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HEAT TRANSFER ENHANCEMENT OF AN AUTOMOBILE ENGINE RADIATOR USING AL_2O_3/CuO WATER BASE NANOFLUIDS

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Abstract

This study investigates convective heat transfer and the performance characteristics of a uniformly heated car radiator using Al_2O_3–Cu/water nanofluids. The experimental approach involves preparing nano-composite powders of Al_2O_3 and CuO suspended in water through a sonication process. Various combinations of these nanoparticles, with concentrations ranging from 0.1% to 1%, are examined alongside different flow rates from 3.5 to 4.5. The fluid enters the system uniformly at 50°C, and experimental results reveal varying Nusselt and Reynolds numbers at different concentrations and flow rates. Specifically, 1% CuO/water nanofluids exhibit slightly higher heat transfer coefficients compared to other volume concentrations and flow rates of Al_2O_3/water nanofluids. Empirical correlations for Nusselt number and friction factor align well with the experimental data. Additionally, Computational Fluid Dynamics (CFD) simulations are performed using ANSYS 18.0 Fluent to model the car radiator design, employing a coarse mesh and applying boundary conditions. The analysis shows laminar flow, and the CFD results are in close agreement with the experimental findings, depicting temperature, velocity, and pressure contours.

Keywords: Heat Transfer in Internal flows, Radiator, Volume concentrations, flow rates

NOMENCLATURE

Re	Reynolds number	Nu	Nusselt number
V	Velocity (m/s)	f	Friction factor
D	Diameter (mm)	ΔP	Pressure drop, (Pa)
Pr	Prandtl number	L	Length of the tube (mm)
Cp	Specific heat capacity (J/kg-K)	R	Radius of dimple (mm)
K	Thermal conductivity (W/m-K)	P	Pitch (mm)
Q	Heat transfer rate (W)	**Greek symbols**	
H	Convection heat transfer coefficient (W/m^2-K)	ρ	Density (kg/m^3)
A	Surface area (m^2)	μ	Dynamic viscosity (N-s/m^2)
T	Temperature (K)	Φ	volume concentration
Q	Heat flux (W/m^2)		

1. Introduction:

Theoretically, it is widely acknowledged that employing nanoparticles can enhance the effectiveness of heat transfer. This research project delves into the practical application of Nano fluids within a heat exchanger experiment.

Nano-fluids are a type of engineered colloid that combines a base fluid with Nano particles, typically ranging in size from 1to100nm. These Nano-fluids demonstrate higher thermal conductivity and improved heat transfer coefficients when compared to the original base fluids. The concept of Nano-fluids involves utilizing suspended metallic or non-metallic nanoparticles in the base fluids to create a new type of heat transfer fluid. The heat transport capabilities of Nano-fluids are influenced by factors such as the properties and size of the nanoparticles, as well as the concentration of solid particles in the fluid.

. This study explored the convective heat transfer properties of silver-water nanofluids across laminar, transition, and turbulent flow regimes. [1].Nano fluid is a suspension of nanoparticles with superior thermal, rheological, and wettability properties, improving various applications like heat transfer, lubrication, drug delivery, and oil recovery. This article discusses Nano fluid stability from preparation to implementation in practical applications, focusing on factors like temperature, pressure, confinement, composition, salinity, external magnetic field, and shear rate. [2]. This study focuses on synthesizing pristine Cu-Al layered double hydroxide (LDH) Nano fluid using a one-step method and studying its thermal properties. Characterization techniques were employed to determine crystallite size, composition, morphology, and interlayer anion vibration. [3].This study used mono-type nanoparticle suspensions, with CuNPs showing the greatest enhancement. Hybrid suspensions did not show the same improvement. Experimentally measured thermal conductivities were consistently greater than theoretical predictions. Mechanisms for this enhancement are discussed [4].The framework analyzes Alumina and Copper-water Nano fluid over a sheet with thermal radiation effects. It incorporates effective thermal conductivity and viscosity for nanoparticles, analyzing temperature influence in the restricted domain. Partial differential equations are obtained from momentum and energy equations [5].This study evaluates the performance of an automobile radiator using nanofluid compared to distilled water as a coolant in a heat exchanger-based radiator. The radiator consists of upright tubes with an elliptical cross-section. The results show that increasing air flow rate and flow rate improves heat transfer performance. The maximum enhancement in heat transfer rate was found to be 44.29% at 0.2% volume fraction of alumina-distilled water-based Nano fluid compared to distilled water [6]. This paper presents a best practice for analyzing Nano fluids in heat transfer applications, specifically for car radiators. The study investigates aluminum oxide and titanium dioxide nanoparticles, focusing on their anti-corrosive properties and comprehensive characterization. Results show a maximum enhancement of thermal performance by 24.21% using Al_2O_3 at a 0.3% volume fraction. [7].

