A concise review on the Suitability of Nano-Refrigerants for Residential Refrigeration Systems (RRS)

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Abstract. Nanoparticles have recently attracted huge attention as an engineering alternative in various fields. This is not unconnected with its established ability to perform better when used to replace some conventional systems or used as an enhancement for the system. Hence, this study reviewed the viability of nanofluids developed from nanoparticles as a possible replacement for conventional refrigerants available. In this review, focus was placed on refrigerants and refrigeration types, Nanoparticles and Nanofluids, Synthesis, Characterization and properties of Nanoparticles and finally on Nano-refrigerants and their viability. Conclusions were reached based on findings of the review.

1 Introduction

Nano-refrigerant is the combination of nanoparticles with the refrigerant to improve the performance of the refrigeration process. The use of nanoparticles along with the conventional refrigerant in a vapor compression cycle is relatively a new idea, where nano-refrigerants are found to have improved thermo-physical properties over the conventional refrigerants. This research seeks to develop a nanofluid from agricultural source (rice husk) and investigate its effects on the domestic refrigerator.

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1.1 Refrigeration

Refrigeration is the process by which heat is absorbed from a space at lower temperature and rejected to a space of comparatively higher temperature by expanding mechanical work. Before the introduction of mechanical forms of refrigeration, ancient peoples such as the Greeks and Romans utilized ice transported from the mountains in cooling their foods, pits were dug into the ground and insulated with firewood to preserve the ice. This became the means of refrigeration. These processes dated back 4000 years [1].

In recent times, refrigeration can be defined as a thermodynamic process which encourages removal of heat [2]. There are extensive applications of refrigeration across human activities such as in the ice manufacture, civil engineering, food industries (storage, processing as well as transportation of aliments), chemical industry, mining (freezing of moisture in unstable water-bearing soils), air conditioning, biomedical Industry, the pharmaceutical industry as well as and fundamental research [3]. The compressor, condenser, capillary tube and evaporator make up the four major components of the basic refrigeration system. These four components are useful in creating a cycle that results in the removal of heat from a body [4] . The system operates using a refrigerant as the working fluid. This fluid undergoes four main processes to reject the heat to the environment, and keep the system at a low temperature [5]. In the last few decades, the issue of energy generation and consumption became a talking point among the relevant leaders and decision makers. The three main consumers of electricity worldwide including; industry, residential and commercial [6]. Vapor compression refrigeration system being a large consumer of power due to the large demands for refrigeration and other applications [7]. The search for more energy conservative systems has been paramount [8]. The major criteria for the performance of the system is coefficient of performance which is defined as the ratio of the refrigerating effect produced and the compressor work [9]. New approaches for the improvement of the coefficient of performance and the reduction of compressor work are being introduced to improve the vapor compression refrigeration system [10]. The refrigeration industry is faced with two of the most urgent environmental issues, namely global warming and ozone depletion. It is logical that these two seemingly related challenges be tackled together not only through new working fluids, but by incorporating innovative thermodynamic cycles [11].

1.1.1 Vapour compression refrigeration

A refrigerant is the means by which heat is absorbed and displaced from the refrigeration space and rejects to the environment. The system contains four components: Expansion valve, a compressor, an evaporator, and a condenser. The refrigerant in vapour form enters the compressor thereby increasing its temperature and pressure. The high temperature vapor is passed through a condenser where it is cooled and turned to its liquid state. The saturated liquid then passes through an expansion valve where the pressure is reduced. The cold mixture then passes through the coil or tubes in the evaporator. In the evaporator, the temperature of the enclosed space is lowered [12-13].
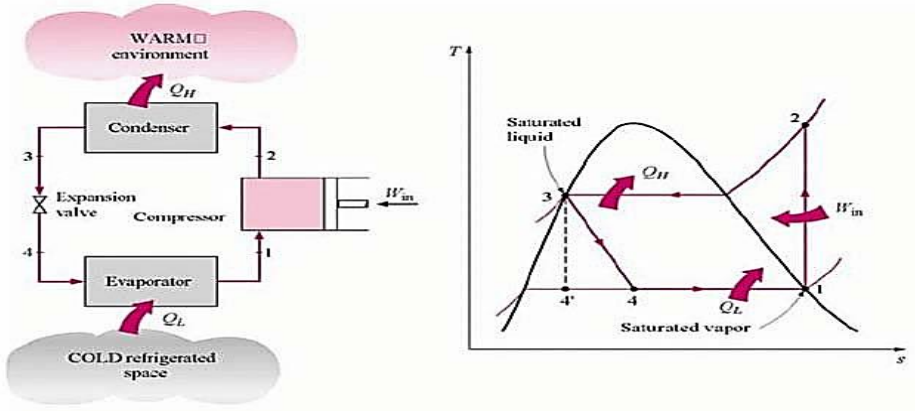
Fig 1. Vapour compression cycle [13]

1.1.2 Vapour absorption cycle

Absorption–refrigeration systems utilizes natural refrigerants driven by geothermal, solar energy etc. The cycle uses different variations of absorbent–refrigerant pairs.

