Enhancing The Performance of Vapour Compression Using Al_2O_3 Nanoparticles

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***Abstract*—Improving the performance of vapour compression refrigeration systems is crucial to increasing energy efficiency and environmental sustainability. This research focusses on using nanoparticles as performance-enhancing additions in refrigerants for vapour compression cycles. Nanoparticles have exceptional thermal qualities, such as strong thermal conductivity and increased heat transfer capacities, which can greatly improve the efficiency of both refrigerants and lubricants. Nanoparticles, including aluminium oxide (Al_2O_3), are tested for their usefulness in traditional refrigerants. To maintain consistent operation, suitable stabilisation techniques are used to address difficulties such as particle agglomeration and sedimentation. The experimental results show that adding nanoparticles increases the coefficient of performance (COP) via improving heat transfer rates and refrigeration efficiency.**

Furthermore, the system consumes less energy, allowing for more sustainable and cost-effective cooling options. The effect of nanoparticle concentration, type, and size on factors including thermal conductivity, pressure loss, and compressor workload is comprehensively investigated. Furthermore, the paper emphasises issues with dispersion stability and mechanical wear while discussing alternative mitigating measures. The study finds that, when properly constructed, nanofluids are a promising breakthrough for improving vapour compression systems. Their application can result in increased heat transfer performance and energy savings, contributing to the growing need for environmentally friendly cooling systems. Future research should investigate optimal nanoparticle compositions, advanced nanomaterials, and compatibility with ecologically friendly refrigerants to further boost performance and sustainability.

This work contributes to the ongoing efforts to develop energy-efficient refrigeration and air conditioning systems, aligning with global energy conservation and climate change mitigation goals.

I. INTRODUCTION

Over the past two decades, the use of nanomaterials in various base fluids has significantly improved heat transfer rates, leading to greater thermal system efficiency. In 1996–97, Choi S. pioneered a technique to enhance nanofluid thermal conductivity by incorporating nanoparticles [1]. This work demonstrated how metal oxide nanoparticles could improve fluid thermal conductivity [2]. Since then, extensive research has confirmed the benefits of nanoparticle-based nanofluids in enhancing thermal applications. Choi's findings facilitated the use of nanofluids in a range of thermal systems. Numerous studies on Al2O3-based nanofluids in refrigeration systems have evaluated performance factors, primarily focusing on energy consumption and the coefficient of performance (C.O.P.). Biet al. [3] investigated Al2O3 and TiO2 nanoparticles with HFC134a refrigerant in a household refrigerator, reporting a 26.1% reduction in energy consumption and other performance improvements. Jwo et al. [4] noted a 2.4% reduction in energy use and a 4.4% increase in C.O.P. when using an Al2O3–POE nano lubricant with R134a refrigerant. Sendilet al. [5] conducted experiments with Al2O3-based POE nanofluids and varied R134a charges, achieving a 10.32% energy consumption reduction and a significant C.O.P. increase. They also observed that Al2O3–POE-based nano lubricants with R134a reduced energy consumption by 2.4% and enhanced C.O.P. by 4.4%. Soliman et al. [6] combined R134a refrigerant with Al2O3–POE nanofluid to optimize the vapor compression cycle, leading to a 50% increase in the heat transfer coefficient, a 10.5% performance boost, and a 13.5% drop in energy consumption. Yusof et al. [7] also reported that incorporating Al2O3-based POE nanofluids with R134a improved system C.O.P. and reduced energy consumption by 2.1%.. The technique of superheating and subcooling in conjunction with Al2O3 nanofluid has demonstrated superior performance for the refrigeration system to increase its efficiency. [8]. Significant heat transfer improvements were demonstrated in vapor compression refrigeration and an absorption refrigeration system using water and an Al2O3 nanofluid based on ammonia. [9]. Other studies comparing Al2O3-based nanofluid to other nanoparticles in the refrigeration system are available in the literature. [13–18] where better nanoparticles have been used, like copper oxide, carbon nanotubes, and titanium dioxide. The researchers found that the performance parameters of the refrigeration system were improved when utilizing these nanoparticles in comparison to Al2O3 nanoparticles. However, the improvement was still greater when compared to the conventional refrigerant system that used Al2O3-based nanofluid. The current study examines the performance and experimental aspects of the R134a and R600a-powered vapor compression refrigeration test rig. Due to the paucity of information on Al2O3 experiments using R600a. [14]. The current work compares an Al2O3-based nanofluid under identical physical conditions to R134a and R600a. Choi created the first "Nanofluids," which are 100 nm nanoparticles mixed with basic fluids including oil, ethylene glycol, and water. Renewable energy is one of the fascinating applications of nanofluids. [11]. Renewable energy is one of the fascinating applications of nanofluids. The remarkable qualities of nanofluids include their thermal characteristics, steadiness, etc. Numerous studies have found that base fluids are not as capable of convective heat transfer as nanofluids. [12] Efficient heat management systems are essential for the proper functioning of car radiators. A study by Choi [13] introduced nanofluids as an advanced coolant for car radiators. These nanofluids have demonstrated promising results in the renewable energy sector, particularly in enhancing convective heat transfer properties and improving thermal conductivity. Due to these remarkable features, nanofluids have inspired further exploration into the concept of nano-refrigerants. The two main applications for nanofluids are coolants and lubricants. In refrigerant systems, nanoparticles are directly added to the refrigerant, whereas in lubrication systems, they are mixed with the lubricant before being introduced to the refrigerant [14]. Although nano lubricants (such as polyol ester oil, POE) and nano refrigerants (refrigerants containing well-dispersed nanoparticles) are distinct, many studies have focused on the thermal properties of refrigeration systems using nanofluids without distinguishing between them. As a result, the specific impact of nanoparticles on refrigeration performance has not been fully explored. However, after reviewing existing literature, we identified four key findings from previous research [15–26].

