nano lubricant with 70 g of R600a refrigerant (Senthilkumar et al., 2023). The variation in the COP for different hybrid nano lubricant concentrations are depicted in Fig 5.2.

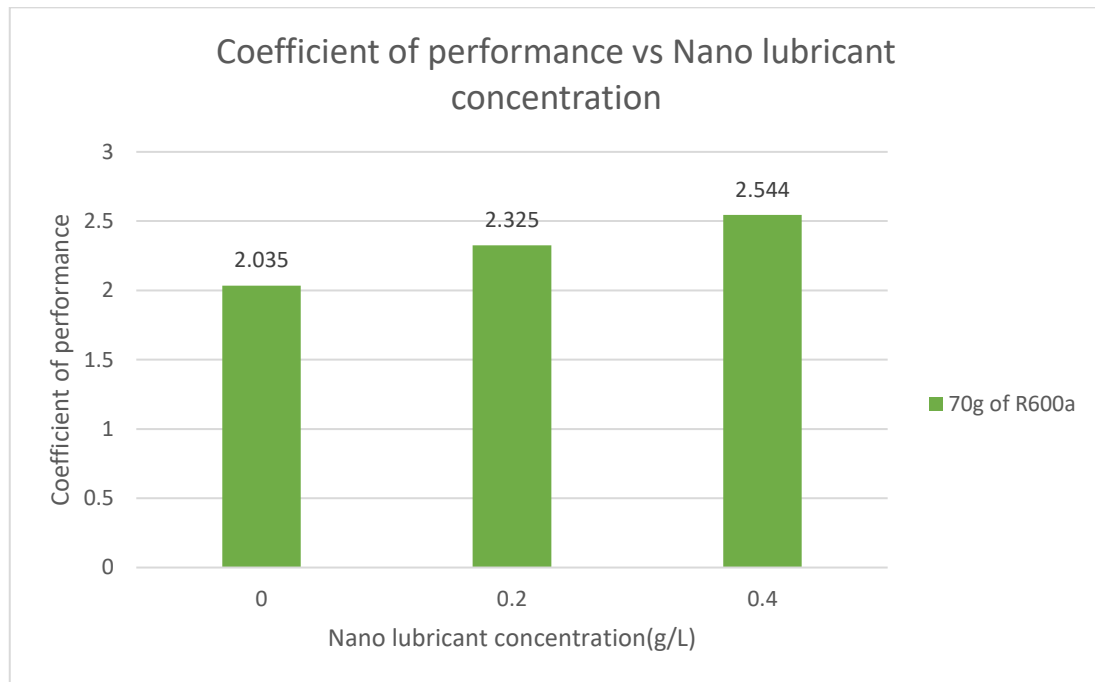


Figure 5.2: Coefficient of Performance vs Nano lubricant concentration

5.2.3. Comparison of Compressor work with different mass concentrations of nano lubricants

During the process of refrigeration effect, the compressor consumes power, and this power consumption is to be reduced for a sustainable development of the environment. The pull-down test was initially conducted with a mass charge of 70g of R600a without the addition of nanoparticles, and the compressor used around 0.2482 KW of energy. The pull-down test is then carried out using two different hybrid nano lubricant mass concentrations of 0.2 and 0.4 g/L separately at the same temperature decrease. According to the findings, the compressor used 0.2334 KW and 0.240 KW, respectively, for 0.2 and 0.4 g/L. The outcomes show that using 0.2

g/L of hybrid nano lubricant will reduce the consumption of electricity by 5.96% when compared to using pure R600a refrigerant. The results of Satyam et al. are similar in that they found a significant decrease in compressor power consumption in the range of 3.27% and 4.83% with 1% and 1.5% copper nanoparticle and R600a, respectively, when using Cu nanoparticle with varied weight percentages of 0.5, 1, and 1.5 in PAG oil during the performance test (Kumar & Tiwari, 2019). The variation in the Compressor power consumption for different hybrid nano lubricant concentrations are depicted in Fig 5.3.