This paper presents findings on the thermal conductivity, viscosity, density, and specific heat of Al_2O_3 nanoparticles in water and ethylene glycol-based coolants used in car radiators. Thermal conductivity, viscosity, and density increased with volume concentrations, while specific heat decreased with nanoparticle volume concentrations [8].

This investigation analyzes the effect of adding Al_2O_3 nanoparticles to MQL cooling fluid on cutting tool temperature distribution using finite element analysis and a discrete phase model [9]. Experimental investigation of temperature and particle volume concentration on water-Al_2O_3Nano fluid dynamic viscosity using a commercial viscometer. Results show increased viscosity with particle volume fraction but decrease with temperature increase [10].

The study investigates the thermal conductivity of Al_2O_3–Cu/EG nanoparticles in ethylene glycol at different concentrations and temperatures. Results show Nano fluid has higher thermal conductivity than base fluid, depending on volume concentration and temperature [11]. A laminar convective heat transfer and pressure drop technique is presented using Al_2O_3–Cu/water hybrid Nano fluid in a uniformly heated circular tube [12]. This study investigated the effect of TiO_2-water Nano fluid on radiator performance, comparing results with pure water and TiO_2-water Nano fluid. The main objective was to check heat transfer aspects [13].

The study investigated the effects of silica Nanospheres, MWCNTs, and hybrids H1 and H2 on distilled water viscosity and density. Results showed that Nano fluids increased with concentration, while temperature reduced them. H2 showed the least increase in viscosity at high concentrations, while H1 showed the least increase in base fluid density [14].The study prepared hybrid carbon Nano fluids (HCNFs) using an acetylene flame synthesis system for heat exchange applications. [15].

This study investigates thermoelectric power generation from cavities with ventilation ports using a rotating conic object and carbon nanotube particles. It examines the effects of parameters like Reynolds numbers, object size, and nanoparticle volume fractions on fluid flow, interface temperature, and output power [16]. This study aims to attract young scholars and experts in heat transfer by discussing hybrid Nano fluids applications and challenges. The authors identify important work orientations and existing problems that hinder their performance and implementation [17]. This paper reviews 160 papers from 1995-2017 on hybrid or composite Nano fluids, focusing on their preparation and thermo physical properties. It also discusses the applications and challenges of these fluids, aiming to stimulate further research in this field [18]. Conventional heat transfer fluids like water and engine oil are widely used in automobile radiators. To improve thermal performance, nano-sized solid particles can enhance thermal conductivity in working fluid [19].

