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EXPERIMENTAL STUDY AND CFD ANALYSIS OF THERMAL PERFORMANCE IMPROVEMENT OF CAR RADIATOR BY CUO/GLYCEROL NANOFLUID

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Abstract: This study investigates the efficacy of CuO/glycerol nanofluid in augmenting the thermal performance of car radiators. Through a combined experimental and Computational Fluid Dynamics (CFD) analysis, the thermal characteristics and heat transfer capabilities of the nanofluid within the automotive cooling system were comprehensively evaluated. The experimental phase involved the implementation of CuO/glycerol nanofluid as a coolant within a typical car radiator setup. Various parameters such as temperature differentials, cooling rates, and overall heat dissipation efficiency were measured and compared against traditional coolants. Results indicated a significant enhancement in heat transfer, showcasing the superiority of the nanofluid in improving the cooling efficiency of the radiator. Complementing the experimental investigation, CFD simulations were conducted to delve deeper into the fluid dynamics within the radiator system. The simulations provided insights into flow characteristics, velocity profiles, pressure distributions, and temperature gradients. These findings elucidated the mechanisms behind the improved thermal performance facilitated by the CuO/glycerol nanofluid, validating the experimental observations. The synergy between experimental validation and computational simulations underscores the viability and effectiveness of CuO/glycerol nanofluid in enhancing car radiator efficiency. The study's outcomes suggest promising prospects for integrating nanofluid technology into automotive cooling systems, potentially paving the way for more efficient and sustainable thermal management solutions in the automotive industry.

Index Terms **- Automotive radiator, Heat transfer, CuO/Glycerol, CFD.**

I. INTRODUCTION

The Roman hypocaust is a historical example of a radiator used to heat building spaces. Russian businessman Franz San Galli, who was born in Prussia and now resides in St. Petersburg, is credited with creating the heating radiator around 1855. Radiators are used for both heating and cooling; thermal energy is converted from one mode to another using radiators. In addition to electronics, radiators are used in cars and buildings. Although their primary function may be to heat the surrounding air, radiators also serve as a supply of coolant for the cooling of automobile engines. The efficient removal of heat from automotive engines is crucial for maintaining optimal operating conditions and preventing overheating. Car radiators play a vital role in dissipating this excess heat, ensuring the engine operates within a safe temperature range. However, conventional radiator designs and cooling fluids have limitations in their heat transfer capabilities. To overcome these limitations, researchers and engineers have been exploring the use of nanofluids as an innovative approach to enhance heat transfer performance. Nanofluids consist of a base fluid, such as water, dispersed with nanoparticles, which can significantly improve thermal conductivity and convective heat transfer properties. In this report, we present an experimental and numerical analysis of heat transfer enhancement in a car radiator using a copper (Cu) nanofluid with water as the base fluid. Copper nanoparticles are chosen due to their excellent thermal conductivity, stability, and compatibility with the coolant system. The objectives of this study are twofold: firstly, to investigate the heat transfer characteristics of the Cu nanofluid in comparison to pure water as the coolant, and secondly, to numerically simulate and analyze the fluid flow and heat transfer performance within the radiator. The experimental analysis involves conducting tests on a prototype car radiator, where the coolant is replaced with the Cu nanofluid. Various parameters such as inlet and outlet temperatures, coolant flow rate, and pressure drop across the radiator will be measured and compared with the results obtained using pure water as the coolant. These experiments will provide valuable insights into the heat transfer enhancement potential of the Cu nanofluid. The findings from this study will contribute to the understanding of the thermal performance improvement achievable by implementing Cu nanofluids in car radiators. The results can aid in the development of more efficient and effective cooling systems, leading to improved engine performance, reduced fuel consumption, and lower emissions.

1.1 NANO FLUID

To evaluate their superiority over the base fluid, the numerical research of a three-dimensional laminar flow and heat transfer utilizing two different nano-fluids, CuO and a Glycerol mixture, travelling through the tubes of an automobile radiator may also be conducted. A liquid (often Glycerol) is cooled by air in radiators, which are critical components in the control of engine temperature in automobiles. The liquid travels through flat tubes, whereas the air travels through channels created by fin surfaces. Nanometer-sized materials offer unique optical, electrical, and thermal properties and are now often used in traditional industries as a result of recent advancements in nanotechnology. Recently, it has been discovered that nanoparticles can disperse in typical heat transfer fluids like water, ethylene glycol, and engine oil. It develops a new class of very effective heat exchange fluids called nanofluids. Many practical and theoretical studies have been conducted, and it has been determined that these new heat exchanger coolants are outstanding.

