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Review of Improving Refrigeration Machine Performance by Adding Nanoparticles to the Refrigeration System Using Computational Fluid Dynamics (CFD) Simulation and Comparing it with Experimental Results

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Abstract-- *In this journal, the author reviews the performance improvement of vapor compression refrigeration machines by adding nanoparticles into the refrigeration system using CFD simulation. This study aims to determine the improvement of refrigeration machine performance by adding nanoparticles into the refrigeration system using CFD simulation and to compare the simulation results with the experimental results. Where the method used in this study is a literature review. The results of the literature study show that the dispersion of nanoparticle additives can affect the increase in the refrigeration system performance coefficient (COP) and can maximize thermal conductivity, heat transfer coefficient, and other heat transfer characteristics so that it can produce lower power consumption. Using the CFD simulation method, the highest increase in refrigeration system performance was obtained through the simulation of* SiO_2 *+ R134a nano refrigerants with a volume concentration of 4% and an increase value of 22.58%. From the experimental results, the highest value was obtained by* Al_2O_3 *+ R134a nano refrigerants with a volume concentration of 0.5% and an increased value of 30.85%. The system's performance showed a significant improvement with the addition of nanoparticles. Therefore, the performance of the refrigeration machine with the addition of nanoparticles in the refrigerant fluid is higher than the system using pure refrigerant fluid (without nanoparticles).*

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1. INTRODUCTION

Nanotechnology is a branch of science and technology that involves modifying and using particles in the atomic and molecular order. These particles can be distinguished, based on their diameter, into three groups, including coarse particles (10000–2500 nm), fine particles (2500–100 nm), and ultra-fine particles or nanoparticles (1–100 nm). Especially in heat transfer applications, using nanoparticles is necessary because using particles with larger sizes can cause problems such as fouling, sedimentation, erosion, and higher pressure drops. In the last few decades, advances in nanotechnology have led to the emergence of a new generation of heat transfer fluids called "nanofluids". Nanofluids are defined as suspensions of nanoparticles in a host fluid. Some nanofluids are ethylene glycol-based copper nanofluids, water-based copper oxide nanofluids, etc. Nanofluids were developed to improve the thermal conductivity of heat transfer fluids, which has now evolved into a promising area of nanotechnology.

Nanorefrigerant is one type of nanofluid, where the base fluid is a conventional pure refrigerant. Experimental studies have shown that nano refrigerants have higher thermal conductivity than base refrigerants [1] [2], and refrigeration systems using nano refrigerants perform better than conventional pure refrigerants. However, the accumulation and sedimentation of nanoparticles in nano refrigerants will minimize the stability of nano refrigerants and limit the application of nano refrigerants in refrigeration systems. Nanorefrigerants are anticipated based on the idea of nanofluids, which are made by mixing nanoparticles and ordinary refrigerants. Three main focus points exist for nanoparticles used in refrigerators [3].

First, nanoparticles can improve the solubility between lubricants and refrigerants. Wang et al. [4] found that TiO_2 nanoparticles can be used as an additive to improve the solubility between mineral oil and hydrofluorocarbon (HFC) refrigerants. A refrigeration system with a mixture of R134a, mineral oil, and nanoparticles performed better by returning more lubricating oil to the compressor. They performed similarly to systems using polyester and R134a.

Second, the refrigerant's thermal conductivity and heat transfer characteristics are increased. Jiang et al. [5] measured the thermal conductivity of nanorefrigerant + R134a and found that the measured thermal conductivity of four kinds of 1.0 vol.% R134a + nanorefrigerant thermal conductivity increased to 82%, 104%, 43%, and 50% respectively.

Third, nanoparticles dispersed in lubricants should reduce the friction coefficient and wear rate. Lee et al. [6] investigated the friction coefficient of mineral oil mixed with 0.1 vol.% fullerene nanoparticles, and the results showed that the friction coefficient decreased by 90% in the evaluation with the raw lubricant, which led us to the conclusion that nanoparticles can improve the efficiency and reliability of the compressor. Jwo et al. [6] conducted a performance analysis of a domestic refrigerator using hydrocarbon refrigerant and 0.1% Al_2O_3 – mineral oil as the working fluid, and the results showed that the power consumption decreased by about 2.4%, and the performance coefficient increased by 4.4%.