Nano fluids have gained significant attention in recent years, with numerous papers discussing their applications. This paper reviews their use in different PHE geometries [20].Hybrid Nano fluids offer promising thermo physical properties, heat transfer rate, and stability, offering potential in various heat transfer applications. This paper summarizes factors affecting their performance and presents conclusions based on data [21].Rapid research on Nano fluids shows their potential as heat transfer fluids in engineering applications, influenced by nanoparticle thermal conductivity, particle volume concentrations, and flow rates [22].The experiment examined the impact of particle size, weight fraction, and working temperature on the thermal conductivity ratio of alumina/water Nano fluids [23]. The thermodynamic analysis evaluates Nano fluid's effect on improving PV/T hybrid solar collector efficiency in Qatar climate using experimental and computational data [24]. Researchers have shown the potential of Nano fluids in various systems, particularly automotive thermal management. Their idiosyncratic thermal and hydrodynamic behaviors make them ideal candidates for evaluation [25].

The study evaluates the enhancement of convective heat transfer performance of hybrid Nano fluids (Ag, Cu, SiC, CuO, TiO2) in Al_2O_3Nano fluid as coolants for louvered FN automobile radiators [26].Conventional heat transfer fluids like water and engine oil are widely used in automobile radiators. To improve thermal performance, nano-sized solid particles can enhance thermal conductivity in working fluid [27]. Radiator heats and cools fluids, such as automotive engine cooling and HVAC dry cooling towers, to improve efficiency and effectiveness in IC engines. Enhancing radiator performance is crucial for overall performance improvement [28]. The automobile industry aims to maximize engine efficiency while maintaining compactness. This can be achieved by decreasing the frontal area of a car, enhancing aerodynamics. Higher thermal conductivity coolants transfer heat faster, reducing engine volume, pumping power, and radiator size. This leads to smaller frontal areas, improved fuel economy, and reduced emissions. Nano-fluids, with their enhanced thermal conductivity, offer better heat dissipation than conventional coolants, making them a potential practical application [29].

2. Thermophysical properties of Nanofluids:

The thermophysical properties of Al_2O_3 and CuO nano-fluids are subsequently estimated at a temperature of 50^0C. Additionally, thermal characteristics such as density, dynamic viscosity, specific heat capacity and thermal conductivity are also estimated at the same temperature by using the relations given below.

Base fluid properties are calculated by

$$\rho_w = 1000 \times \left[1.0 - \frac{(T_w - 4.0)^2}{119000 + 1365 \times T_w - 4 \times (T_w)^2} \right]$$

$$\mu_w = 0.00169 - 4.2526e-5 \times T_w + 74.9255e-7 \times (T_w)^2 - 2.09935e-9 \times (T_w)^3$$

$$k_w = 0.56112 + 0.00193 \times T_w - 2.60152e-6 \times (T_w)^2 - 6.08803e-8 \times (T_w)^3$$

Density of Nano fluid is calculated by

$$\rho_{nf} = \left(\frac{\phi}{100}\right)\rho_\rho + \left(1 - \frac{\phi}{100}\right)\rho_w$$

Specific heat of Nano fluid is calculated by

$$C_{nf} = \frac{\frac{\phi}{100}(\rho C_p)_p + (1 - \frac{\phi}{100})(\rho C_p)_w}{\rho_{nf}}$$

Thermal conductivity of the Nano fluid is calculated by using

$$k_r = \frac{k_{nf}}{k_w} = \left[0.8938\left(1 + \frac{\phi}{100}\right)^{1.37}\left(1 + \frac{T_{nf}}{70}\right)^{0.27}\left(1 + \frac{d_p}{150}\right)^{-0.0336}\left(\frac{\alpha_p}{\alpha_w}\right)^{0.01737}\right]$$

$$k_{nf} = k_w \times k_r$$

Dynamic Viscosity of Nano fluid is calculated by using

$$\mu_r = \frac{\mu_{nf}}{\mu_w} = \left(1 + \frac{\phi}{100}\right)^{11.3}\left(1 + \frac{T_{nf}}{70}\right)^{-0.038}\left(1 + \frac{d_p}{170}\right)^{-0.061}$$

$$\mu_{nf} = \mu_r \times \mu_w$$

3. Methodology

Figure represents the project architecture, showcasing the system's functionality and the interaction between various devices. The system design process commenced by selecting a suitable heat exchanger, and in our case, we opted for a car radiator equipped with a fan.