1.2 NANO-FLUID PREPARATION

Fabrication Methods of Nanofluids. The production procedures for One-Step Method and Two-Step Method are the two main categories into which nanofluids can be separated. When the One-Step Method technology is applied, nanoparticles are generated or suspended instantaneously inside the base fluid. The pre-synthesis of using nanoparticles in a two-step process is followed by their mixing or dispersion into the base fluid. Regarding particle dispersion, scalability, cost, and the ensuing stability of the nanofluid, each approach offers benefits and cons. The size of the nanoparticles, surface modification, and base fluid selection all affect how well the resulting nanofluid performs and is efficient in a given application. A fluid known as a nano fluid has particles suspended in it that are smaller than a nanometer. When compared to larger particles of the same material, nanoparticles are a class of materials with unique physical and chemical properties. Experiments remain the most dependable source of knowledge when dealing with complex flow situations like multiphase flows, boiling, or condensation. In order to create Nano fluids, the two-step method employs a two-stage process in which Nanoparticles are first prepared as a dry powder and then dispersed into a base fluid in a subsequent processing phase. Although some agglomeration may happen during the production, storage, and dispersion of nanoparticles, it is well known that these agglomerates can be broken up into smaller pieces with comparatively little energy. Because of this, even agglomerated Nano crystalline powders can be successfully dispersed in fluids and display desired qualities. This two-step process is effective in various applications, particularly for oxide and nonmetallic nanoparticles. In this experiment, the Nano fluid was made utilizing a two-step process. The nanoparticle was taken in a precise quantity. A mechanical stirrer was used to make sure that it was well combined with the water. To lessen the agglomeration issue, it was put in a sonicator and subjected to vibrations. The nanofluid was kept still for two days to check for sedimentation. After two days, there was no noticeable sedimentation, and the most important fact is that when it was stirred once again, it changed into a homogenous fluid with evenly suspended nanoparticles.

1.3 SPECIFICATION OF NANO-FLUID

The Detailed Specification of Material used for Experimentation

Table.1.1: Characteristics of Copper Oxide

Material	Specification		
COPPER OXIDE	Chemical formula	CuO	
	Appearance	Black	
	Crystal structure	monoclinic	
	Density	6.310 g/cm^3	

Table.1.2: Characteristics of Glycerol

Material	Specification		
GLYCEROL	Density	1.261g/cm^3	
	Melting point	17.8°C	
	Viscosity	1.412Pas	
	Flash point	160°C	

Table.1.3.: Specification of different Concentration Ratio

Particular		Concentration Ratio (Ø)		
		0.25	**0.5**	**0.75**
Velocity of Nano fluid in m/s	ϑ	1.00	1.00	1.00
Heat transfer of Nanofluid in W/m^2 k	h	125.41	163.02	205.31
Specific heat of Nano fluid in J/kg ºC	C_p	2406.27	2382.99	2306.19
Viscosity of Nanofluid in Ns/m^2	μ	0.9578	0.9636	0.9684
Density of Nano fluid in kg/m^3	ρ	1273.84	1286.69	1299.54
Density of Base fluid in kg/m^3	ρ_b	1.1556	1.1556	1.1556
Hydraulic Diameter in m	d_h	0.01125	0.01125	0.01125
Mass of air in kg/sec	$\dot{m}a$	1.0907	1.0907	1.0907

1.4 SOFTWARE

Computer-aided design, or CAD, is the use of computers and graphics software to support or enhance product design, from conceptualization to documentation. The term "CAD system" most frequently refers to the use of an interactive computer graphics system. Systems for computer-aided design are effective tools for geometric modelling and mechanical design of goods and components. Mechanical design CAD software can generate raster graphics that represent the overall appearance of created items, or it can employ using vector-based graphics to depict the traditional drafting's items. But it involves more than just forms. Similar to manual drafting of technical and engineering drawings, the output of CAD must convey information, including materials, techniques, measurements, and tolerances, in compliance with application-specific regulations. Ansys' computational fluid dynamics (CFD) products enable engineers to make decisions more rapidly and efficiently. Our certified CFD simulation products are well acknowledged for their accurate results and great computational capability. Enhance the performance and safety of your product while requiring less time and effort to develop. Our program for computational fluid dynamics is very powerful, easy to use, and accelerates the development of new products. Ansys CFD tools are being used more and more due to the push to optimize goods and increasingly reducing error margins enable you to make remarkable advancements through innovation. A branch of fluid mechanics known as computational fluid dynamics, or CFD, uses numerical methods and algorithms to study and resolve fluid flow issues. The millions of Computers perform the calculations required to simulate the interactions of gases and liquids on the complex surfaces used in engineering. Still, even with powerful supercomputers and simplified equations, only approximations may be obtained in many scenarios.

II. EXPERIMENTAL SETUP

Because of its effective heat exchange design, using automobile radiators as part of an experimental setup for nanofluids can be a creative method. The experimental setup consists of a storage tank, thermometers, temperature indicators, a fan, a flow controller radiator, a centrifugal pump, and heaters. Radiator coolant is pumped throughout once it has been heated in a heat source. Globe valves can be used to control the constant rate that the pump provides. The sole type of insulation used for the piping in the text section is asbestos rope. Forced convection causes coolant heat to be rejected to the outside with the help of the radiator fan. The fins on the radiator speed up heat transfer. The coolant is once again making its way back to the source of heat. Figure 2.1 depicts a standard Schematic Radiator Test Rig.