In this journal, the author tries to review the improvement of refrigeration machine performance by adding nanoparticles into the refrigeration system using CFD simulation.

The objectives of this study are:

1. To determine the increase in refrigeration machine performance by adding nanoparticles into the refrigeration system using CFD simulation.
2. To determine which nanoparticles have a higher performance increase value than others.
3. To compare the results of CFD simulations with experimental results.

The novelty of this research is that in previous studies, no review has been conducted regarding improving the performance of refrigeration machines by adding nanoparticles to the refrigeration system using CFD simulation.

2. METHODOLOGY

2.1 Research Method

The method used in this research is a literature review, which is a systematic, explicit, and reproducible method to identify, evaluate, and synthesize research works and ideas that have been produced by researchers and practitioners [7]. Where the steps in conducting the literature study are as follows:

- Defining the scope of the topic to be reviewed
- Identifying relevant sources
- Reviewing the literature
- Writing the review
- Applying the literature to the study to be conducted

In this study, the author uses secondary research data obtained from data sources of journals or related national and international articles conducted by previous researchers. In conducting this study, the author searched for research journals published online. The data collection process is carried out by filtering based on criteria determined by the author from each journal taken. The criteria for collecting journals are as follows:

- The year of the literature source taken from 2009 to 2020, the suitability of the writing keywords, the relevance of the writing results, and the discussion.
- Strategy in collecting various literature journals using accredited journal sites such as ProQuest, PubMed, Research Gate, Sage Pub, Scholar, etc.
- Effective writing methods for journal settings include entering keywords according to the writing title and conducting searches based on advanced searches.
- Conducting searches based on full-text
- Conducting an assessment of the journal based on research objectives.

2.2 Research Parameters

The parameters of this research refer to the results of experiments conducted by previous researchers where the stages in the experimental process are as follows:

A. Assumptions For Experimental System

In this study, there are many assumptions related to the experimental system, namely:
- Stable conditions
- Newtonian flow
- One dimension
- No heat generated
- Constant heat flux
- No friction

B. Refrigeration System Component Equations

- Work input into the compressor

By increasing the temperature and pressure of the operating fluid, energy is consumed in the compressor so that the work input is as follows [8]:

$$W_{in} = h_2 - h_1 \qquad (1)$$

Where:
h_1 = Compressor Inlet Enthalpy
h_2 = Compressor Outlet Enthalpy

- Heat transfer obtained from the evaporator

Heat is absorbed from the space conditioned by the evaporator. In this process, the working fluid evaporates with the heat obtained. The equation formula is as follows [8]:

$$Q_{evap} = (h_1 - h_4) \qquad (2)$$

Where:
h_4 = Enthalpy Outlet Evaporator

- Coefficient of Performance (COP)

Refrigeration efficiency is represented as COP, which is equal to the heat obtained from the evaporator divided by the energy consumption in the compressor, where the energy consumption is inversely proportional to the COP, which can be calculated from the following equation [8]

$$COP = \frac{Q_{evap}}{W_{\mathrm{in}}} \qquad (3)$$

- Compressor pressure ratio

The compressor pressure ratio is the refrigeration vapor pressure at the compressor discharge to the vapor pressure at the compressor suction, which is formulated as follows:

$$\mathrm{Pr} = \frac{P_{\mathrm{dIS}}}{P_{\mathrm{SUC}}} \qquad (4)$$

C. Properties of Nanoparticles

First, nanoparticles are added to the lubricating oil, and then the mixture is mixed with refrigerant. There are two steps to calculate the thermophysical properties of the final refrigerant-oil-nano fluid. In the first step, the properties of non-lubricating oil are calculated based on the volume fraction of nanoparticles in the base fluid-lubricating oil, so the mass fraction concentration must be converted into volume fraction concentration as in the following equation:

$$\emptyset = \frac{\omega_n\, \rho_o}{\omega_n\, \rho_o + (1-\omega_n)\rho_n} \qquad (5)$$

