CFD Letters

Journal homepage:
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ISSN: 2180-1363

CFD Analysis of Improving Air Conditioning System Performance by Adding SiO_2 Nanoparticles to the Compressor Oil

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ARTICLE INFO

Article history:
Received 25 January 2024
Received in revised form 21 February 2024
Accepted 22 March 2024
Available online 30 September 2024

Keywords:
CFD; Nanoparticles; Heat Transfer; Laminar Flow; Fluid Flow; Cooling Application

ABSTRACT

The overall performance of air-conditioning systems is necessary to evaluate the comfort conditions and equipment life. in order not to varnish energy. The aim of this study is to improve performance of air conditioning by adding nanoparticles to oil of compressor. The research applied computational fluid dynamics CFD to simulate the use of SiO_2 nanoparticles in air-conditioning systems. Silicon dioxide (SiO_2) nanoparticles have better thermal properties than pure oil and can also significantly enhance the performance of compressor oils as well as heat transfer capability in HVAC systems. This research investigates the reactions between (0.1%, 0.4%, and %0.7) of SiO_2 nanoparticles with compressor oil, to determine their impacts on heat dissipation, lubricant efficiency as well as performance overall. Results show that the addition of nanoparticles to the oil lubricant increases the COP of the air conditioning system.

1. Introduction

Air conditioning systems and refrigeration are the most device famous of domestics' applications. These systems are necessary for numerous cases, such as health care, transportation; food preservation, and everyday life comfort [1]. They allow people to live and work in harsh climates, providing heating – and cooling options. Refrigeration systems serve several different purposes – cold storage, food preservation, and cryogenic applications [2]. Air conditioning systems assist in keeping pleasant indoor temperature and humidity levels [3]. These systems also play a role in energy efficiency and cost reduction since they control the operation of each section by using incoming air temperature [4]. Moreover, the development of these systems aims at improving efficiency and environment-friendly refrigeration technologies, as well as its application on such industries as data centre cooling, electrical vehicle thermal management cryobiology best antibody array providers [5]. The application of nanomaterials in refrigeration and air conditioning systems has been proven to enable an increase in heat transfer parameters, provide for a greater cooling capacity, and enhance the overall performance of the systems [6-9]. Nanorefrigerant are mixtures of nanoparticles and pure refrigerants; heat transfer in heat exchangers has been shown to improve by using such refrigerants,

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https://doi.org/10.37934/cfdl.17.2.136147

as well as performance when using a vapour compression refrigeration cycle [10]. Also, nanofluids generated from the use of nanosized particles have been studied as possible alternatives for conventional refrigerants with successful outcomes concerning their feasibility and potential contribution to improved system performance [11]. Further, utilizing hybrid nano lubricants with both the lubricant and nanoparticles has had an effect in improving the characteristics of individual fullerene nanofibers while also increasing COP for vehicles' air-conditioning systems [12]. In summary, the use of nanomaterials in refrigeration and AC systems has a significant promise when it comes to improving energy efficiency while preserving environmental friendliness. Different studies have been conducted on the utilization of nanomaterials in oils for refrigeration and AC systems. However, one research tested the application of nanodiamond polyester (NDPOE) lubricant oil in and AC system. It revealed that it contributed to a decrease in compressor discharge temperature and pressure but enhanced COP [13]. Another paper concentrated on the heat transfer of nano refrigerants and showed that nanoparticles in fluids could increase the cooling effect capacity for HVAC-R systems [14]. Moreover, the lubrication properties of rod-shaped Sepiolite (SP) and its different carbon composites were studied, implying that incorporating SP – r GO nanoparticles in improved cooling COP system [15]. studies have demonstrated that the utilization of nano lubricants and refrigerant nano can enhance the performance of cooling systems and air conditioners by improving COP further reducing power consumption that taken from the previous studies [16,17].

Summarizing of the literature survey is showed that improving COP is led to reduce power consumption so that the adding solid nanoparticles to the oil of compressor will increase COP. The aim of this study is to improve COP of air conditioning which reduce power consumption. The CFD analysis by ANSYS/FLUENT adopted to solve the governing equations. The concentrations of nanofluid are 0.1%, 0.4%, and %7 of SiO_2 nanoparticles with compressor oil.