The secondary solution is the absorbent, and it absorbs the primary solution known as refrigerant in the vapor phase. The most common used working fluid pair is ammonia–water and lithium bromide–water [14].
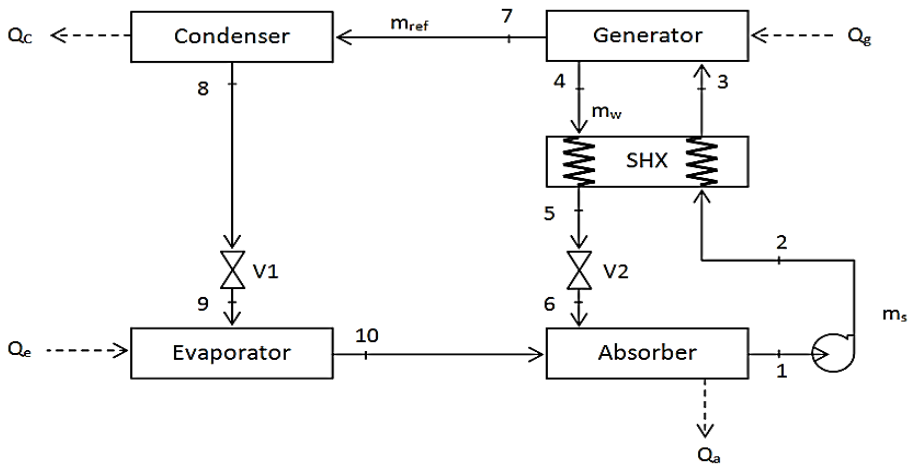

Fig 2. Vapor absorption cycle [15]

The different means of improving the performance of the refrigeration cycle performance are by tackling the heat transfer performance. Then assessing the solubility and miscibility, and lastly, reviewing the tribological improvement [15-16].

1.2 Refrigerants

In the 1600s and 1700s, physicists laid the groundwork for artificial refrigeration. Employing a working fluid in a closed cycle for ice formation was initially proposed by Oliver Evans. He described a device that made refrigeration by evaporating ether

under vacuum and pumping the vapor to a heat exchanger where it could condense and be reused. Despite the fact that he never created it, his theories impacted both Jacob Perkins and Richard Trevithick. In 1828, the latter proposed an air-cycle refrigeration system, but did not build one. Perkins, on the other hand, did so in the 1830s with the production of the VCR machine, and therefore refrigerants [17]. Jacob Perkins, recognized as the "Father of Refrigeration," was the first to design a working refrigeration machine and receive the first operational refrigeration patent in the early 1800s. Later in the nineteenth century, others followed Perkins' lead by filing patents for various refrigeration devices and units that used ethyl ether (R-610) as the first commercial refrigerant. When the liquid was dropped on the hand, it was simple to feel the chilling impact of this refrigerant [18].

The refrigerant, which acts as a heat absorber and cooling agent, is the working fluid of the refrigerator. At low temperatures and pressures, the refrigerant absorbs heat and dissipates it by condensing at high temperatures and pressures. In the early stages of refrigerator architecture, the most frequent refrigerants were known solvents and volatile fluids. Almost all of the early refrigerants were flammable, poisonous, or both, and some of them were also quite reactive [6]. In the face of an impending energy shortage, it is critical to design energy-efficient thermal systems. Refrigerators and air conditioners are thermal equipment that use a lot of electricity. It's critical to create energy-efficient refrigeration and air-conditioning systems that use environmentally friendly refrigerants [12].

Natural refrigerants were used in the early days of refrigeration (1800), but synthetic refrigerants with higher thermal performance, and safety were introduced in 1929. Ethyl-Ether was utilized in the first mechanical cooling manufacturing in 1834. After that, natural refrigerants such as ammonia, CO_2, hydrocarbons, water, and air were used [19]. Because it is poisonous and combustible, ammonia is a well-known refrigerant that is commonly employed in medium and large-scale refrigeration systems. It necessitates specific safety precautions and, in many cases, an indirect system. Despite its toxicity, its pungent odour is used as a warning for potential leaks. It's also lighter than air and mixable with water, making it ideal for water purification systems. Because ammonia is a by-product of the nitrogen cycle, it is relatively affordable when compared to manufactured refrigerants. However, ammonia will corrode copper and copper alloys when mixed with water, making this refrigerant an expensive alternative to existing systems that use CFCs or HCFCs because most of the pipework is copper [20]. CO_2 has a long history dating back to the mid-nineteenth century, although it was phased out of appliances after 1950 in favor of more efficient refrigerants. CO_2 is making a comeback in refrigeration in a variety of applications nowadays. R744 is not like other commonly used refrigerants. Its benefits include being nontoxic and nonflammable, having a high volumetric cooling capacity, having excellent thermophysical qualities, being less sensitive to pressure drop, being compatible with most materials, and having a low price. Today, CO_2 is the preferred refrigerant for commercial refrigeration systems, and it is an important substitute for R404A [19]. Natural refrigerants like R290, R600a, R1150, R1270, R170 were used in the early days of mechanical refrigeration, which dates back to the early 1800s. This includes methyl chloride, ammonia, and Sulphur dioxide, were utilized in refrigerators produced between the late 1800s and 1929. For the first hundred years, the common refrigerants were based on availability. These included a lot of flammable, poisonous options [1]. Fluorocarbon refrigerants were introduced in 1930 for reasons. R-12 (dichlorodifluoromethane) was introduced as a commercial refrigerant for refrigerators a year later, followed by R-