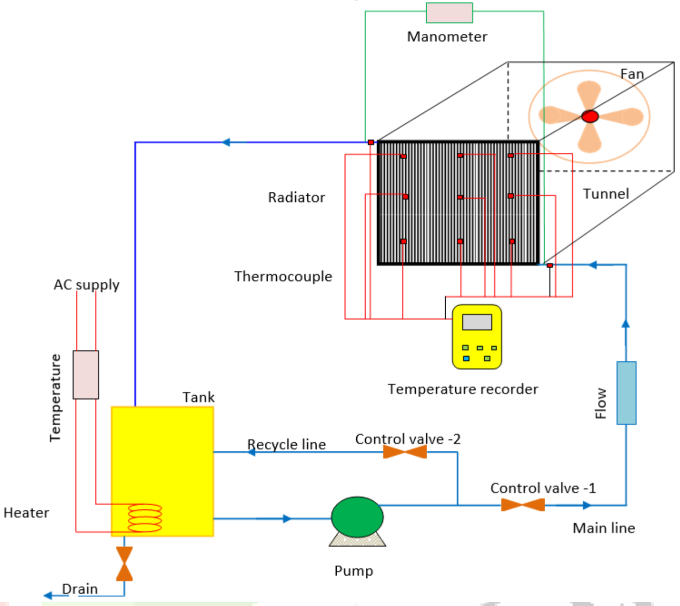


Fig.2.1: Schematic Radiator Test Rig

2.1 CALCULATIONS

1. To determine the base fluid's density and the nanofluid's specific heat,

$$PV = mRT$$

$$\rho = \frac{P}{R} \times T$$

Using the various correlations that are now accessible, the thermal and flow parameters of a nanofluid are computed as follows:

2. Timofeeva correlations for thermal conductivity as shown below,

$$K_{nf} = [1 + 3\emptyset]K_b$$

3. Using the following Drew and Passman correlation, determine the viscosity of the nanofluid,

$$\mu_{nf} = \mu_{bf} \times \frac{1}{(1-\emptyset)^2}$$

4. The Density with the following Pak and Cho connections,

$$\rho_{nf} = (1-\emptyset)\rho_{bf} + \emptyset\rho_{nf}$$

5. The specific heat utilizing the following Pak and Cho connections,

$$C_{nf} = \frac{(1-\emptyset)(\rho C)_{bf} + \emptyset(\rho C)_{p}}{\rho_{nf}}$$

6. The following represents the rate of heat transfer coefficient between the radiator's coolant and airflow,

$$Q_{nf} = \dot{m}_{nf} \times Cp_{nf} \times (T_i - T_o)$$
$$Q_{bf} = \dot{m}_{b} \times Cp_{b} \times (T_{ob} - T_{ib})$$

7. Effectiveness between coolant and airflow in radiator as below,

$$\varepsilon = \frac{\dot{m}_{nf} \times Cp_{nf} \times (T_i - T_o)}{\dot{m}_{b} \times Cp_{b} \times (T_i - T_{ib})}$$

8. Flow velocity of the fluid as below,

$$\vartheta = \frac{V}{A_c}$$

9. Area of cross section of Radiator as below,

$$A_c = \frac{\pi}{4} \times d^2$$

10. Surface Area of Radiator as below,

$$A_s = P \times L$$

11. Perimeter of radiator as below,

$$P = \pi d + 2(D - d)$$

12. Hydraulic diameter of radiator tube as below,

$$d_H = \frac{4A_c}{P}$$

13. Reynolds number can be calculated by using equation,

$$Re = \frac{\rho \vartheta d_H}{\mu}$$

14. The equation can be utilized in determining the heat transfer coefficient,

$$Q = h \times A \times \Delta T$$

15. Nusselt number can be calculated by using equation,

$$Nu = \frac{h d_H}{k}$$

16. Prandtl number can be calculated by using equation,

$$Pr = \frac{\mu\, C_p}{k}$$

III. RESULTS AND DISCUSSION

A study that combines computational fluid dynamics (CFD) analysis and experimentation to examine the use of CuO/glycerol nanofluid to improve the thermal performance of an automobile radiator may produce informative outcomes. The experiment was conducted at mass flow rates of 5LPM using coolant at varying volume concentrations of 0.25%, 0.5%, and 0.75%. Throughout the experiment, the air's velocity at the radiator remains constant. According to the experimental inquiry, nanofluids have a higher heat transfer rate than basic coolant. A 65.83% boost in heat transmission is observed at a volume concentration of 0.75%. Although the radiator's coolant inlet temperature variance has a modest impact on the rate at which heat is transferred by a nanofluid is improved by raising the working fluid flow rate. This advancement in heat transmission could result in lighter, smaller radiators, which would save money both up front and over time. The nanoparticle volume concentration in the nanofluid increases as does the coolant's temperature differential between the inlet and outflow. Nanofluid in the graph exhibits superior temperature rejection. The volume concentration of nanoparticles in the nanofluid increases, Additionally, the Heat Transfer Rate rises. In the graph, the nanofluid's rate of heat transfer is higher. The volume concentration of nanoparticles in the nanofluid increases along with the radiator's efficacy. In summary, nanofluids are more heat-transmitting than traditional coolants, and their applications are only going to grow. They can work well in many different heat transfer applications. Additionally, it is shown that although the use of nanofluids appears promising, there are a number of obstacles facing the field's advancement. When employing nanofluids, two important considerations are their stability and cost of manufacture. Furthermore, the CFD study would have provided insightful information about the radiator's heat transfer processes and fluid flow behavior. It could have aided in comprehending the minute aspects of how the nanofluid enhances heat dissipation, potentially reduces hotspots, and interacts with the radiator surfaces. Careful consideration must be given to elements like as the stability of the nanofluid, its long-term impacts on the radiator material, and practical issues in mass production.