2. Methodology

2.1 CFD Simulations

CFD Air-conditioning is improved and system performance when nanoparticles of SiO_2 are utilized in air conditioning systems. Air conditioning of 4m length, 4m width and 2m height room in summer environment conditions. Simulations involving these scenarios have demonstrated that enhanced insulation levels and elevated set point temperature can lead to energy efficiency improved by decreasing cooling load consumption, compressor and fan energies [18-20]. Moreover, CFD models can predict the airflow velocity and temperature distribution in a room which is essential for providing user thermal comfort. To perform CFD simulations, we would need to follow these steps: 3D Modelling and Mesh Generation: Generate a 3-Dimensional model of the room intended for cooling via an air-conditioning system taking into consideration its geometry as walls, floor or roof with windows on it according to Figure 1. Once the geometry is created, generate a mesh to discretize the domain. The mesh should be fine enough to capture the room accurately as shown in Figure 2. Meshing Process has been conducted as Pre-processing which involves setting up the meshing parameters, such as element size, type, and quality criteria. The type of Mesh can be used as structured or unstructured. The choice of mesh type depends on the geometry and simulation requirements. Boundary Layer Meshing is generated near solid surfaces to capture the velocity and thermal gradients close to the walls accurately. Finally, the visualization of mesh may be visualized to inspect the element distribution, refinement zones, and overall mesh quality before proceeding with the simulation setup.

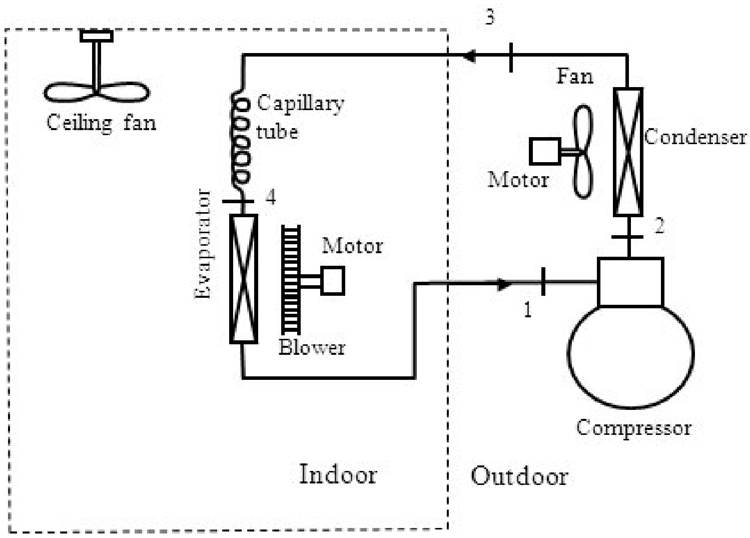
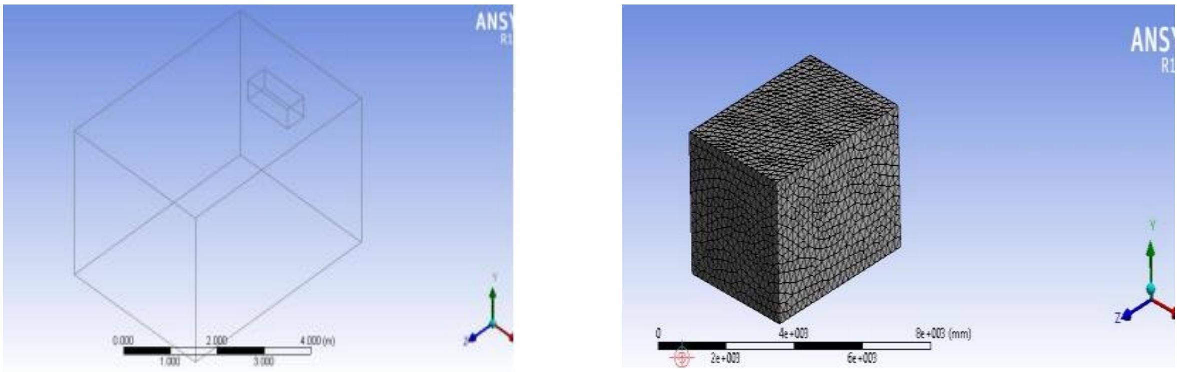


Fig. 1. Schematic diagram of room with air conditioning system [1]



(a) (b)