11. Because of their flammability and toxicity, hydrocarbons (HCs) were abandoned as refrigerant fluids in refrigerators, and chlorofluorocarbons (HCFCs) dominated the second generation of refrigerants, with usage mostly in household and small businesses. Ammonia, on the other hand, is still used in large-scale systems [4]. The key points in their favor were total safety and environmental non-harmfulness. Both of these allegations were later proven to be false. CFCs and related substances were clearly contributing to global warming and climate change, two of the most serious environmental issues. Several organizations expressed worry about their use and demanded prompt action to begin banning CFC-based refrigerants. Since then, there have been increased efforts to create suitable replacements for CFCs, but similar problems have arisen as a result of the release of many other new compounds into the environment. One of the major issues of our time is the widespread usage of increasingly more novel substances [18]. Recent years have seen some research on the use of pure hydrocarbons to replace CFCs, HCFCs, and HFCs. By 2020, consumption of HC refrigerants will reach 75%, based on the present situation. In commercial uses, R1270, R290, and R152a showed better performance than R502. In terms of COP and energy efficiency, hydrocarbons at the compressor discharge temperature and refrigerant charge are hence a potential for healthier fluid [21]. Because of hydrocarbon refrigerants like the German-made isobutaneR-600, scientists have been compelled to create more environmentally friendly refrigerants and uses. R-290 and R-600a refrigerants were tested independently and together in the refrigerator by Richardson and Butterworth. The researchers observed that using R-12 refrigerant produced a greater COP value and used a vapor condensing equipment as a test facility. A blend of R-290 and R-600a has been proposed by Lim et al. to replace R-12 in home refrigerators. The refrigerating impact of the system was improved, and the overall amount of energy used was lowered by about 3%, according to the data. Additionally, research comparing the application of R-600a, a mixture of R-290 and R-600a, and R-134a to replace R-12 in household freezers was published in the magazine "hydrocarbon technology" in 1996. This research revealed that using R-600a produced an 8.5 percent higher COP value [22].

2 Nanoparticles and nanofluids

The inspiration for new science and technology sometimes originates from the human ideas and imaginations. Comparable imaginations gave rise to the development of nanotechnology. Nanotechnology is the control of matter with dimensions between one and one hundred nanometers. The year 1925 saw developments in the area. The idea of a "nanometer" came from Chemistry Nobel Laureate Richard Zsigmondy. It was the first time a microscope had been used to measure the size of particles like gold colloids, and the phrase was employed to define particle size. The father of contemporary nanotechnology is Richard Feynman, a 1965 Nobel Prize winner in Physics. In his address, he discussed how matter's atomic structure can influence its behavior [23]. "Upon this basic Idea of Nanotechnology," a 1974 study by Norio Taniguchi, is when the term "nanotechnology" was first used. Dr. K. Eric Drexler, a graduate of MIT, developed Feynman's idea in his book "Engines of Creativity" from 1986. There have since been various definitions of nanotechnology. In the case of nanotechnology, the dictionary defines it as "the skill of manipulating materials on an atomic or molecular scale, especially to construct minuscule devices" [24]. Nanotechnology is the synthesis and use of materials whose constituents exist at the nanoscale, which is defined as a size of less than 100 nanometers [25-26]. Nanotechnology has the potential to create new products, to replace existing ones, by improving their performance, leading to

reduced material, energy consumption, and environmental harm. Although a reduction in material and energy use is good for the environment, nanotechnology offers intriguing opportunities to solve challenges in a more sustainable way [27]. Nanomaterials have piqued the interest of scientists and engineers because of their unique features that aren't seen in bulks of the identical chemicals. Special optical, magnetic, and electrical properties, among other things, may be among those outstanding qualities. Electronics, spintronics, medicinal applications, and other gadgets could all benefit from these unique features. Although some nanomaterials may be found in nature, they were most likely created in laboratories using engineering procedures [28].

2.1 Types and classification of nanoparticles

Nanoparticles are classified into four major material-based categories including:

2.1.1 Africa's generation capacity

These NMs are made up of carbon and come in a variety of shapes, including hollow tubes, ellipsoids, and spheres. This division includes fullerenes (C60), carbon nanotubes (CNTs), e.t.c. The main production processes for these carbon-based compounds (excluding carbon black) include laser ablation [29].

2.1.2 Metal Nanoparticles

Well-defined polymers, such as dendrimers, may regulate the size, shape, and stability of nanoparticles with sizes ranging from 1nm to 4 or 5 nm.10 Metal nanoparticles are largely used for their unique features in the fields of catalysis, magnetic, magnetic, and optical [30].

2.1.3 Nanocomposites

These are a type of poly-phase solid material in which one phase has two or three dimensions of less than 100 nanometers. Unlike traditional composites, nanocomposites have ratio of surface to volume. The physio-chemical qualities may differ depending on the size and shape of the object. There are various sorts of nanocomposites, such as nanomaterials. Ceramic Matrix Nanocomposites (CMNC), Metal Matrix Nanocomposites (MMNC), and Polymer Matrix Nanocomposites (PMNC) are the three types [31].