The mass fraction of nanoparticle concentration/oil suspension is [9]:

$$\omega_n = \frac{m_n}{m_n + m_o} \qquad (6)$$

The density of nano lubricant oil can be determined from equation (7) [10]. In this study, the volume fraction in the initial equation is modified by the mass fraction:

$$\rho_{n,o} = (1 - \emptyset)\rho_o + \emptyset_n\, \rho_n \qquad (7)$$

The viscosity of nano lubricant oil can be calculated from this equation [10]:

$$\mu_{n,o} = \mu_o\left[\frac{1}{(1-\emptyset_n)\ 2.5}\right] \qquad (8)$$

The thermal conductivity can be found in equation (9) for nano-lubricant oil, while the thermal conductivity of nano-oil refrigerant is determined from equation (10) as shown below:

$$K_{n,o} = K_o\left[\frac{K_n + 2K_o - 2\emptyset n\,(K_o - K_n)}{K_n + 2K_o + 2\emptyset n\,(K_o - K_n)}\right] \qquad (9)$$

The specific heat of nano-lubricant oil and nano-oil refrigerant is calculated through the equation below [11]:

$$C_{p,n,o} = (1 - \emptyset_o)C_{po} + \emptyset_n\, C_{pn} \qquad (10)$$

C. Evaporator Analysis

This section analyzes the evaporator model using Computational Fluid Dynamics (CFD) simulation software. The simulation is carried out in the following 3 steps [12]:

1) Geometry is designed in Space Claim after fetching the required parameters from the test rig.
2) Performing the meshing process.
3) Definition of properties and constraints are placed in FLUENT so that iterations to solve the problem are executed to record the analysis results.

3. STUDY OF NANOPARTICLES IN REFRIGERATION MACHINES USING CFD SIMULATION METHOD

Below, the author has summarized several studies conducted by previous researchers regarding the effect of nanoparticles on refrigeration machines using the CFD simulation method.

In this study, Arslan K. et al. [12] conducted numerical investigations for TiO_2-based nano refrigerant R134a with volume fractions of 0.8%, 2%, and 4%. Commercial CFD software, ANSYS FLUENT 14.5, was used to conduct the numerical studies. The results showed that increasing the volume fraction of nanoparticles in the nano refrigerant increased the convective heat transfer in the channel, but increasing the volume fraction of nanoparticles did not affect the pressure drop in the channel. Adding TiO_2 nanoparticles into R134a with a volume fraction of 4% increased the heat transfer coefficient in the channel up to 9.0% compared to pure R134a (without nanoparticles).

In this study, Che Sidik N.A. et al. [13] conducted numerical simulations for turbulent mixed convection heat transfer in a concentric annulus using Al_2O_3, ZnO, CuO, and SiO_2 nano refrigerants. A three-dimensional grid arrangement was constructed to simulate the geometry using Computational Fluid Dynamics (CFD) software using the finite volume method (FVM). The results showed that SiO_2 had the most significant mussel number, Al_2O_3, ZnO, and CuO, and the lowest value for pure refrigerant (without nanoparticles). The effect of heat flux on the inner and outer walls of the annulus on the heat flow was significant.

Zohud M. et al. [14] This study numerically investigated the flow, heat transfer, and entropy generation of several hydrocarbon-based nano refrigerants flowing in a circular tube at constant heat flux boundary conditions. Numerical tests have been carried out for 4 types of nanoparticles, namely Al_2O_3, CuO, SiO2, and ZnO, with a diameter of 30 nm and a volumetric concentration of 5%. These nanoparticles were dispersed in several hydrocarbon-based refrigerants, namely tetrafluoromethane (R134a), propane (R290), butane (R600), isobutane (R600a), and propylene (R1270). The results showed that propylene had the best heat transfer and pressure drop characteristics among all the hydrocarbon refrigerants tested. CuO as nanoparticles and a volumetric concentration of 5% were the most suitable due to their high thermal and fluid characteristics.