Fig. 2. Geometry and mesh generated (a) Geometry (b) Meshing

2.2 Boundary Conditions

The boundary conditions in a Computational Fluid Dynamics (CFD) simulation typically include specifying the conditions at the boundaries of the computational domain. These conditions help define how the fluid interacts with the boundaries and can include parameters such as velocity, temperature, pressure, and turbulence. Specific boundary conditions commonly used in CFD simulations for air-conditioning systems may include:

i. Inlet conditions: Prescribing the velocity, temperature, and/or mass flow rate of the incoming air into the room or HVAC system.
ii. Outlet conditions: Specifying the pressure, velocity, or other parameters at the outlets to simulate the flow exiting the domain.
iii. Wall conditions: Defining the properties of the walls, such as temperature, roughness, and material properties, which affect heat transfer and airflow patterns.
iv. Symmetry conditions: Applying symmetry boundary conditions for symmetric geometries to reduce computational costs.
v. Heat transfer conditions: Setting conditions for heat transfer, such as convection coefficients, radiation properties, and heat fluxes at surfaces.

vi. Turbulence conditions: Defining turbulence parameters at boundaries, such as turbulent intensity and length scale for turbulent flows.

2.3 Evaluation of Heat Dissipation Capabilities

Researchers have been investigating ways to improve the performance of air-conditioning systems by enhancing fuel efficiency. One approach is through optimizing the coefficient of performance (COP) of air-conditioning systems.

The use of SiO2 nanoparticles dispersed in lubricants was also investigated for applications in air conditioning systems. It was discovered that SiO2 nanolubricants' viscosity and thermal conductivity increased with volume concentration but decreased with temperature. The allowable volume concentration of SiO2 nanolubricants for air conditioning compressors was determined to be up to 1.0%, with higher thermal conductivity. Overall, the studies demonstrated the potential of SiO2 nanoparticles in improving heat transfer and tribological properties in air-conditioning systems as in references [21-25]. The thermophysical properties of SiO2/water nanofluid are including in Table 1.

Table 1
The thermophysical properties of SiO2/water nanofluid [21]

Materials	Density (kg/m^3)	Thermal conductivity (W/m.K)	Viscosity (Pa.s)
SiO_2 nanoparticles	2559	1.5	-
0.1% SiO2/water	2662	0.74	0.008
0.4% SiO2/water	2726	0.79	0.019
0.7% SiO2/water	2822	0.82	0.032

2.4 Examination of Overall System Performance

The use of SiO2 nanoparticles in air-conditioning systems has gained attention for improving system performance and reducing environmental impacts. The use of SiO2 nanoparticles in refrigeration systems has also shown improvement in heat transfer and overall performance. However, factors like dispersion, aggregation, stability, and sedimentation should be considered for sustainable performance improvement. Challenges like cost, toxicity effects, poor stabilization, erosion effects, high viscosity, and clogging issues require further attention. Nanoparticle doping in refrigeration systems has the potential for enhancing performance and reducing environmental impact but needs careful consideration of various factors as in references [26].

3. Results and Discussion

Computer simulations provide an opportunity to validate aspects of ventilation, smoke movement, natural airflow, and thermal comfort during the design stage. This study used CFD simulations to study forced ventilation in an air conditioning room using ANSYS Fluent. Results showed that the room temperature was higher than the comfort temperature due to the flow stagnant zone on the backside. Three cases were used, with the room dimensions and AC duct locations being the same. In the first case, the air temperature at the inlet point of the AC dust was 18^{o}C with a velocity of 0.39 m/s. In the second case, the room temperature was 37°C with a temperature of 20°C and an air velocity of 0.78 m/s. The wall temperature of the room was 40°C, influenced by the environmental temperature. All room designs use identical room dimensions of

(6x4x3.2m), a 1-ton air conditioning unit is used in this study contours of temperature, pressure and streamline of airflow in the room are indicated in (Figure 3, Figure 4, and Figure 5).