2.1.4 Solid lipid nanoparticles

In the 1990s, solid lipid nanoparticles played a key role in drug delivery control. As a colloidal carrier system, there are some alternatives to emulsions, liposomes, and polymeric nanoparticles [31].

2.2 Nanoparticle Synthesis

Nanoparticles can be synthesized using three different methods. Biological, physical, and chemical approaches are the three types. The biological approach is simple and straightforward, usually requiring only one step and is environmentally benign. In this case, we can use microbes as well as various plant parts to make nanomaterials [31]. The synthesis method is crucial in determining the physical properties and uses of nanomaterials. As a result, finding the best and most relevant synthetic pathway for nanomaterial design is at the heart of many innovative methodologies. As a result, many methods for the creation of nanomaterials have been developed. In the numerous processes used to synthesize nanoparticles, there are two primary approaches.

Process for producing mechanical-physical particles: Top-down synthesis is another name for this technique. Crushing a huge particle into smaller ones that can be used as nanoparticles in this procedure requires a lot

of force. This can be accomplished using a variety of techniques, including grinding, lithographic cutting operations, milling, chemical vapor deposition, crushing, as well as, physical vapor deposition. Both ceramic and metal-based nanoparticles are produced using this technique [32]. It is sometimes referred to as the building up technique because NPs are constructed from very simple building blocks. Procedures like sedation and weight reduction are two instances of this. Spinning, green synthesis, sol gel as well as biological synthesis are all covered [33]. Grinding/milling by hand: The mechanical milling method is a top-down strategy in which grinders are used to decompose large structural components into coarse particles. Mechanical, thermal, and centrifugal forces are used in this procedure. Nanoparticles ranging in size from 10 to 1000 nm are generated using this method. They're used to make nanocomposites and bulk materials with nano-grained grains. For this procedure, planetary ball mills, attrition ball mills, high-energy ball mills, low-energy tumble mills, and vibrating ball mills are all options [32].

Method of laser evaporation: For the manufacture of magnetic nano powders, laser evaporation is a viable bottom-up process. Lasers are used to change the phase of raw metal oxides, which are employed as synthesis base materials. The size of the particles and magnetic phase can be modified by adjusting the laser power and gas composition in the evaporation chamber [31].

The sol gel method: Which is primarily employed to create mixed oxide composites and metal oxide nanoparticles with appropriate nanostructures. A common sol gel technique involves the steps listed below: hydrolysis, condensation, and drying processes. Metal hydroxide is created by first hydrolyzing the metal precursor, and this product is subsequently condensed to create gels. The completed gel is dried to create xerogel or aerogel [32,34]. Due to the presence of dangerous compounds absorbed on the surface, chemical manufacturing procedures have been connected to a wide

range of adverse effects. Chemical and physical manufacturing methods for nanoparticles are not as environmentally friendly as biological methods that use microorganisms like enzymes, fungi, plants, or plant extracts. An essential area of nanotechnology is the development of these environmentally friendly techniques for synthesizing nanoparticles [35].

2.3 Nanoparticle characterization

The most crucial factors to take into account while defining NPs are their size and form. In addition to the surface chemistry, we also look at the surface area, level of aggregation, size distribution, as well as surface charge. The size, size distribution, and organic ligands on the surfaces of NPs may affect their other properties and uses. Additionally, the crystal structure and chemical composition of the NPs are thoroughly studied following nanoparticle synthesis [36]. Characterization helps establish whether a synthesis technique was successful as well as the composition and structure of materials. Quantitative approaches and qualitative methods both exist [37].

2.3.1 SEM (Scanning electron microscope)

The SEM can magnify images up to 200.000 times. It determines particle size and characterization, as well as the conductivity or sputter coating of the sample and sensitivity down to 1nm. The classification of the size, shape, and morphologies of the samples are determined via scanning electron microscopy examination. This produces images of the sample's surface at high resolution as depicted in Figure 3 [38]. Quantum Dots Measurements: In semiconducting QDs, shape, structure, and other characteristics, are typically critical to define. In order to estimate them, transmission emission microscopy (TEM) and Electro-Dispersive X-ray diffraction spectroscopy (EDS) can reveal the sample's composition, while TEM (TEM) can reveal

the crystalline structure. The right approach should be utilized depending on the particles [28].
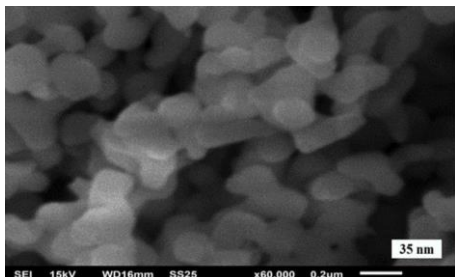

Fig 3. SEM Image for Al_2O_3 nanoparticle particle size [39]

Diffraction of X-rays (XRD): The XRD power is measured using a diffractometer. The following is the result of an XRD study: The nanoparticles were discovered to have a spherical FCC structure with a size of roughly 15 nanometers. XRD spectral methods indicated the presence of the crystalline structure. The structural characteristics of the generated NPs may be analyzed using the Seifert 3003TT XRD. This diffraction supports the creation of the phase, as well as the fact that the produced particles are pure covellite. The diffraction patterns were captured using monochromate Cu K radiation (= 1.54) on a Rigaku D/Max 250. 60 The creation of CuNPs is confirmed by the XRD results [30].