The fig.3.1 shows the Nano-fluid and air temperature distribution along the radiator from the above figure we can get the Inlet Temperature (T1) is 373K and Outlet Temperature (T2) 358K respectively.

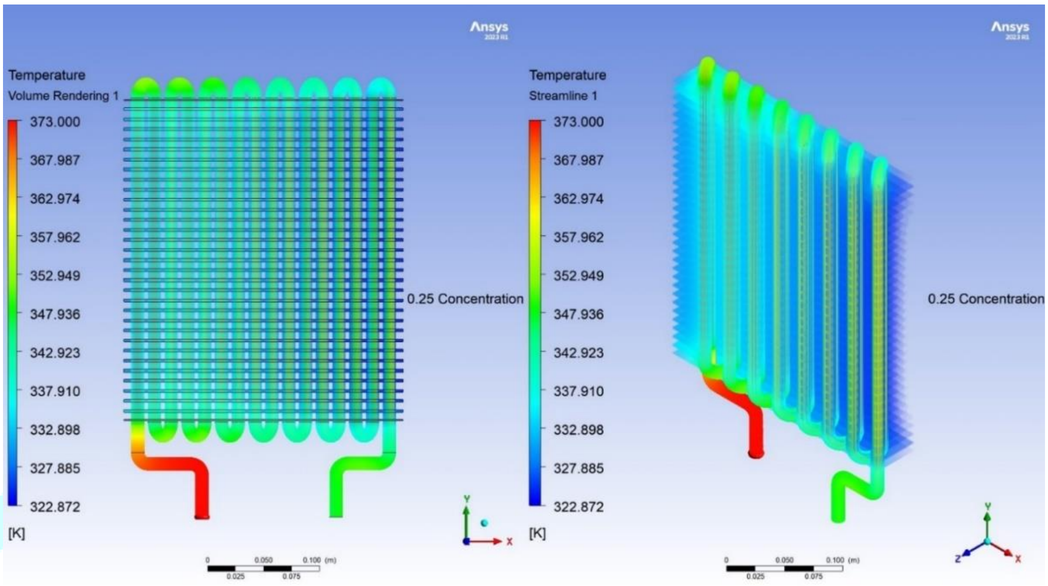


Fig.3.1: Schematic Radiator with Inlet and Outlet Flow Temperature for 0.25 Concentration

The fig.3.2 shows the Nano-fluid and air Velocity distribution along the radiator from the above figure we can get the Inlet Velocity is 1.00 m/s and Outlet Velocity 0.911 m/s respectively.

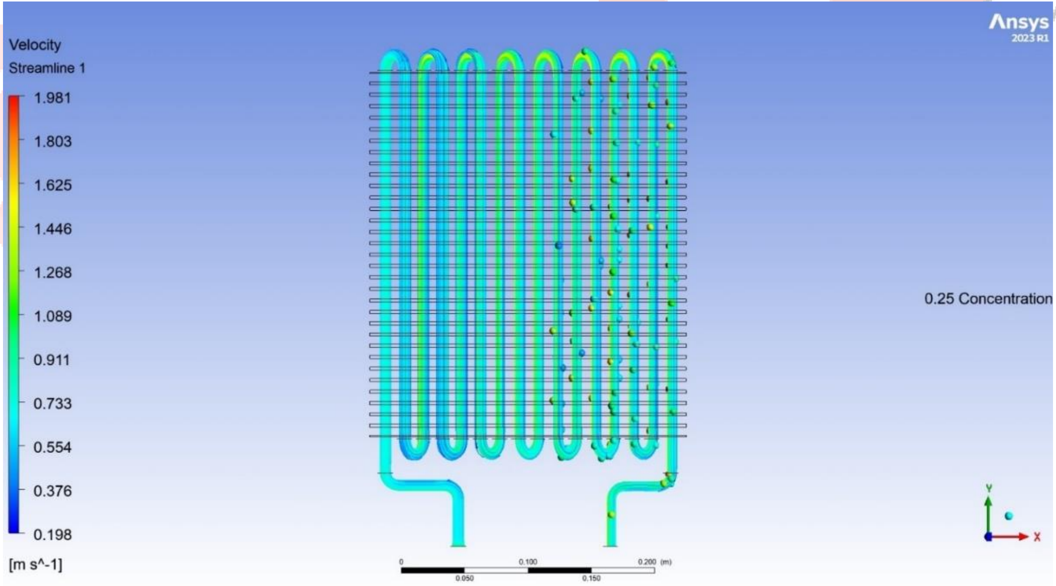


Fig.3.2: Schematic Radiator with Inlet and Outlet Flow Velocity for 0.25 Concentration

The fig.3.3 shows the Nano-fluid and air temperature distribution along the radiator from the above figure we can get the Inlet Temperature (T1) is 363K and Outlet Temperature (T2) 347K respectively.