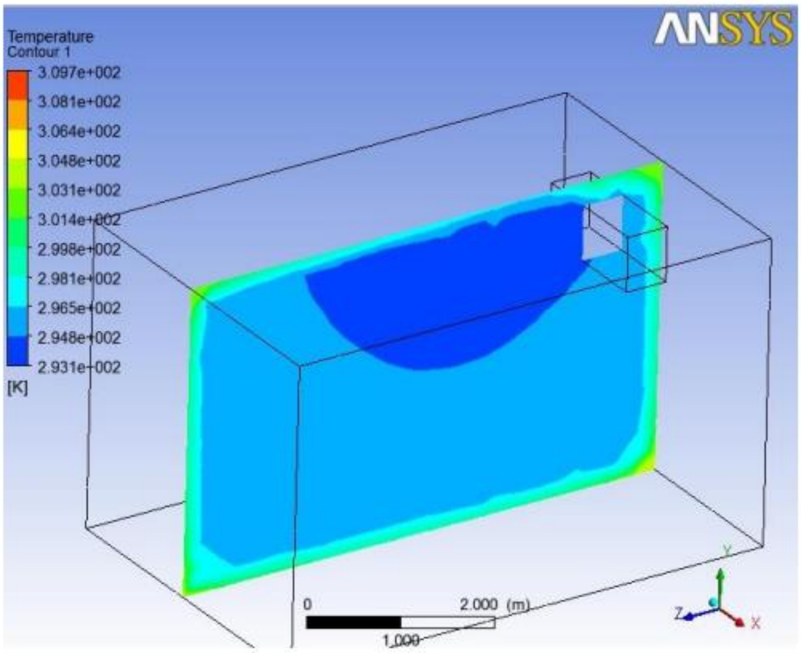


Fig. 3. Temperature variations in Room

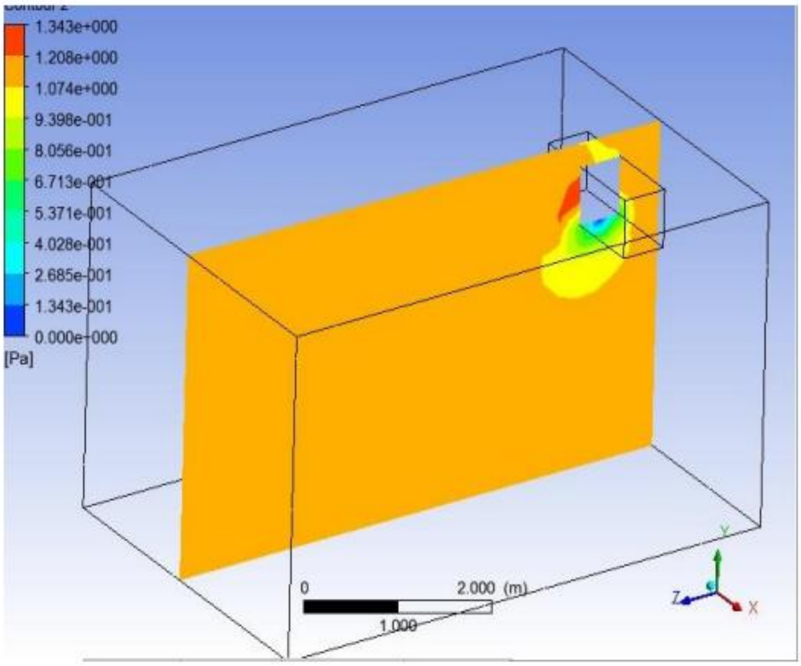


Fig. 4. Pressure generated due to air flow of AC duct in Room

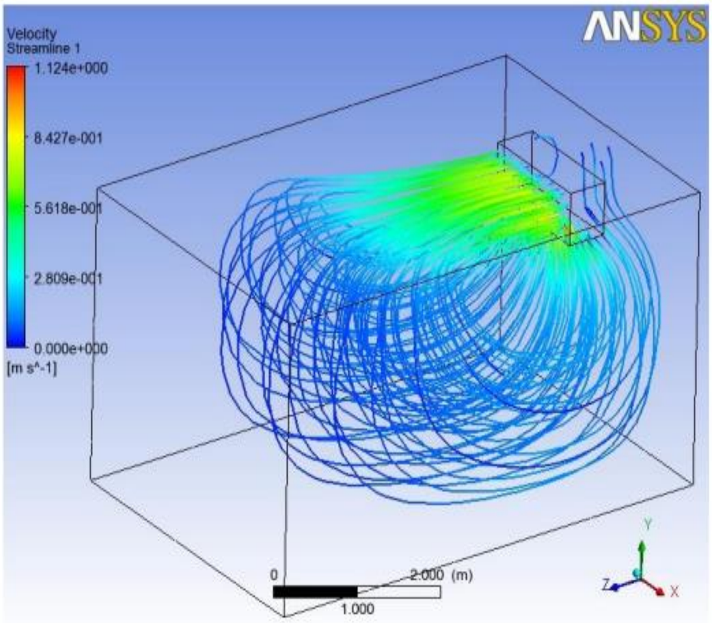


Fig. 5. Streamline of air flow in Room

3.1 Insights Into the Thermal Behavior of SiO2-Enhanced Compressor Oil

The use of SiO2 nanoparticles in lubricants for air conditioning compressors has gained attention due to their potential to enhance heat transfer and tribology properties. A comparative study investigated the heat conductivity and viscosity of SiO2 nanoparticles dissolved in lubricants made of polyalkylene glycol (PAG) and compared them with Refs. [27-30]. Nanoparticle additives have shown significant improvements in lubricating characteristics compared to pure oils. Nano-lubricants exhibit enhanced thermophysical properties and anti-friction behaviours due to the small size of nanoparticles, allowing for effective delivery to tribological contacts.

Furthermore, understanding the thermal behaviour of SiO2-enhanced compressor oil provides valuable information about the performance of SiO2 nanoparticles in air-conditioning systems. Nano lubricants have the potential to enhance heat transfer efficiency and reduce energy consumption in refrigeration systems. Further research is needed to explore the application of nanoparticle-enhanced lubricants in various components and optimize their performance for improving energy efficiency in air conditioning systems.

Figure 6 indicates that the room has a minimum temperature of cooling which found that is 32 ^{o}C when using standard air conditioning while the additive of 0.1%, 0.4% and 0.7% of SiO2 nano lubricant the minimum temperatures are 31 ^{o}C, 30 ^{o}C, 29 ^{o}C respectively. It seems that the addition of SiO2 nanoparticles to the oil of the compressor has the potential power to reduce the temperature and time of the cooling system.

Figure 7 shows the COP of the air conditioning system with different SiO2 nano lubricant volume fractions. It can be seen that the addition of nanoparticles to the oil lubricant increases the COP of the air conditioning system.