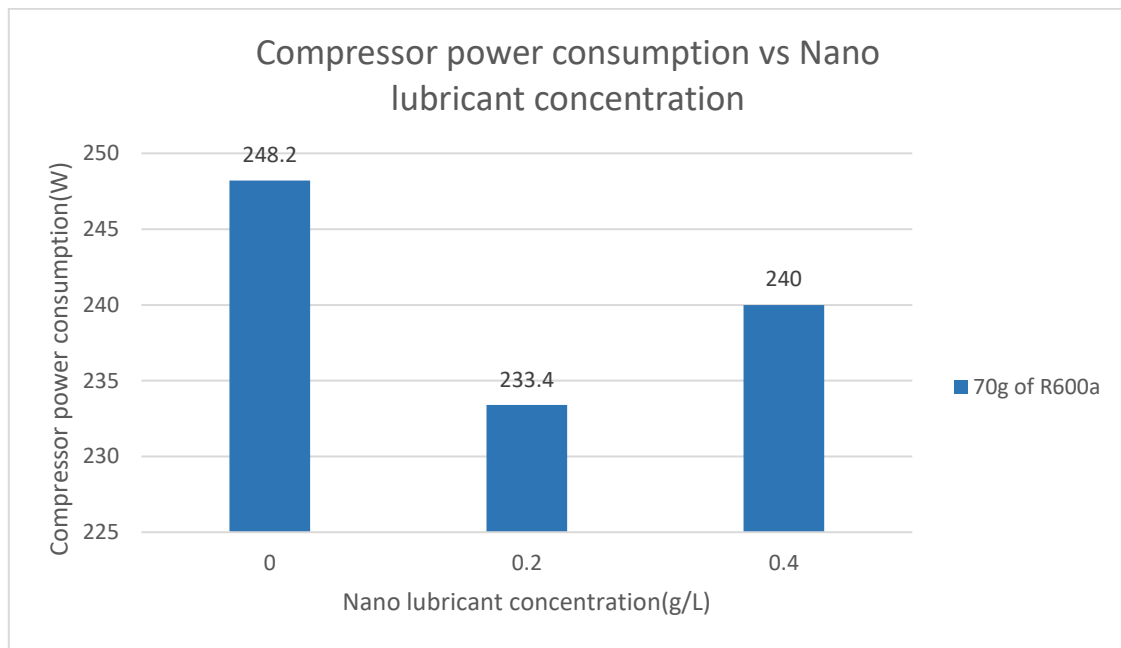


Figure 5.3: Compressor power consumption vs Nano lubricant concentration

5.2.4. Comparison of Pull-down time taken with different mass concentrations of nano lubricants

The pull-down test is defined as the performance evaluation test, which determines various important factors like COP, Cooling effect, and Pull-down time. The amount of time it takes for the VCRS to cool down from the starting temperature to the ultimate desired set point temperature is known as the pull-down time. At first set at 30 °C, the temperature is lowered to the desired level of 20 °C. The time taken for this temperature drop is called pull-down time. Initially, without the use of nano particles, the time taken for the pull-down test was measured using stop clock and

its value is 580 s. And with the use of hybrid nano particles, the time taken for the mass quantity of 0.2 g/L of hybrid nano particles with R600a refrigerant is 540 s. Additionally, the pull-down time is 480 s with a mass amount of 0.4 g/L, indicating a short time when compared to the test conducted with pure R600a refrigerant. The use of hybrid nano lubricants can be inferred from the fact that the pull-down time is significantly decreased, increasing the COP and decreasing power usage. Fig 5.4 shows the difference in hybrid nano lubricant pull-down durations for various mass concentrations.

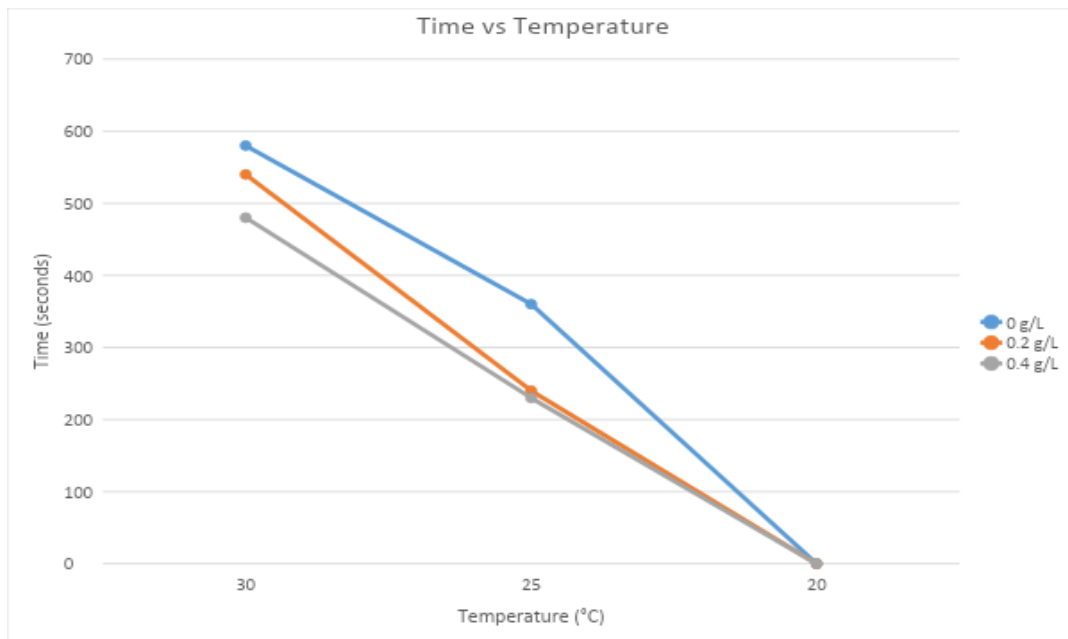


Figure 5.4: Time vs Temperature

5.2.5. Comparison of Evaporator temperature with different mass concentrations of the nano lubricants

The temperature at which the refrigerant gas enters the coil of the evaporator is called the inlet temperature of the evaporator. The refrigerant is typically at low pressure and temperature currently and is just beginning the cooling process. The refrigerant takes heat from the surroundings during this process, evaporates, and then returns to the compressor to start the next cycle. The temperature differential between the evaporator outlet and inlet is known as the approach temperature. By increasing the approach temperature or lowering the evaporator inlet temperature, we can increase the refrigeration system's effectiveness. As a result, in the pull-

down test from a temperature drop of 30 to 20 °C, the mass concentration of 0.4 g/L of hybrid nano lubricant shows the largest approach temperature difference. The approach temperature differential for hybrid nano lubricant at 0.4 g/L is 12.4 °C, higher than the difference for the mass concentration of hybrid nano lubricant at 0 g/L, which is 1.6 °C. The variation in the Evaporator temperature for different hybrid nano lubricant concentrations are depicted in Fig 5.5.