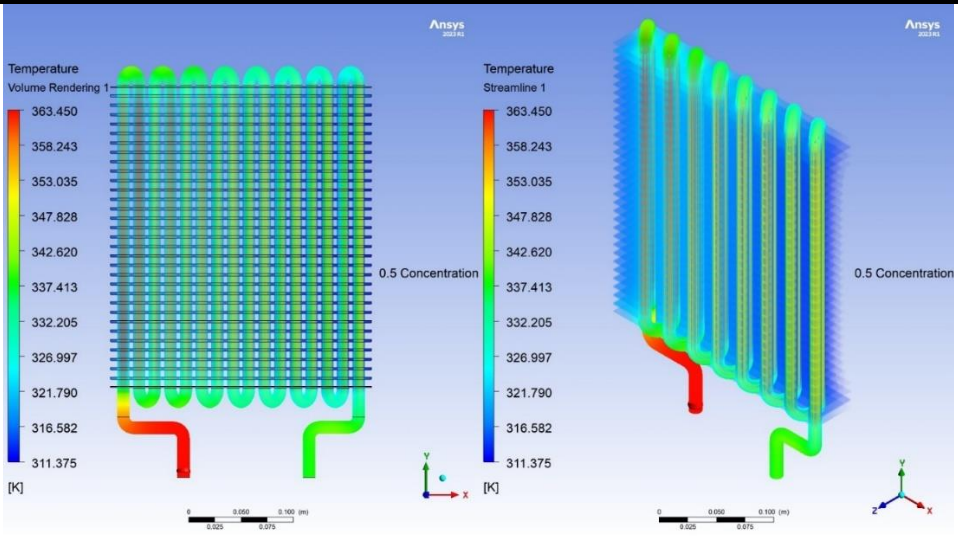


Fig.3.3: Schematic Radiator with Inlet and Outlet Flow Temperature for 0.5 Concentration

The fig.3.4 shows the Nano-fluid and air Velocity distribution along the radiator from the above figure we can get the Inlet Velocity is 1.00 m/s and Outlet Velocity 0.911 m/s respectively.

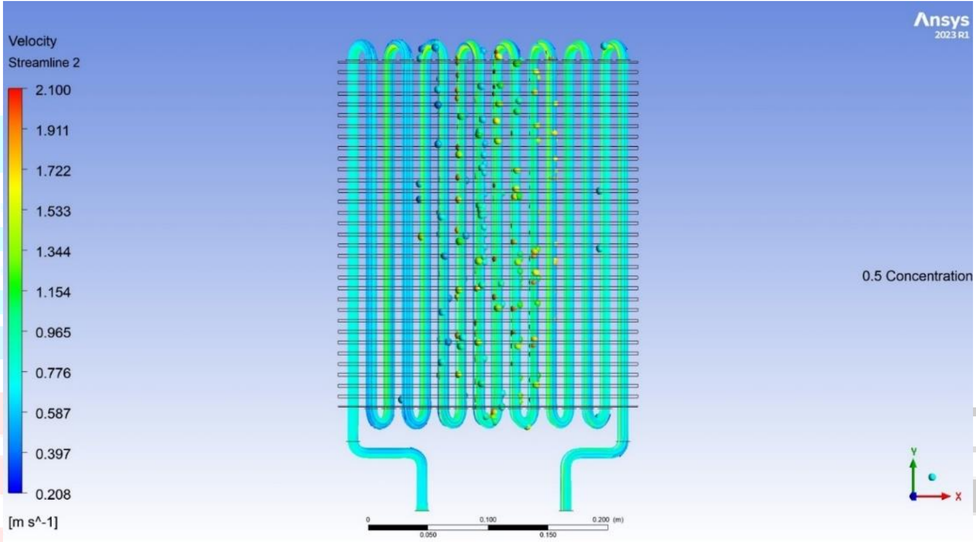


Fig.3.4: Schematic Radiator with Inlet and Outlet Flow Velocity for 0.5 Concentration

The fig.3.5 shows the Nano-fluid and air temperature distribution along the radiator from the above figure we can get the Inlet Temperature (T1) is 354K and Outlet Temperature (T2) 338K respectively.