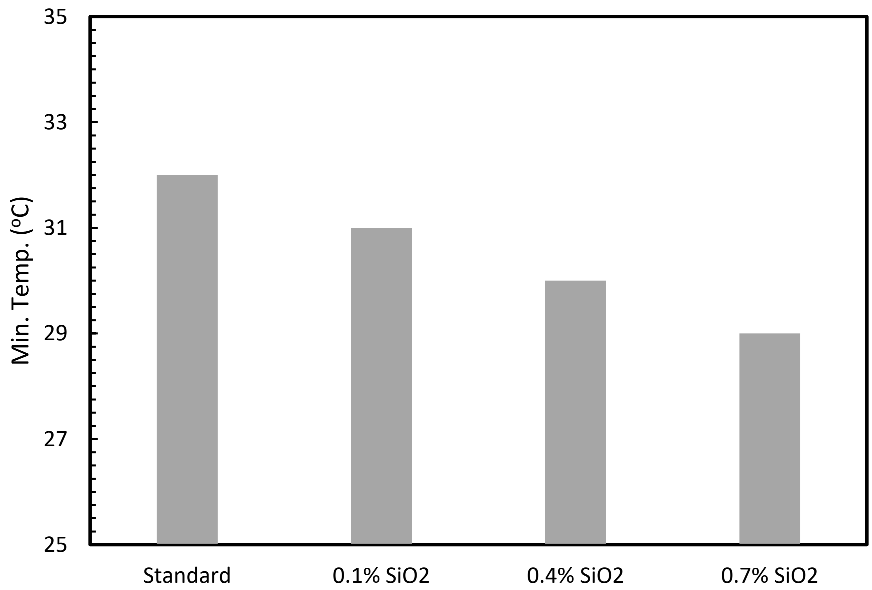


Fig. 6. Minimum temperature with SiO2 nano lubricant volume fractions

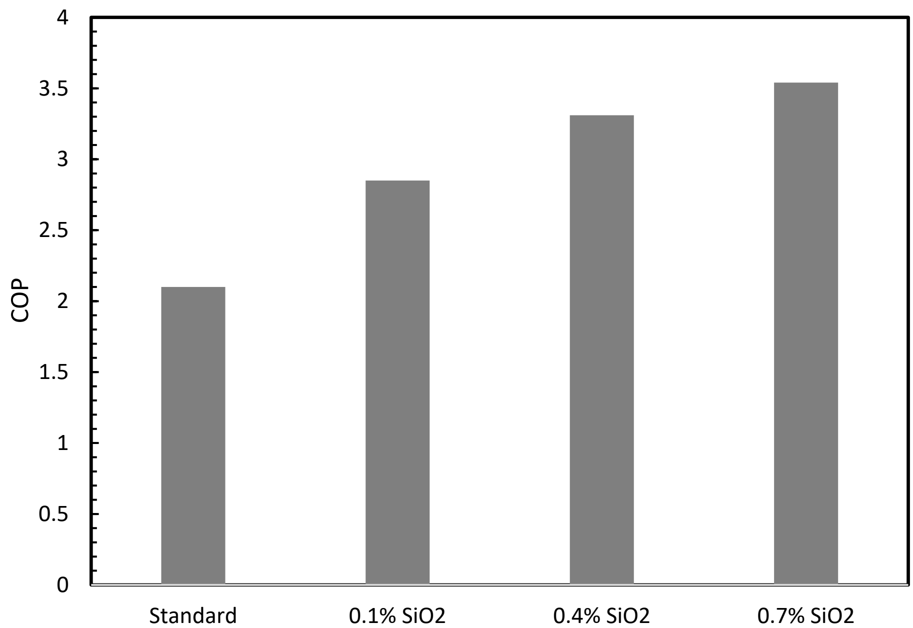


Fig. 7. COP with SiO2 nano lubricant volume fractions

3.2 Potential for Improved Efficiency and Energy Savings

Nano-sized SiO2 particles have been found to be highly promising in enhancing the performance and delivering energy savings of air conditioners. The compressors in these systems are one of the key power consumers and lubricants play a significant role in reducing friction to achieve maximum efficiency. Research conducted previously has shown that incorporating nanoparticles in lubricants increases the effectiveness and performance of air-conditioning systems. Zawawi *et al.,* [28] assessed the application of nanolubricants based on multi-walled carbon nanotubes that led to a 17% decrease in power consumption of compressors compared with conventional oils used for such purposes. This also reveals the possibility that SiO2 nanoparticles can boost air-conditioning systems' energy efficiency. The viscosity of the lubricant used is crucial to system efficiency. High viscosity can impede oil flow and productivity of the system, while low viscosity may cause metal parts in direct contact inside systems. This means that there is a need for careful selection of lubricants with appropriate viscosity balance. Where once the provision of air-conditioning was considered a luxury, it is now already seen as almost fundamental to providing comfort and safety in many buildings; there has become an increased focus on sustainability properties of such systems coupled with energy efficiency within them too. Adding nanoparticles enhances heat transfer mechanisms and results in improved system performance. However, challenges such as stability, distribution, agglomeration, and sedimentation need to be addressed for sustained performance improvement. Overall, the introduction of SiO2 nanoparticles into air-conditioning systems holds great potential for improving efficiency, reducing energy consumption, and enhancing performance as shown in Figure 8. Continued research and development in this field will contribute to the advancement of sustainable and efficient air-conditioning solutions in the automotive industry, ultimately benefiting both inside room and the environment [30-34].