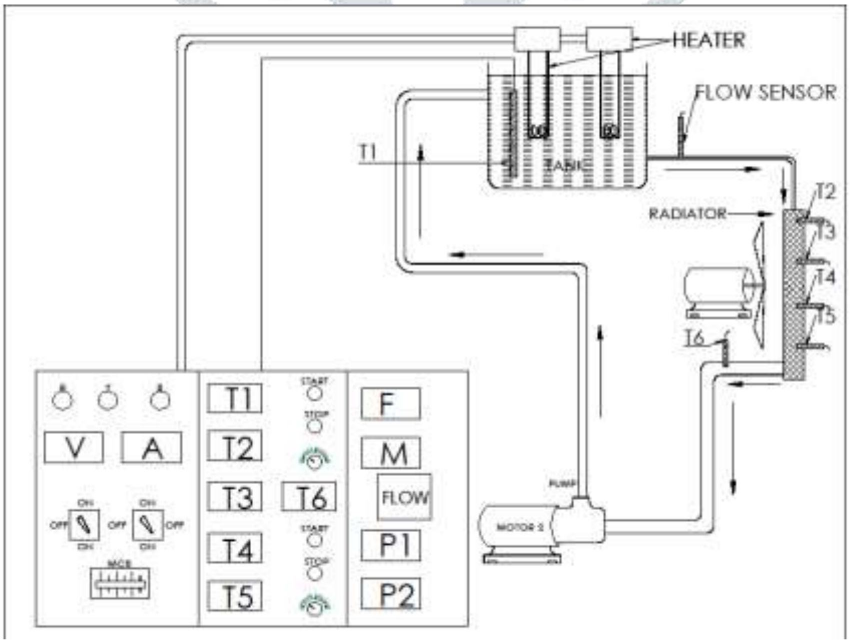

Figure: 1 Project architecture diagram

The figure consists of water tank, heaters, thermo couples, fan, radiator, flow meter, motor, pressure gauge and water pump. However, it should be noted that the water pump commonly used in cars is mechanically connected to the engine and does not align with the requirements of our experiment. By selecting a water pump specifically suited for our experimental needs, we ensure the smooth operation and functionality of the entire system. The project architecture depicted in figure provides a clear overview of how the devices within the system interact and work together to achieve the desired goals. It serves as a visual representation of the system's design and operation, aiding in the understanding and communication of the project's technical aspects.

3.1 Geometry Specifications of car radiator

Parameter	Dimensions
Height of radiator	0.75m
Width of radiator	0.55 m
No. of radiator tubes	53
Each tube diameter	0.016 m
Length of the radiator tube	16.25m

Table-1

3.2 Fluid Preparation:

In our experiment, the initial fluid used is water. A total volume of 60 liters of water is employed for the setup. Water is a common base fluid in many heat transfer applications due to its excellent thermal properties and availability. By using 60 liters of water, we ensure an adequate amount of fluid to facilitate the flow and circulation throughout the system. Water has a high heat capacity and thermal conductivity, making it an efficient heat transfer medium. Its abundance and low cost also make it a practical choice for experimental purposes. The use of water as the base fluid provides a baseline for comparison when evaluating the performance of the Nano fluid. Overall, the inclusion of 60 liters of water in our experiment allows us to study and analyze the impact of the Nano fluid on enhancing heat transfer capabilities in comparison to the traditional base fluid. The nano fluids were prepared by the sonication process at 90^0C and 2hrs time period.

3.4 Input parameters

Parameter	**Range**
Inlet Temperature	50^0C
Volume Concentrations	0.1% - 1%
Flow rates	$3.5m^3$/hr -$4.5m^3$/hr

Table-2

The dimensions mentioned in Table-1 are used for creating a 3D model of the test section and the input parameters mentioned in Table-2 are used for the analysis. The solid models of the test section are shown in Fig. 1 and Fig. 2 respectively. In Fig. 1, Hexahedral meshing is used, number of nodes are 924798 and number of elements are 798995.