In this paper, Kanthimathi T. et al. [15] investigated the heat transfer coefficient of nano refrigerants based on the different volume concentrations of Al_2O_3 nanoparticles suspended in R134a. The correlations from the existing studies have been used to determine the thermophysical properties such as thermal conduction, viscosity, density, and specific heat of nano-refrigerants. The results showed that the heat transfer coefficient will also increase by increasing the volume concentration of nano refrigerants.

Soheel A.H. et al. [16] This paper presents a numerical investigation and comparison of heat transfer coefficients for eco-friendly refrigerants R134a and R600a with Al_2O_3 and TiO_2 nanoparticles at concentrations of 1, 2, 3, and 4%. The numerical investigation was simulated with a CFD model using ANSYS FLUENT 14.5 software. The results showed that higher heat transfer coefficients increased with increasing concentration of nanoparticles. R134a+TiO_2 nano refrigerant is an excellent nano refrigerant in vapor compression systems because it has higher heat transfer coefficients than other nano refrigerants. The increase in heat transfer coefficient of refrigerant R600a with TiO_2 & Al_2O_3 nanoparticle concentrations is 18.81% and 17%, respectively, then the increase in refrigerant R134a with TiO_2 & Al_2O_3 nanoparticle concentrations is 4.5% and 4% respectively.

Hadi H.S. et al. [17] this study was to study the effect of using nanofluids (Al_2O_3-R22 and Ag-R22). The investigation in this study was carried out experimentally by utilizing a test rig and numerically through the design of a 3D model using Computational Fluid Dynamics (CFD) software, namely ANSYS FLUENT 16.1. The results showed that the cooling effect of the evaporator increased by increasing the mass fraction of nanoparticles. The maximum increase in the refrigeration effect was 5.61% for Al_2O_3 and 8.73% for Ag. COP increased by increasing the mass fraction until it reached a critical point and decreased. The increase in COP for Ag and Al_2O_3 nanoparticles was 9.064% and 6.188% at a mass fraction of 0.15%.

Haque M.E. et al. [18] This study focused on improving the performance and efficiency of refrigerators through CFD analysis and nanotechnology. The aim was to develop a CFD model for airflow and temperature distribution inside the refrigerator. To improve the refrigerator's performance, SiO_2 nanoparticles were added to the compressor lubricant to improve the lubrication of Polyol Ester (POE) oil with a volume concentration of 0.1%. The results showed that the refrigerator's COP increased by 29% when SiO_2 nanoparticles were added to the compressor lubricant.

Moraveji M.K. et al. [19] used CFD to investigate the effect of convective heat transfer on nanofluid flow in the expansion region of the tube with constant heat flux. Nanofluids containing Al_2O_3 and water are a single liquid phase with a nanoparticle size of 150 nm and a volume concentration of 1, 2, 4, and 6%. The results showed that increasing nanoparticle concentration and Reynolds number increased the heat transfer coefficient. Furthermore, the heat transfer coefficient decreased with increasing axial location and particle diameter.

The results of the review related to studies on nano refrigerants carried out by the researchers mentioned above showed an increase in the performance of refrigeration machines using various nano refrigerants, as shown in Table 1 below.