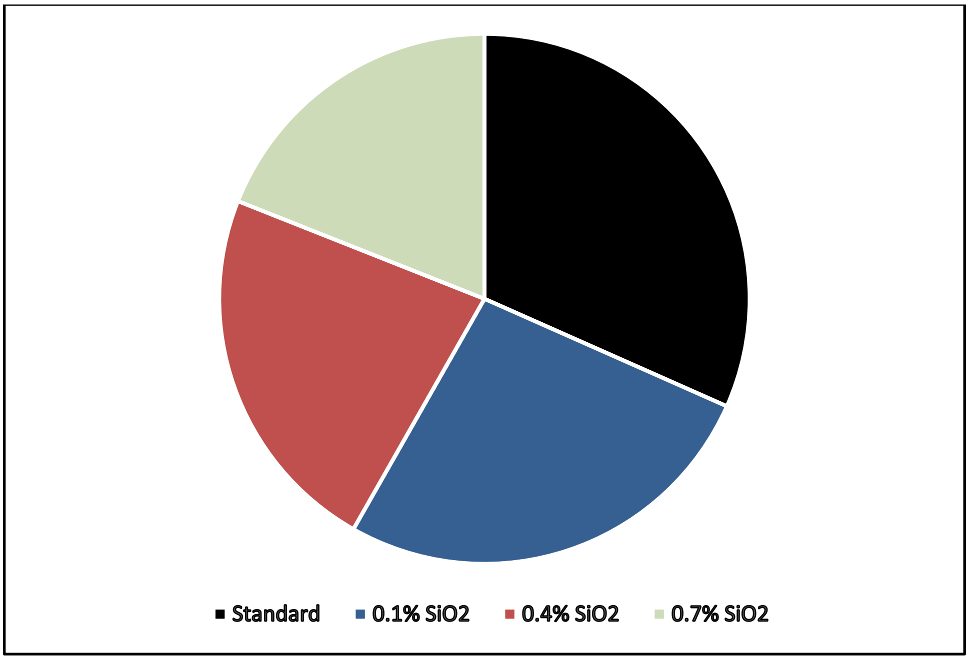


Fig. 8. Energy saving with SiO2 nano lubricant volume fractions

3.3 Work of Compressor

SiO_2 nanoparticles offer environmental benefits in air-conditioning systems. Conventional air-conditioning systems consume a lot of energy and have negative environmental impacts, but SiO2-enhanced systems provide a more efficient alternative. These systems effectively utilize waste heat from the internal combustion engine, reducing energy consumption and improving efficiency. They also use environmentally friendly refrigerants and have fewer moving parts, making them sustainable and efficient cooling solutions for vehicles.

Figure 9, shows the work of compressor for SiO2/POE nano lubricant at different volume fractions. The air conditioning system with SiO2/POE nano lubricant is conducted with lower work of compressor than the standard system. The reduction of compressor work happened for almost all volume concentrations except 0.1% and dropped up to 9% at 0.3% volume fractions. The work of the compressor with SiO2/POE nano lubricant at 0.1% volume fractions indicated a small increment higher than POE lubricants but insignificant.

This discovery is connected to tribology and rheological behaviour. According to the prior literature, the lower nano lubricants than their base lubricants contribute to lowering compressor work in the current investigation via SiO2/POE nano lubricant. The compressor with nano lubricants may run at low power levels, considerably decreasing compressor effort. However, owing to rheological behaviour, increasing the volume percentages of nano lubricants would increase compressor work. The viscosity of nano lubricants rose as the volume concentration increased.

As a result of the large viscosity increase, the compressor work of SiO2/POE nano lubricant is higher than POE lubricants at volume concentrations greater than 0.07%. Though there seem to be some worthwhile challenges that need addressing namely cost parameters, nanoparticle stability when using SiO2 in air conditioning systems holds a lot of promise for efficient and environmentally responsible cooling. These systems provide major environmental advantages compared to the conventional ones, which makes them a suitable choice for moving the auto industry toward sustainability. In conclusion, the use of SiO2 nanoparticles can transform air conditioning by increasing energy efficiency and minimizing environmental effects. Systems with improved SiO2 offer a sustainable and efficient method of cooling systems due to the use of waste heat and enhanced lubricants [32-36].