Characterizations optical: Optical characteristics are very vital in their applications; thus, scientists learned a lot about technique to figure out the relationships in the photochemical processes and how they work. These descriptions are based on the well-known Beer-Lambert rule and the fundamental light principle. They can be determined using these techniques. It is of popular knowledge that NPs, particularly metallic in nature, have a variety of hues and are hence best suited for photo-related applications which should be known to understand how they can be applied The null ellipsometer, ultraviolet–visible (UV–Vis), and photoluminescence (PL) are well-known optical equipment that can be used to explore these characteristics [33].

2.4 Nanoparticle properties

Thermal properties: Metal Nanoparticles are well-known for having better thermal conductivities than other solid-state fluids. The thermal conductivity of oxides like alumina (Al_2O_3) is higher than that of water. As a result, as compared to typical heat transfer fluids, fluids having solid particles suspended in them should have much better thermal conductivities. Nanofluids are made by infusing solid nanoparticles in a liquid like water, or oils thereby outperforming traditional heat fluids [33].

Magnetic properties: Magnetic NPs have piqued the interest of researchers. According to the literature, NPs work best when their size is between 10 and 20 nanometers [33]. Magnetic properties result from NPs' unequal electronic dispersion. Various synthetic processes such as solvothermal, co-precipitation, micro-emulsion, thermal breakdown, and flame spray synthesis can be employed to prepare these qualities [33].

Nanoparticles' physical and chemical features are intricately linked to their atomic and molecular origins. Small clusters have radically different electrical and optical characteristics, as well as chemical reactivity, than larger clusters. To anticipate the evolution of such features with particle size, complex quantum mechanical models are required, as are often very well-defined conditions for comparing experimental results with theoretical predictions. Particle aggregation which depends on the fluid's viscosity and polarization [28].

2.5 Applications of nanoparticles

In terms of bettering the diagnosis and treatment of human illnesses, nanomedicine has substantial opportunities. The creation of nanoparticles using microorganisms is an environmentally favorable approach. Additionally, the sector has the potential to alter a variety of biotechnological tools by making them more affordable, secure, and

user-friendly. [35]. Nanoparticles as catalysts: The reaction happens in several ways, including lowering the activation energy, binding to reagents to polarize bonds, obtaining effective collisions by bringing reactive species closer together, and increasing product yield. Catalysts can help reduce the temperature of a reaction while also decreasing the occurrence of side reactions. The surface area per unit mass is increased when the nanoparticles are smaller. This increases the surface area available for catalytic chemical reactions. As a result, the reactivity of nano catalytic processes is higher than that of traditional catalytic reactions involving bulk materials. Metal-based Nano catalysts, quantum dots, carbon-based Nano catalysts, thin-layer nano catalysts, core–shell nano catalysts, and ceramic nano catalysts are examples of nano catalysts [31].

Biological Applications: Biologically manufactured Nanoparticles can be employed as a coating for household products as well as in the production of antibacterial paints. They also aid in the reduction of fouling in maritime environments. The generated Nanoparticles can subsequently be utilized as a biocide, providing superior protection against biofilm formation and better control against leaching due to their increased surface area, and hence are used in antifouling coatings. They're also utilized to detect dangerous mercury ions at concentrations as low as 1ppm. Because of their low toxicity, they are also used in sewage treatment and other wastewater management approaches [30].

Dental applications: Nanotechnology has a lot of potential in dentistry for improving dental treatment, care, and prevention. Tooth sealants and fillings that use nanosized particles to improve their strength, luster, and wear resistance have been used nanotechnology in dentistry. To prevent dental cavities, antimicrobial nanoparticles are employed in restorative composite materials. Silver particles, for example, are utilized as antibacterial agents in fillers, and toothpastes can help to prevent bacterial growth and tooth damage [39].

Nanofood refers to foods that have been enhanced with nanotechnology techniques, tools, or produced nanoparticles during cultivation, production, processing, or packaging. Nanofood is being developed for a variety of reasons. Improvements in food safety, nutrition, and flavor, as well as lower production and consumer prices, are among them. Furthermore, nanofood has a number of advantages, including health-promoting ingredients, extended shelf life, and new flavor variants [38-39].

Nanofluids are base fluids with colloidal suspensions that have been tailored to improve their properties at low concentrations. Nanofluids exhibit stronger heat transfer between particles and fluids than regular solid liquid suspensions due to larger nanoparticle surface area, improved dispersion stability to base fluid [40].

2.6 Nanofluids

A revolutionary class of fluid called a nanofluid consists of a working fluids immersed in nanoparticles (1–100 nm). These often metal or metal oxide particles increase conduction and convection coefficients, facilitating greater heat transfer from the coolant. Nanofluids are liquid suspensions of functionalized nanoparticles. They are composite materials that have developed into their own industry and were created with the intention of increasing heat transfer fluids [41].