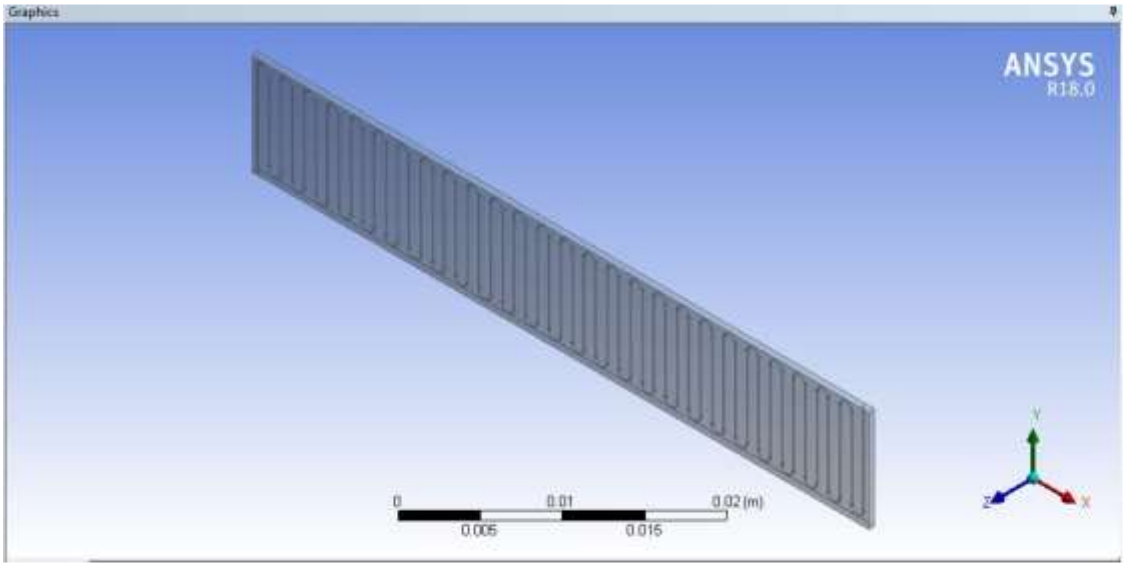

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Figure.2 Geometry model of Car Radiator.

In this window geometry is selected, once the geometry is selected, we will be in design modeler page. Initially, sketch is created on XY plane to create circle with 1 mm diameter and was extruded to 16.25m which means total length is 16.25m. In this window geometry is selected, once the geometry is selected, I shall be in design modeler page. Initially sketch is created on XY plane to create circle with 1mm diameter and draw the pipe of diameter 1 mm and length 16.25m. By using Boolean operation, the two solid bodies form a single part. Then using Pattern operation, enter 10mm pitch distance and enter 53 copies which means total length is 16.25m.