Several researchers have examined refrigeration systems that aim to reduce Global Warming Potential (GWP) and Ozone Depletion Potential (ODP), primarily through two strategies. The first involves replacing conventional refrigerants with low-GWP refrigerants, often utilizing nanofluids in the process [27–30]. While nano refrigerants contain well-dispersed nanoparticles, nano lubricants, such as POE oils, contain nanoparticles mixed with lubricants. Though they differ, studies on nanofluids' thermal properties in refrigeration systems have typically not separated them into nano refrigerants and nano lubricants. Consequently, the effect of nanoparticles on refrigeration system efficiency has not been fully assessed.

From the literature, four significant findings emerged. One study [31–42] experimentally demonstrated an improvement in thermal conductivity in a nano refrigerant composed of carbon nanotubes (CNT) and R113. Mahbubul et al. [32] conducted solubility tests with R134a and a POE lubricant containing TiO2 nanoparticles, reporting no impact on solubility. Furthermore, Cremaster et al. [42] observed that Al2O3 nanoparticles suspended in R22 increased the boiling heat transfer coefficient. Additionally, Park and Jung [34] showed that nano lubricants could enhance the pool boiling heat transfer coefficient of refrigerants and developed a model to predict the boiling heat transfer coefficient in evaporators containing nano lubricants.

II. NANOFLUID

2.1 Synthesis of nano-refrigerants

The development of nano-refrigerants and the preparation of well-dispersed nanofluids have been key research topics. In the one-step method, nanoparticles are initially synthesized and then dispersed into the base fluid using various practical techniques. This method demonstrates how quickly nanoparticles tend to settle in the base fluid, emphasizing the importance of preventing clumping before dispersion. The two-step process is more commonly preferred due to its simplicity and cost-effectiveness, as illustrated in Fig. 2. Nanoparticles used typically include metals like copper, nickel, and aluminium, as well as oxides such as Al2O3,. Factors like nanoparticle type, concentration, size, shape, and preparation method must be carefully examined for optimal refrigeration system performance. The behaviour of migration and aggregation is discussed in Section 6. Peng and colleagues [46]

2.2 Development of nano-refrigerants and nano-lubricants

Nanoparticles are utilized in vapor compression refrigeration (VCR) systems to enhance efficiency, forming nano-lubricants and nano-refrigerants. In nano-lubricants, nanoparticles are mixed with oil to reduce compressor power consumption, while nano-refrigerants feature particles evenly dispersed within the base refrigerant, improving thermophysical and tribological properties (35, 36, 37). Typically, up to 50% of the lubricant remains in the compressor, with the evaporator and dryer using 20% each, and the condenser and hoses utilizing 10% (HVAC Equipment Manufacturer Data). Nano-refrigerants primarily enhance heat absorption, while nano-lubricants improve compressor efficiency through better tribological performance (38, 39).