Nanofluids are a new class of enhanced heat-transfer fluids created by distributing nano particles with diameters smaller than 100 nanometers (nm) in traditional heat transfer fluids. When compared to solids, the thermal conductivity of traditional heat transfer fluids is weak. Nanotechnology has opened up a new field of study for the processing and production of nanoparticles, which are materials with average crystalline sizes of less than 100 nm. The term "Nanofluids" refers to nanoparticles suspended in ordinary fluids. In addition, nanoparticles have a substantially higher surface area per unit volume than microparticles. These qualities can be employed to make stable suspensions

with better flow, heat transmission, and other attributes [42].

Nanofluids are a new technology that adds nano-sized (100 nm) particles to traditional fluids (e.g., water) to improve heat transfer characteristics. As a result, milli and micro-sized particles aren't new, as they've been well-tested and documented heat transmission strategies. Nanofluids have dominated the literature in recent years, transforming the thermofluids sector. James Clerk Maxwell was the physicist who devised a valid theory for the effective thermal conductivity, k, of two-phase mixtures including powders with particle sizes in the millimeters or micrometers range [43].

Nanofluids have gotten a lot of attention in recent years, and they've broken new ground in a number of engineering sectors. Because of their excellent thermophysical qualities, they may now be used in refrigeration cycles, which has resulted in significant energy savings and reduced environmental effect in many circumstances. For example, adding 0.1 percent titanium dioxide to R134a in a residential refrigerator saves 10,863MWh between 2012 and 2030, according to Javadi and Saidur. Furthermore, by 2030, the use of this nano refrigerant could have reduced direct and indirect carbon dioxide emissions by 7.47 million tons [44].

2.6.1 Nanofluid preparation

The first stage in creating fluids with increased thermal conductivity is to prepare nanoparticles. Nanoparticles with size ranging 1–100 nm are suspended in normal fluids in appropriate concentrations to produce these nanofluids. Theoretically, adding these nanoparticles with high thermal characteristics to fluids improves overall thermal conductivity due to changes in heat transfer properties of the liquid. Nonmetallic particles and metallic particles have frequently been used to do this [45].

Nanofluids aren't only a mix of liquids and solids. Special requirements include an even, stable, and long-lasting suspension, little

particle agglomeration, and no chemical change in the fluid. Nanofluids can be made in a single or two-step process [46].

(a) One step method:

This process involves simultaneously manufacturing nanoparticles and dispersing them in a base fluid. Because unnecessary stages eliminated, the chances of particle aggregation and coagulation are reduced, resulting in a very stable nanofluid. The various reduction techniques are all part of the single-step process for preparing nanofluids [47].

Nanofluids in general have higher dispersion stability because they bypass the drying, transportation, and storing processes in one step. However, the needed base fluid is rarely a solution for synthesizing nanoparticles, particularly when using a chemical reduction process that can easily produce by-products. As a result, the two-step approach is the most extensively utilized nanofluids technology for energy and heat transfer applications [48-49].

(b) Two step method

In comparison to the one-step procedure, the two-step method is more commonly utilized in industries to produce large-scale nanofluids. The nanoparticles are distributed into the base fluid using the two-step procedure, after they have been produced using various synthetic techniques. For preparing nanofluid, the majority of the researchers employed this method. Senthilraja et al. generated single CuO and Al_2O_3 nanofluids and Al_2O_3 -CuO hybrid nanofluids using a two-step process. For CuO, Nano diamond, Al_2O_3, and Fe_3O_4 nanofluids, Sundar et al. adopted a two-step technique. Many researchers have also used the two-step process to create carbon nanotubes containing nanofluids. Instead of metallic particles-based nanofluids, Eastman and Choi suggested a two-step approach for creating oxide nanoparticle-based nanofluids. It is difficult to avoid agglomeration of nanoparticles in the two-step approach, which is one of the most

important concerns or obstacles, but this method has a lower manufacturing cost than the one-step method [50].

Maxwell pioneered the use of solid particles to improve the thermal characteristics of fluids more than a century ago. Nanofluids are the next-generation heat transfer medium. Nanofluids are colloidal nanoparticle suspensions in a base fluid that have been manufactured. Nanofluids have distinct characteristics that set them apart from traditional solid-liquid mixes that contain millimeter and/or micrometer-sized particles [51].

2.6.2 Nanofluid characterization

The characterization of nanofluids includes (i) determining the chemical composition, size, and morphology of nanoparticles, as well as the size of agglomerations, and (ii) determining the dispersion stability of nanofluids. This includes tests such as scanning electron microscope, Transmission electron microscopy (TEM), e.t.c. [52].

2.7 Nanorefrigerants

Nano-refrigerant is a blend of nanoparticles and refrigerants that offers greater heat transfer performance than regular refrigerants, according to expectations. Wang scientists have been working on nano-refrigerants since 2005 in order to improve the heat transfer performance of refrigeration and air conditioning systems [53].

Nanofluids have gotten a lot of attention in recent years, and they've broken new ground in a number of engineering sectors. Because of their excellent thermophysical qualities, they may now be used in refrigeration cycles, which has resulted in significant energy savings and reduced environmental effect in many circumstances. Choi and Eastman are the creators of the nano refrigerant concept. Nanoparticles are dispersed in water, glycol, oils, and conventional refrigerants to produce these refrigerants. Because of the improved characteristics of adding metal solids over

liquids, it efficiently improves their thermal conductivity [44].