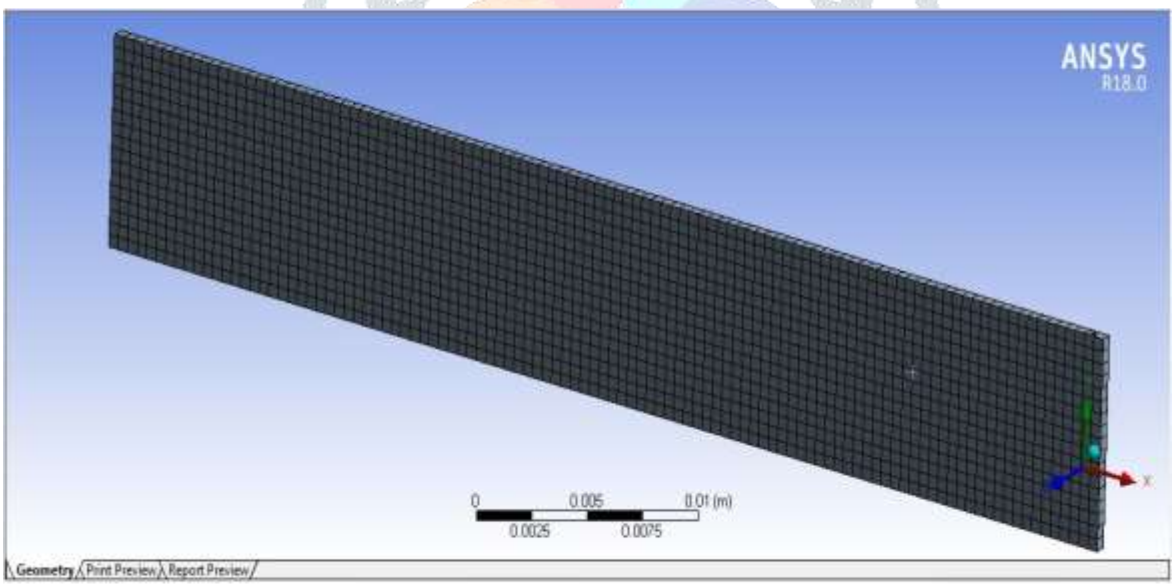

Figure.3 Meshed model detail view

Figure.3 represents the meshing is a next step once the model is completed. The entire domain material is assigned as FLUENT, every edge of domain is planned to divide to gain hexahedral or tetrahedral meshing.

4. Results and Discussion

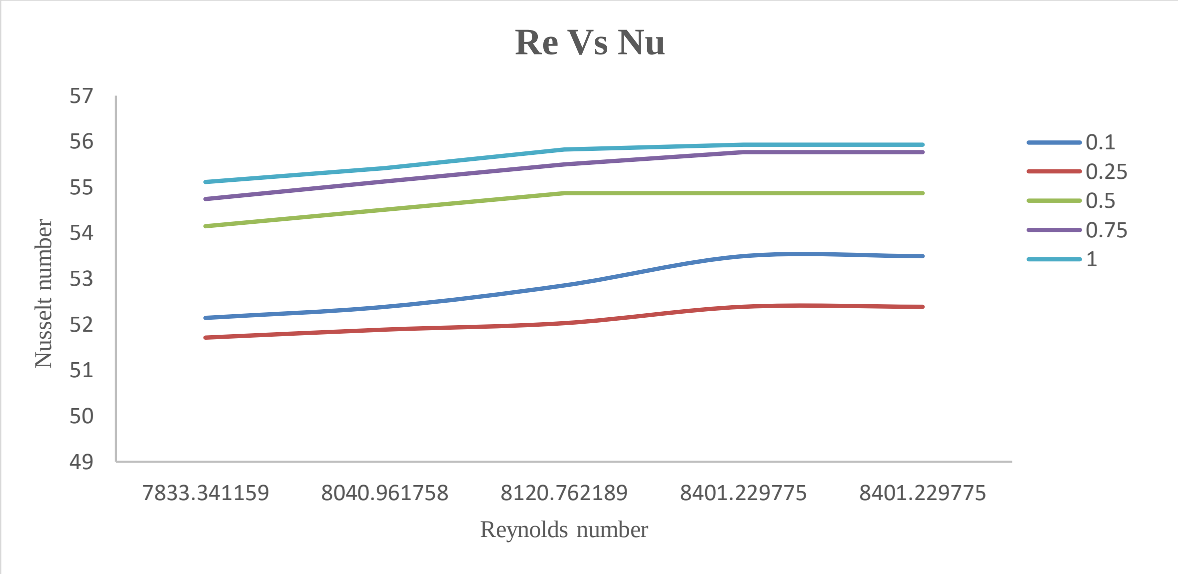

Figure: 4 Graph between Reynolds number and Nusselt number

Figure: 4 shows that the graphical representation effectively illustrates the correlation between the heat Reynolds number and Nusselt number. In this context, it is noteworthy that Aluminium oxide consistently outperforms other fluids in each scenario examined. These findings underscore Aluminium oxide's superior performance of various flow rates.