Table 1. Improvement of refrigeration machine performance for various nano refrigerants by CFD simulation method

Researcher	Nano refrigerant	Volume Fraction (%)	Performance Improvements (%)
Arslan K et al.	TiO_2 + R134a	0,8; 2 & 4	0,8; 5,6 & 9,0
Che Sidik N.An et al.	SiO_2 + R134a	4	22,58
Che Sidik N.An et al.	CuO + R134a	4	6,67
Che Sidik N.An et al.	Al_2O_3 + R134a	4	10,00
Che Sidik N.An et al.	ZnO + R134a	4	10,00

Zohud M et al.	Al_2O_3 + R1270	5	15,00
Zohud M et al.	CuO + R1270	5	16,67
Zohud M et al.	SiO_2 + R1270	5	5,0
Zohud M et al.	ZnO + R1270	5	13,33
Kanthimathi T et al.	Al_2O_3 + R134a	1; 2; 3 & 4	9,21; 14,47; 18,42 & 21,05
Soheel A.H et al.	Al_2O_3 + R600a	3 & 4	17,00
Soheel A.H et al.	Al_2O_3 + R600a	3 & 4	18,81
Soheel A.H et al.	TiO_2 + R134a	3 & 4	4,5
Soheel A.H et al.	SiO_2 + R134a	3 & 4	4,0
Hadi H.S et al.	Al_2O_3 + R22	0,15	6,188
Hadi H.S et al.	Ag + R22	0,15	9,064
Moraveji M.K et al.	Al_2O_3 + R134a	1	8,93
Moraveji M.K et al.	Al_2O_3 + R134a	4	12,5
Moraveji M.K et al.	Al_2O_3 + R134a	6	16,07

The results of the review related to studies on nano refrigerants carried out by previous researchers, which involved improving the performance of refrigeration machines for various nano refrigerants using experimental methods. The results of these studies are shown in Table 2 below.

Table 2. Improvement of refrigeration machine performance for various nano refrigerants by experimental methods

Researcher	Nano refrigerant	Volume Fraksi (%)	Peningkatan Kinerja (%)
P.K. Kushwaha et. al	Al_2O_3 + R134a	0,25 & 0,5	10,28 & 12,37
D. Sendil Kumar et. al	Al_2O_3 + R134a	0,2	10,32
Kuljeet Singh et. al	Al_2O_3 + R134a	0,5 & 1	8,5 & 5,4
K. Dilip Kumar et. al	Al_2O_3 + R134a	1,5; 1,7 & 1,9	19,14; 21,6 & 11,22
K.T. Pawale et. al	Al_2O_3 + R134a	0,5 & 1	30,85 & 8,55
V.K. Dongre et al.	Al_2O_3 + R134a	0,3	12,96
Aly M. A. Soliman et. al	Al_2O_3 + R134a	0,1	10,53
F. Selimefendigil et. al	TiO_2 + R134a	0,8 & 1	15,72 & 21,42
Sumit Shinde et. al	SiO_2 + R134a	0,1; 0,2 & 0,3	6,97; 9,9 & 12,68
N.S. Desai et. al	SiO_2 + R134a	1; 2 & 2,5	7,61; 14,05 & 11,9
Sakshi Mishra et. al	CuO + R134a	0,1; 0,7; 1,05 & 1,4	2,17; 2,71; 5,16 & 11,41
V.K. Dongre et al.	CuO + R134a	0,3	13,85
Ahmed J. Hamad	CuO + R134a	0,4	10

4. CONCLUSIONS

1. The review results using the CFD simulation method show that the highest value of the refrigeration system performance improvement was obtained by SiO_2 + R134a nano refrigerant with a volume concentration of 4%, with an increased value of 22.58%. Meanwhile, from the experimental results, the highest value was obtained by Al_2O_3 + R134a nano refrigerant with a volume concentration of 0.5%, with an increased value of 30.85%.
2. With the experimental method and the CFD simulation method, it can be concluded that the dispersion of nanoparticle additives can affect the increase in the refrigeration system performance coefficient (COP) and maximize thermal conductivity, heat transfer coefficient, and other heat transfer characteristics, resulting in lower power consumption.
3. The volume fraction of each nanoparticle, where adjusting the volume fraction will affect the increase or decrease in performance in the refrigeration system.
4. The type of refrigerant used will affect the increase in performance of the refrigeration system, where the increase in performance of each type of refrigerant will differ from that of the other.

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