Nano-refrigerant refers to a nanofluid that has a refrigerant as its host fluid. The thermal conductivity of nano-refrigerant is higher than that of the host refrigerant, as it is for other nanofluids. The usage of a nano-refrigerant has been researched for enhancing the energy efficiency of a refrigeration system. Because the boiling heat transfer coefficient is influenced by thermophysical qualities [54].

Vamshi et al., [49] noted that nano-refrigerants have an advantage over the common heat transfer fluids due to their effects on the environment and impact on global warming and ozone depletion. New technologies and tactics are continually being introduced to increase performance and reduce environmental effect, notably for residential, industrial, and mobile air conditioning systems. The fundamental thermodynamic parameter that defines performance is the COP, compressor work, and cooling capacity performance [56].

The effect of SiO_2 nano-lubricant in a R410A vapor compression system was investigated by Senthilkumar & Anderson, [6]. The investigation was carried out using a concentration ranging from 0-0.6 g/L of Silicon dioxide (SiO_2) nanoparticles concentrations in POE lubricating oil with varying mass as 30-70 g of R410A refrigerant. The results showed a minimum compressor work of 80 W with 0.4 g/L nano-lubricant and 40 g of R410A refrigerant. The cooling capacity was maximum at 160W for a 0.4 g/L nano-lubricant with 40 g refrigerant mass charge. .

Menlik, [51] investigated the effect of using alumina (Al_2O_3) nanoparticles to promote passive heat transfer in an ammonia/water pair. He looked at how it was used in diffusion absorption coolers and how it affected the system's heat performance. Adding nanoparticles to a fluid improves heat transmission significantly as a result of the nanoparticles. Because of the nanoparticles, the fluid's capacity increases. As a result, the impact of Al_2O_3 nanoparticles in cooling/absorption fluid

mixes on system performance was investigated in this work. The system with nanoparticles produced higher heat absorption characteristics according to the results of the studies. Because the heat transfer periods were shorter, the system's operation time was lowered. As a result, the desired temperature was achieved faster.

Vamshi et al., [50] studied the thermophysical parameters of a nano-refrigerant or nano-lubricant and their performance. The review determined that as concentration rises, thermal conductivity rises as a result of rising temperature, and that nanoparticles concentration has a direct link with viscosity. Pressure drop increases as viscosity rises, necessitating high pumping power and hence high energy consumption to sustain flow.

Al_2O_3, Cu, and SiC based Nano-refrigerants were investigated by Bhat et al., [52]. Domestic refrigerators have been highlighted as a significant source of emissions due to the use of environmentally unfriendly refrigerants, as well as consuming a significant portion of the total energy budget. Nanoparticles were utilized in refrigerants to improve thermo-physical qualities such thermal conductivity, density, viscosity, and specific heat, and thus improve refrigeration system performance. There was an improvement in all the properties as the volumetric concentration of nanoparticles increased, apart from the specific heat values which fell.

Bhattad et al., [47] looked at different ways to use nanofluids to improve the performance of refrigeration systems. The research covers everything from nanofluid synthesis and characterization to enhanced thermal properties. To sum it up, Nanofluid's thermal conductivity rises with temperature and volume concentration. It does, however, increase when particle size decreases, but viscosity increases as particle volume concentration rises. However, it drops as the temperature rises, and density rises with the volume concentration of nanoparticles and falls as the temperature rises.

In order to discover more effective working fluids for refrigeration systems, Ajayi et al. [53] looked at the flow properties of nano refrigerants through adiabatic capillary tubes. With the use of a CFD simulation/solver, the CFD flow research was completed, and the outcomes of the simulations were examined to ascertain the variations among common refrigerants (R134a, R600a) and nano-refrigerants (CuR134a, CuR600a). Showing that heat wasn't transferred quickly enough to raise the temperature of the subsequent region, the results showed that there were more isothermal zones, indicating that the base fluid's thermophysical properties had been improved by the nanoparticles. The previous refrigerant also had far greater pressure contour densities, necessitating the use of a larger compressor and more power.

The thermal conductivity of micro refrigerants with low volume concentrations was examined by [60]. The thermal conductivity of R141b-based nano refrigerants with low particle concentrations of Al_2O_3, TiO_2, and SiO_2 nanoparticles is examined experimentally in this research. A model for the thermal conductivity of nano refrigerants is proposed based on experimental data, taking into account nanoparticles aggregation and Brownian motion-induced nano-convection. The inclusion of nanoparticles increased thermal conductivity as nanoparticles concentration and temperature increased, while lowering thermal conductivity as nanoparticles size increased.

Rezaeianjouybari et al. [56] used nano refrigerants to conduct an experimental study to maximize heat transfer in condensation flow. CuO nanoparticles were distributed in a refrigerant-oil mixture (R600a/POE) with a concentration of 0.5-3.5 percent to make the nano refrigerant in the experiment. A bypass was used to inject the oil and oil/nano particle mixture to the refrigerant. To homogenize this mixture, the system was run continuously for 2 hours. The heat transfer improvement was greatest in nano refrigerants containing 1.5–2.2

percent nanoparticles, according to the findings.