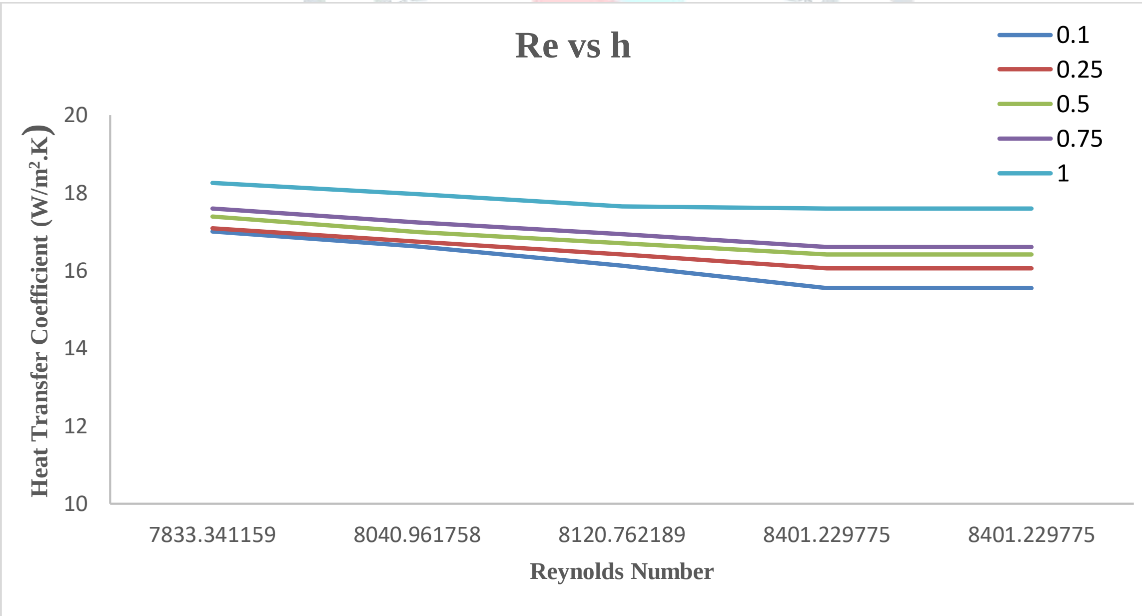

Figure: 5 Graph between Reynolds number and Heat transfer coefficient

The graphical representation effectively illustrates the correlation between the heat transfer coefficient and Reynolds number. In this context, it is noteworthy that Aluminium oxide consistently outperforms other fluids in each scenario examined. These findings underscore Aluminium oxide's superior performance when it comes to enhancing the heat transfer coefficient across various flow rates.