Two main research approaches focus on nanoparticle integration: direct mixing with refrigerants and suspension in lubricants. Nano-refrigerants improve flow, pool boiling, and condensation heat transfer by enhancing thermal conductivity, reducing the required pumping power. Conversely, nano-lubricants, having a higher nanoparticle concentration, demonstrate superior wear and friction reduction but face challenges due to increased viscosity (39, 40). Optimizing nanoparticle concentration is essential for balancing performance gains with potential drawbacks (40).

Early experiments using TiO_2-R134a-MO nano-refrigerants demonstrated improved coefficient of performance (COP) (39). Kedzierski and Gong (41) observed that CuO-POE-R134a nano-lubricants increased pool boiling heat transfer by up to 275%, with even slight thermal conductivity improvements yielding substantial heat transfer gains. Subsequent studies by Bartelt et al. (42) confirmed these findings for R134a-POE mixtures in flow boiling, emphasizing the critical role of nanoparticles in enhancing refrigeration system performance.

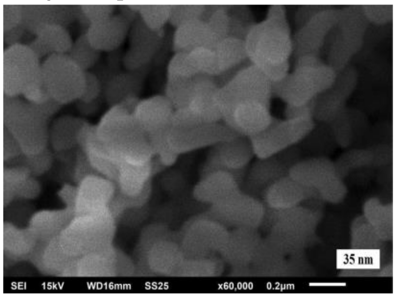

Fig.1. SEM Image for AL203 nanoparticle particle size

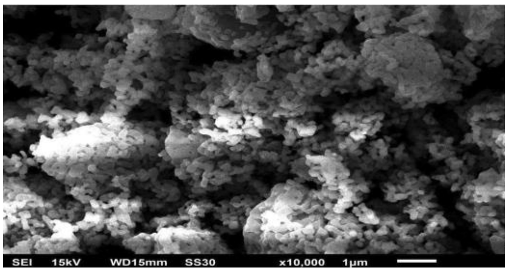

Fig 2. SEM Image for AL2O3 nanoparticle Uniformity

III. PERFORMANCE ENHANCEMENT OF NANOFLUID

3.1 Co-efficient of performance

The performance of the refrigeration system was significantly enhanced by incorporating nanofluids. Among the refrigerants tested, R600a outperformed R134a. The addition of Al2O3 nanoparticles to R134a-POE-based nanofluids led to improvements in the C.O.P., with increases of 19.38% at 0.02 weight percent, 22.44% at 0.04 weight percent, 29.5% at 0.07 weight percent, and 29.5% at 0.1 weight percent. The system performed better with R600a-MO-based nanofluids compared to R134a-POE. While pure R600a refrigerant showed an improvement over R134a, the use of R600a-MO led to a C.O.P. increase of 3% at 0.02, 0.04, 0.07, and 10.25 weight percent of Al2O3, with a peak improvement of 14.95% at 0.1 weight percent. The highest C.O.P. of 2.69 was achieved with R600a-MO-based nanofluid, although the rate of improvement for R134a-POE nanofluid was distinctly different from that of R600a-MO. [47].

IV. FUTURE SCOPE

This study utilizes numerical methods and simulation techniques. Nevertheless, to validate the effectiveness of nano refrigerants and assess energy efficiency in real-world cooling systems, experimental research is necessary, which this paper does not address. The current study is limited to lower concentrations and smaller nanoparticle dimensions. Subsequent research could expand to explore higher concentrations, various nanoparticle geometries, and different sizes within the refrigerant.

V. CONCLUSION

In conclusion, the incorporation of nanoparticles into vapor compression systems presents a promising method for improving energy efficiency and system performance. When nanoparticles are spread throughout the refrigerant, they can alter its thermophysical properties—such as thermal conductivity, viscosity, and surface tension—leading to enhanced heat transfer and decreased compressor workload. These enhancements result in reduced energy usage, which is crucial for lessening the environmental impact of refrigeration and air conditioning. Additionally, nanoparticles assist in preserving the long-term stability of refrigerants, guaranteeing consistent system performance and contributing to the overall longevity of vapor compression systems. This technology also possesses the potential to minimize the size and cost of systems, making it an attractive choice for industries pursuing more sustainable and economically viable solutions. Nevertheless, there are obstacles to address, such as ensuring nanoparticle stability, avoiding clogging, and creating compatible lubricants for effective operation..

In conclusion, the application of nanoparticles in vapor compression systems demonstrates considerable potential for enhancing cooling technologies. With additional research and development, it can offer energy-efficient, eco-friendly, and cost-effective solutions for various industries in the future.

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