Randa, [56] looked into the effects of nanoparticles behavior in VCRs with various refrigerants. He investigated the solubility, heat transfer properties, and VCRS performance of nanomaterials that he had implemented. The results revealed that when nano refrigerants and nano lubricants were used, thermal conductivity improved by about 4%, and heat transfer coefficient increased by 12 percent to 101 percent. With the use of nano lubricants, friction and wear costs were reduced by approximately 32% to 13%. As a result, the use of nano refrigerants and nano lubricants improved the overall performance of the VCRS by about 11 percent and increased the COP by about 24 percent.

2.8 Use Of agricultural products as nanoparticle source

Agriculture is one of the world's most important industries. The majority of the gathered farming goods are crucial sources of food for people all over the world. China, the United States, India, Nigeria, and Brazil are among the top producers of various agricultural products such as fruits, vegetables, cereals, and so on. Following the harvest and consumption of agricultural products, several waste materials such as rice husk ash, palm oil fuel ash, coconut shell, and coal bottom ash remain as leftovers. Because the chances of reusing agricultural waste are slim, the majority of it is disposed of in the surrounding areas. Because of the environmental impact, repurposing such waste materials in a variety of uses can provide a number of benefits [58]. Nano-science is one of the key areas of research that is currently being pursued. Nanoparticles have been discovered to be useful in a variety of sectors, including ceramics, chromatography, refrigeration, anticorrosion agents, and catalysis. Agricultural waste materials such as rice husk, groundnut shell, bamboo leaves, and sugarcane bagasse, among others, can be used to make these nanoparticles. When disposed of improperly, these waste materials cause serious environmental problems, but they can also be used to help nanotechnology [59-63]. Nanotechnology is the study of the synthesis, design, and manipulation of particles with diameters ranging from 1 to 100 millimeters. Nanotechnology is becoming increasingly important in everyday life, such as in medicine, cosmetics, the food industry, drug delivery, and electronics, and new nanoparticle applications are emerging rapidly in a variety of fields. Nanoparticle synthesis techniques necessitate the use of extremely expensive and toxic chemicals that pose a risk to the environment and human health. As a result, biological methods of using plant extracts, microorganisms, and enzymes have gained popularity due to their eco-friendly and cost-effective nature [59]. Yang et al., [44] used agricultural waste to examine the production of gold nanoparticles (mango peel extract). The mango peel (50g) was crushed in a juicer with 150 ml purified water. In a water bath, the reaction mixture containing 3.0 ml of extract in 27.0 ml of HAuCl4 solution was incubated for 15 minutes. 0.1 N HCl or 0.1 N NaOH solutions were then used to alter the pH. The synthesis reaction rate is relatively faster than that of other plant extracts. XRD, TEM, and FTIR were used to characterize the GNPs. The biosynthesized GNPs had a size range of 6.0372.77 to 18.0173.67 nm, according to the findings. Ibrahim, [61] explored the numerous parameters affecting the reduction of silver nanoparticles that were manufactured utilizing a banana peel extract as a reducing and capping agent. The best conditions were found when its chemical components were incubated for a duration of 72 hours. After heating the reaction mixture for 5 minutes, banana peel extract reduces the silver ions into silver nanoparticles, as shown by the generated reddish-brown color. Dynamic light scattering revealed that the average size of nanoparticles was 23.7 nm.

According to Bankar et al., [62], banana peels could be employed as an Agro-waste source in the synthesis of gold nanoparticles.

The average size of the nanoparticles under conventional synthetic settings was around 300nm, according to dynamic light scattering (DLS) tests, and scanning electron microscopy and energy dispersive spectrometry (EDS) of the manufactured particles confirmed these findings. Antifungal and antibacterial activity was also observed in the produced nanoparticles against the harmful fungus and the majority of bacterial cultures.

Kumar et al., [63] investigated the green synthesis of Zinc oxide nanoparticles and their use in the fabrication of nanocomposite materials with improved mechanical and microstructural properties. The ZnO nanoparticles were made by burning cicer arietinum as a fuel. The A357 alloy was reinforced with nanosized ZnO nanoparticles, resulting in an aluminum nanocomposite. The results reveal that adding weight percentages of ZnO NPs increased ultimate tensile strength, yield strength, and microhardness values, while reducing ductility, with the best results coming from adding 3 wt. percent of ZnO manufactured nanoparticles.

Anju et al. [64] investigated the environmentally friendly production of silver nanoparticles using Aloe vera leaf extract. In accordance with the research [65-66], plant - mediated from natural sources can offer a healthy technique to make nanoparticles while phytocomponents add extra properties. The results of qualitative experiments demonstrate that AgNPs are produced, and that the gel extract's acemannan serves as a reducing and stabilizing agent for nanoparticle production. The discovered increased antibacterial activities of the generated AgNPs against both gram-positive and gram-negative pathogens suggest medicinal relevance.

3 Conclusion

In this study, the viability of nanofluids developed from agricultural wastes as possible alternatives for conventional refrigerants has been reviewed. The following are a summary of the conclusions based on the review:

  i. nanoparticles find useful applications in biomedicine, dentistry, engineering and in the food industry.
  ii. the use of agricultural wastes in the development of nanofluids and nano-refrigerants serves a dual purpose of waste recycling and an alternative clean refrigerant source;
  iii. nano-refrigerants are a viable alternative to the conventional hydrocarbons used as refrigerants in the domestic refrigerators

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