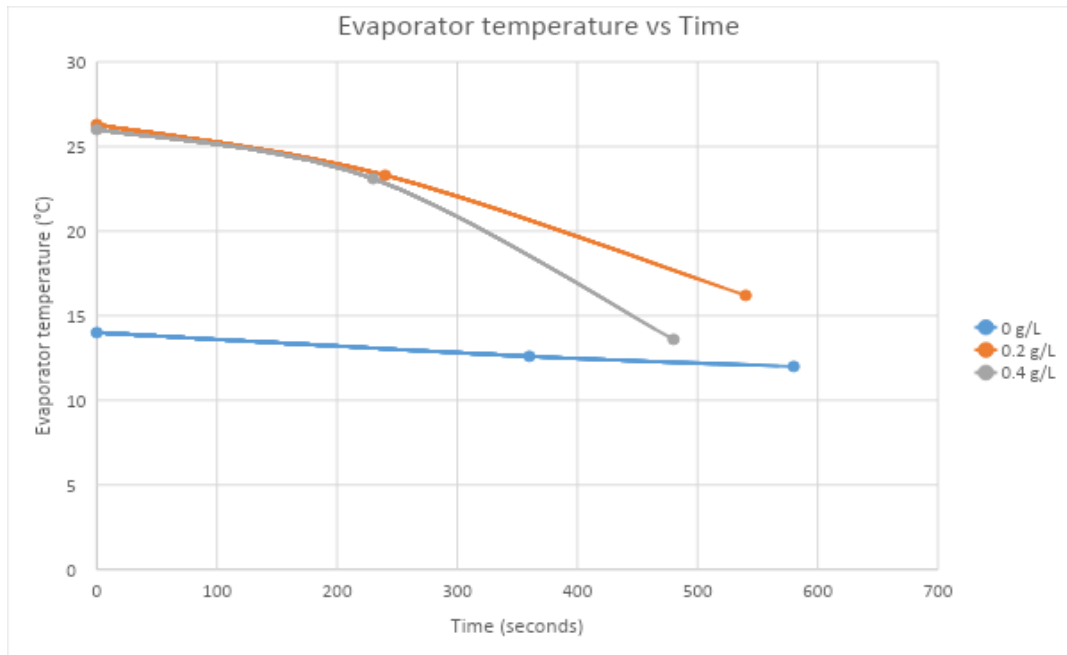


Figure 5.5: Evaporator temperature vs Time

CHAPTER – 6

CONCLUSION

This experimental study evaluated the R600a refrigeration system's performance in terms of several performance factors, including compressor power usage, refrigeration effect, COP, and the pull-down time. In the early phases of the experiment, R600a refrigerant without the inclusion of nanoparticles was assessed, and its performance was contrasted with a system using $\text{Al}_2\text{O}_3/\text{TiO}_2$ hybrid nano lubricants with varying mass ratios of 0.2 and 0.4 g/L. Inferences that can be drawn from the use of mixed nano particles includes the following:

- The highest refrigeration effect of the R600a VCRS using 0.4 g/L of hybrid $\text{Al}_2\text{O}_3/\text{TiO}_2$ nanoparticles was 0.6106 KW, which is 20.83% more cooling effect than the system using R600a refrigerant without nanoparticles.
- With a mass concentration of 0.4 g/L of $\text{Al}_2\text{O}_3/\text{TiO}_2$ hybrid nanoparticles, the R600a VCRS had a maximum COP value of 2.5441, which is 25% better than the COP of a system using only pure R600a refrigerant.
- In comparison to systems using pure R600a refrigerant, the R600a refrigeration system with mass quantity of 0.2 g/L of $\text{Al}_2\text{O}_3/\text{TiO}_2$ hybrid nanoparticles resulted in a minimal power consumption by the compressor of 0.2334 KW, or 5.96% less power consumption by the compressor.
- The pull-down time for the R600a VCRS with a mass quantity of 0.4 g/L of hybrid $\text{Al}_2\text{O}_3/\text{TiO}_2$ nanoparticles was 480 s, which is 100 s faster than the time for the system using pure R600a refrigerant.

As a result of the above conclusion, the hybrid nanoparticles $\text{Al}_2\text{O}_3/\text{TiO}_2$ used as an additive in the VCRS, along with the R600a HC refrigerants that are environmentally friendly (zero ODP and low GWP), play a critical role in energy conservation while also enhancing the overall performance of the VCRS.

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APPENDIX I



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