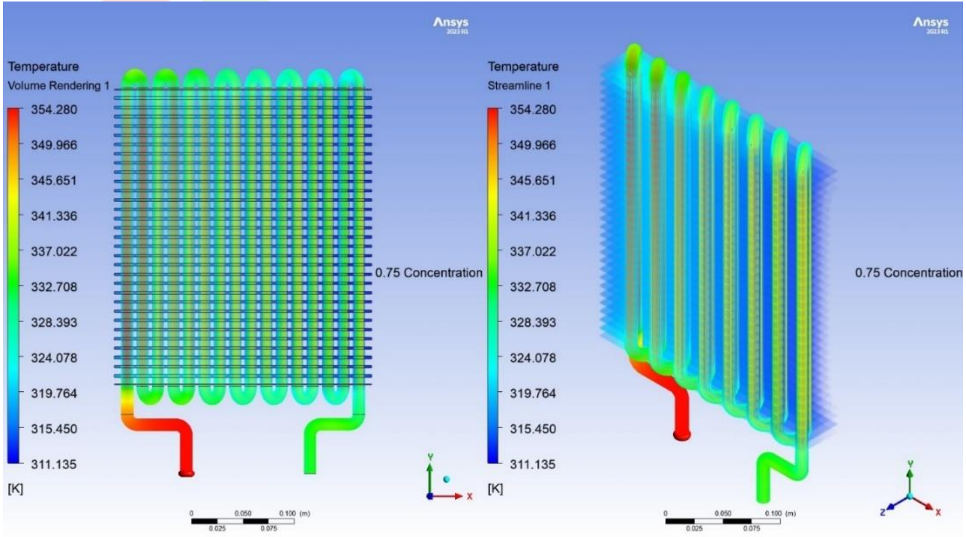


Fig.3.5: Schematic Radiator with Inlet and Outlet Flow Temperature for 0.75 Concentration

The fig.3.6 shows the Nano-fluid and air Velocity distribution along the radiator from the above figure we can get the Inlet Velocity is 1.00 m/s and Outlet Velocity 0.911 m/s respectively.

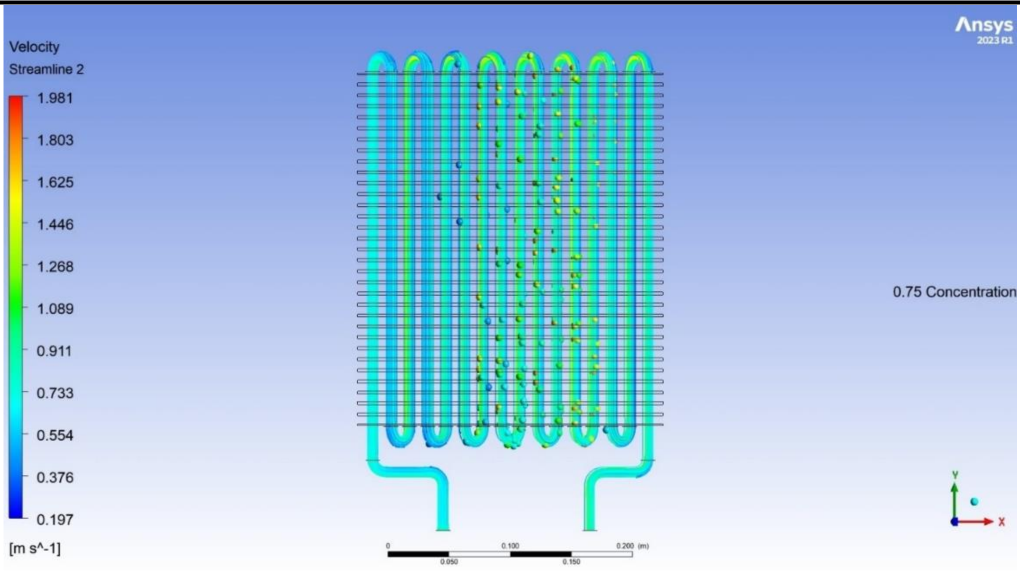


Fig.3.6: Schematic Radiator with Inlet and Outlet Flow Velocity for 0.75 Concentration

Table.3.1.: Results of different Concentration Ratio

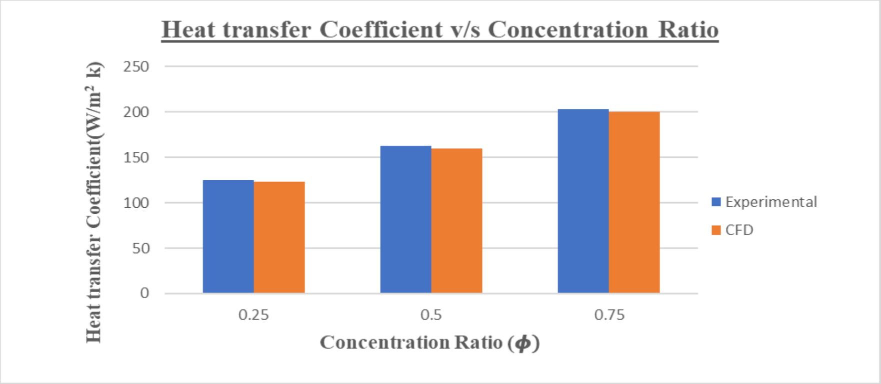
Particular		**Concentration Ratio (Ø)**		
		0.25	**0.5**	**0.75**
Thermal conductivity in W/m k	k	0.28713	0.28927	0.29145
Rate of Heat transfer coefficient in W	Q_{nf}	3637.25	3952.86	4061.36
Velocity of Nano fluid in m/s	ϑ	1.00	1.00	1.00
Heat transfer of Nanofluid in W/m^2 k	h	125.41	163.02	205.31
Specific heat of Nano fluid in J/kg °C	C_p	2406.27	2382.99	2306.19
Viscosity of Nanofluid in Ns/m^2	μ	0.9578	0.9636	0.9684
Density of Nano fluid in kg/m^3	ρ	1273.84	1286.69	1299.54
Density of Base fluid in kg/m^3	ρ_b	1.1556	1.1556	1.1556
Area of Cross section in m^2	A_c	7.85×10^{-5}	7.85×10^{-5}	7.85×10^{-5}
Surface area in m^2	A_s	0.1749	0.1749	0.1749
Perimeter of radiator in m	P	0.0354	0.0354	0.0354
Effectiveness	ε	0.08073	0.07923	0.07854
Hydraulic Diameter in m	d_h	0.01125	0.01125	0.01125
Mass of air in kg/sec	$\dot{m}a$	1.0907	1.0907	1.0907
Renyolds Number	Re	14.96	15.022	15.09
Nusselt Number	Nu	4.9136	4.9756	5.0436
Prandtl Number	Pr	8034.979	8035.042	8035.112