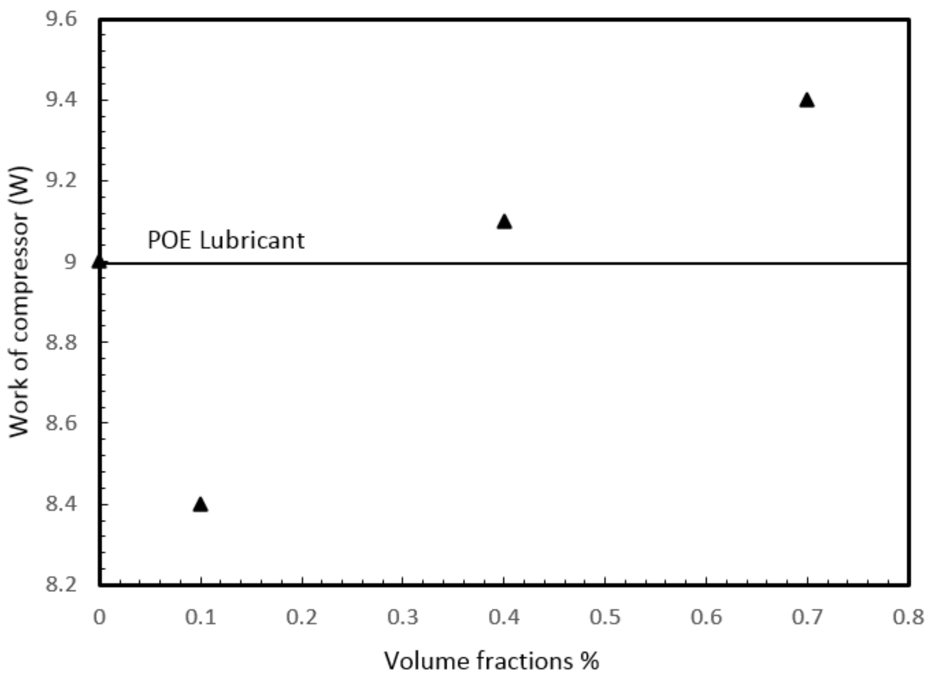


Fig. 9. Work compressor with SiO2 nano lubricant volume fractions

Figure 10 indicates the validation of CFD analysis and the experimental data available in the literature. The performance of air conditioning is increased with nanoparticles concentrations. It was observed that similar behaviour of present work performance with other data [1, 5].

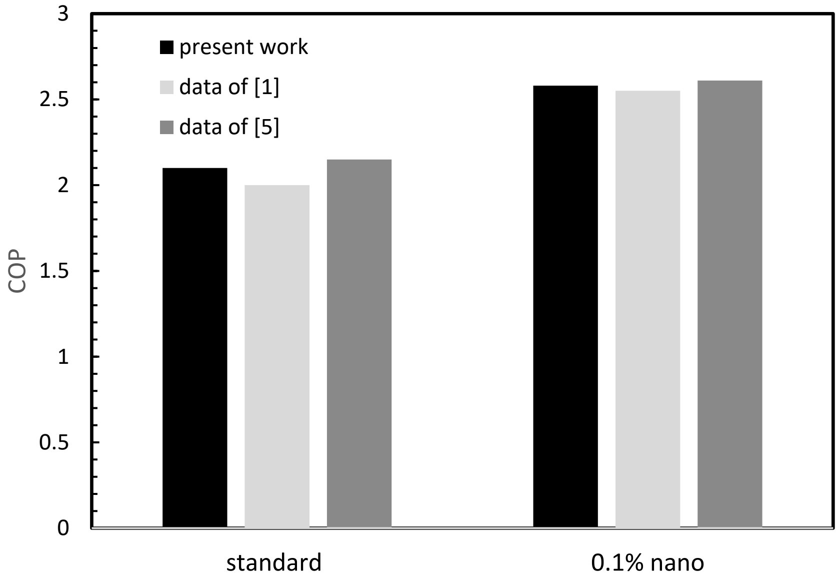


Fig. 10. Validation of CFD analysis with the experimental data available

4. Conclusion

According to the data obtained from different studies, can be argued that using SiO2 nanoparticles in air-conditioning systems has helped improve their performance significantly. One of the main conclusions is that the incorporation of SiO2 nanoparticles in lubricants enhances their thermal and topological characteristics, prolonging life under unfavourable conditions. In the end, this means using less energy and having longer-lasting components. To increase the efficiency of air conditioning systems, high-efficiency components must be included. Modifying a component's design, however, may be expensive and time-consuming. A potential remedy is provided by nanoparticle dispersion technology, which improves system performance without changing the current parts.The conclusions of this study are summarized as:

i. The addition of SiO2 nanoparticles to the oil of the compressor has the potential power to reduce the temperature and time of the cooling system.
ii. The introduction of SiO2 nanoparticles into air-conditioning systems holds great potential for improving COP, reducing energy consumption, and enhancing performance.
iii. SiO2 nanoparticles have the potential to revolutionize air-conditioning by improving energy efficiency and reducing environmental impacts.
iv. 4. Future study should address issues such stability, homogenous distribution, aggregation, sedimentation, high cost, hazardous effects, inadequate stabilisation, erosion effects, high viscosity, and clogging.
v. Additionally, the volume fractions of nanoparticles resulted in significant reductions in compressor work (up to 23%) and power consumption (up to 18%).
vi. By enhancing the thermal and topological properties of lubricants, SiO2 nanoparticles contribute to reducing friction and surface degradation, ultimately leading to energy savings and extended component lifespan.

Acknowledgment
This research was not funded by any grant.

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