An increase in the concentration of particle volume leads to an increase in the coolant fluid's thermal conductivity. The volume fractions of 0.25, 0.50, and 0.75 have average increments of 42.5%, 60%, and 79.27% respectively. Particle volume concentration increases cause the coolant fluid's density to rise. The volume fractions of 0.25, 0.50, and 0.75 have average increments of 39.70%, 56.83%, and 66.39%, respectively. Specifically, Heat The coolant fluid capacity decreases with an increase in particle volume concentration. Volume fractions of 0.25, 0.50, and 0.75 have average falls of 17.78%, 27.57%, and 33.77%, respectively. The rate of heat transmission is increased when CuO nanoparticles are added to the base fluid, such as glycerine. The average rate of heat transfer increment is 39.48%, 54.12%, and 65.83% for volume fractions 0.25, 0.50, and 0.75, respectively. Particle volume concentration increases cause the coolant fluid's dynamic viscosity to rise. The volume fractions of 0.25, 0.50, and 0.75 have average increments of 38.46%, 55.55%, and 65.21%, respectively. According to the experimental inquiry, nanofluids have a higher heat transfer rate than basic coolant. A 65.83% boost in heat transmission is observed at a volume concentration of 0.75%. Although the radiator's coolant inlet temperature variance has a modest impact on the rate at which heat is transferred by a nanofluid is improved by raising the working fluid flow rate.

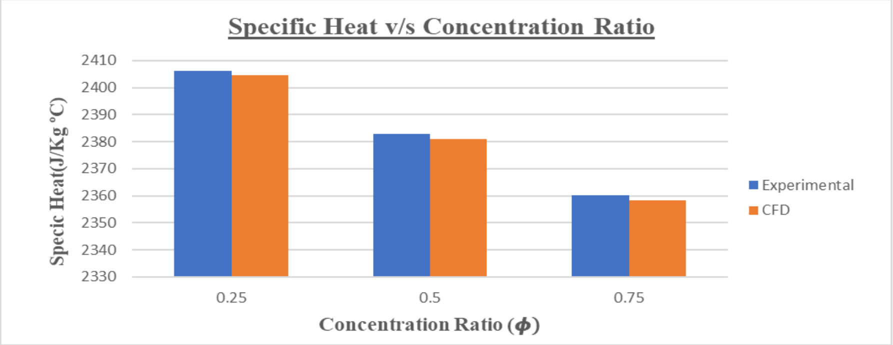
Table.3.2.: Experimental and CFD Calculation Validation

Particular			Concentration Ratio Ø		
			0.25	**0.5**	**0.75**
Heat transfer Coefficient in W/m^2 k	h	Experimental	125.41	163	203
		CFD	123.40	160	200
Specific Heat in J/kg ºC	C_p	Experimental	2406.27	2382.99	2360.19
		CFD	2404.70	2380.99	2358.19
Density in kg/m^3	ρ	Experimental	1273.84	1286.69	1299.54
		CFD	1272.40	1285.80	1298.50
Thermal Conductivity in W/m k	k	Experimental	0.28713	0.28927	0.29141
		CFD	0.28701	0.28904	0.29130
Dynamic Viscosity in Ns/m^2	μ	Experimental	0.9578	0.9636	0.9684
		CFD	0.9576	0.9634	0.9680

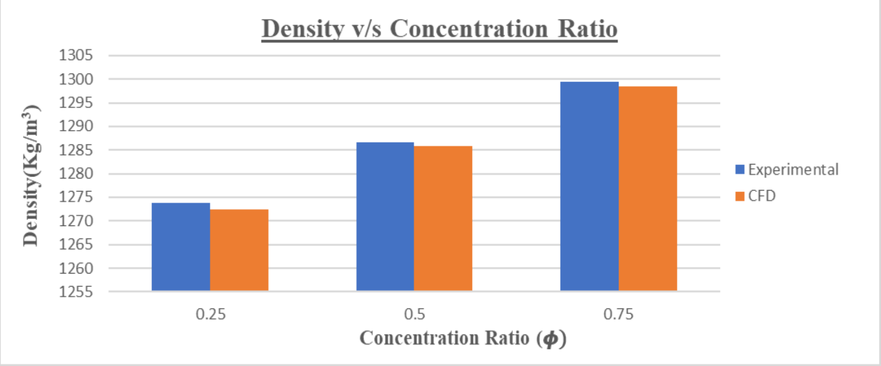
Graphical representation of Experimental values and CFD for Different concenteration of nano-fluids for h, C_p, ρ, k, μ in fluent flow.



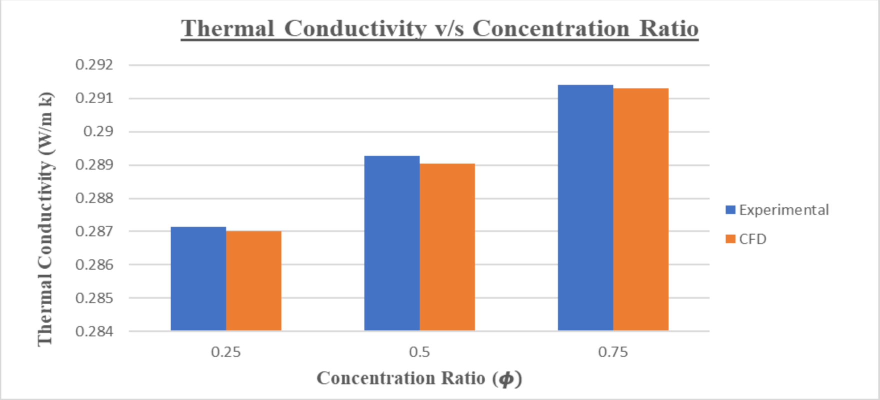
Grph.3.1: Heat transfer coefficient variation (Exp & CFD) at varying concentrations



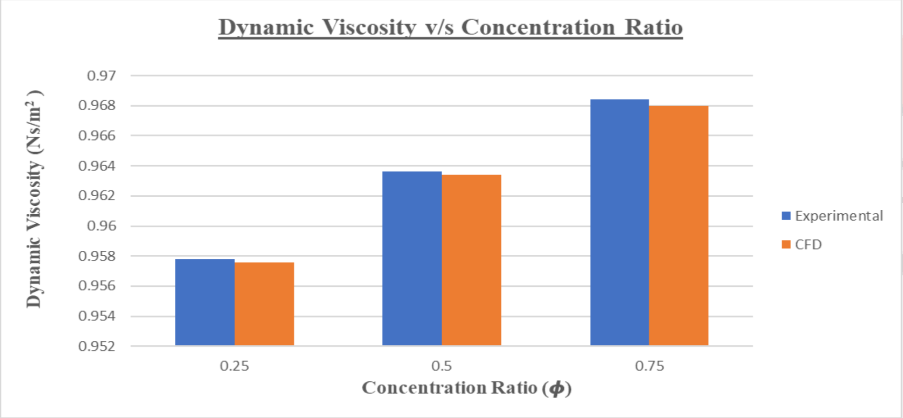
Grph.3.2: Specific Heat Variation (Exp & CFD) for Various Concentrations



Grph.3.3: Density Variation (Exp & CFD) for Various Concentrations



Grph.3.4: Thermal Conductivity Variation (Exp & CFD) for Various Concentrations



Grph.3.5: Dynamic Viscosity Variation (Exp & CFD) for Various Concentrations

The following graphs show the graphical depiction of the experimental and CFD analyses: Graphs 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6. Illustrates the distinction between specific heat and concentration ratio, heat transfer rate and concentration ratio, Density and Concentration ratio, Thermal Conductivity and Concentration ratio, Dynamic Viscosity and Concentration ratio, between CFD and Theoretical validation.

IV CONCLUSION

According to the experimental inquiry, nanofluids have a higher heat transfer rate than basic coolant. A 65.83% boost in heat transmission is observed at a volume concentration of 0.75%. Although the radiator's coolant inlet temperature variance has a modest impact on the rate at which heat is transferred by a nanofluid is improved by raising the working fluid flow rate. This advancement in heat transmission could result in lighter, smaller radiators, which would save money both up front and over time. The nanoparticle volume concentration in the nanofluid increases as does the coolant's temperature differential between the inlet and outflow. Nanofluid in the graph exhibits superior temperature rejection. The volume concentration of nanoparticles in the nanofluid increases, Additionally, the Heat Transfer Rate rises. In the graph, the nanofluid's rate of heat transfer is higher. The volume concentration of nanoparticles in the nanofluid increases along with the radiator's efficacy. In summary, nanofluids are more heat-transmitting than traditional coolants, and their applications are only going to grow. They can work well in many different heat transfer applications. Additionally, it is shown that although the use of nanofluids appears promising, there are a number of obstacles facing the field's advancement. When employing nanofluids, two important considerations are their stability and cost of manufacture.

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