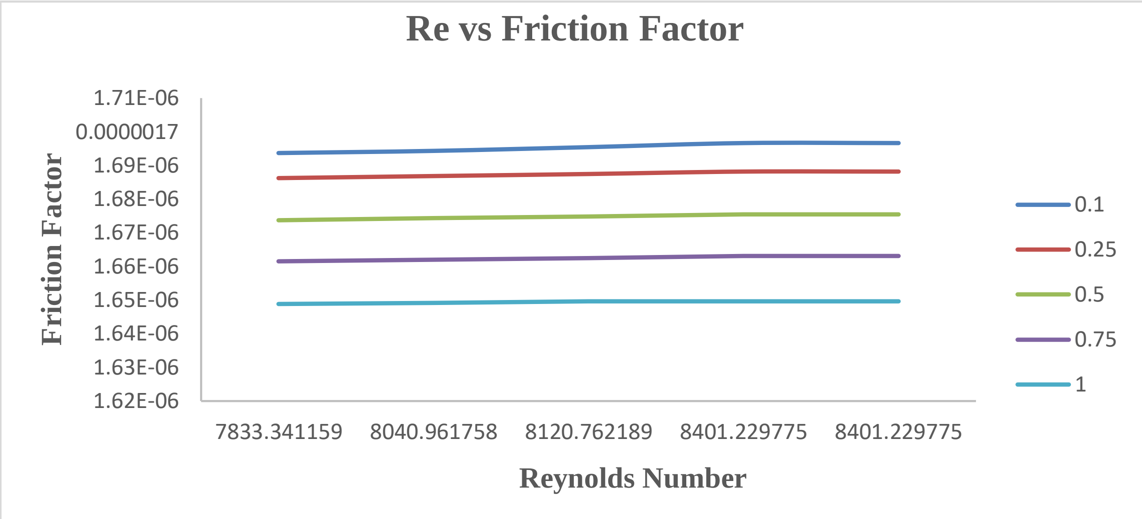

Figure: 6 Graph between Reynolds number and Friction

The visual representation efficiently demonstrates the connection between the friction factor and the Reynolds number. It's important to highlight that, in every scenario investigated, Aluminium oxide consistently surpasses other fluids. These results emphasize the superior performance of Aluminium oxide in enhancing the friction factor across different flow rates. This lower value positions the Nano fluid as an ideal option for applications related to radiator cooling.

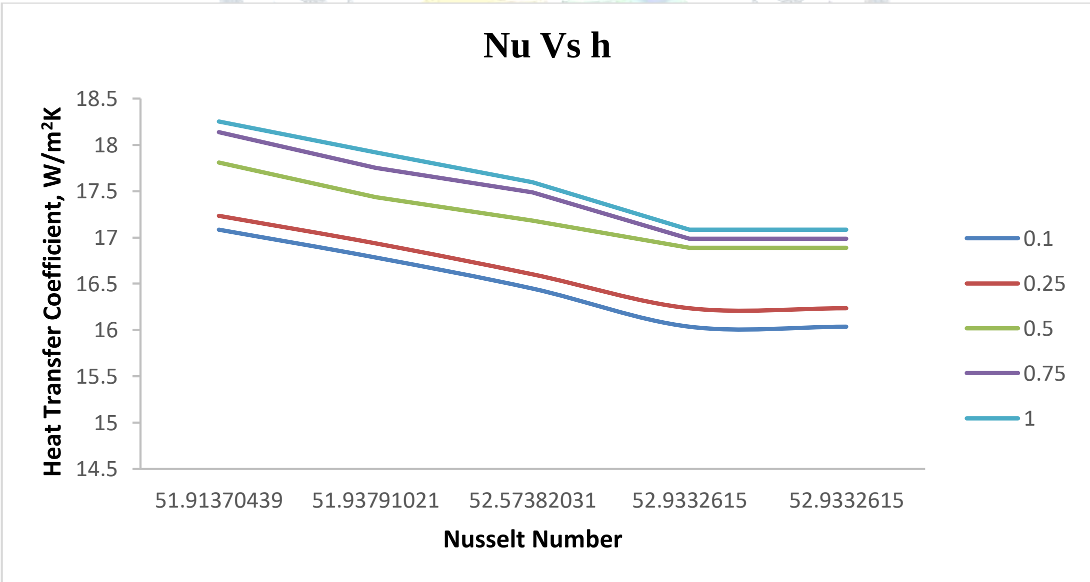

Figure: 7 Graph between Nusselt number and Heat transfer coefficient

The visual representation efficiently demonstrates the connection between the Nusselt number and the Heat transfer coefficient. It's important to highlight that, in every scenario investigated; Copper oxide consistently surpasses other fluids. These results emphasize the superior performance of copper oxide in enhancing the friction factor across different flow rates. This lower value positions the Nano fluid as an ideal option for applications related to radiator cooling.

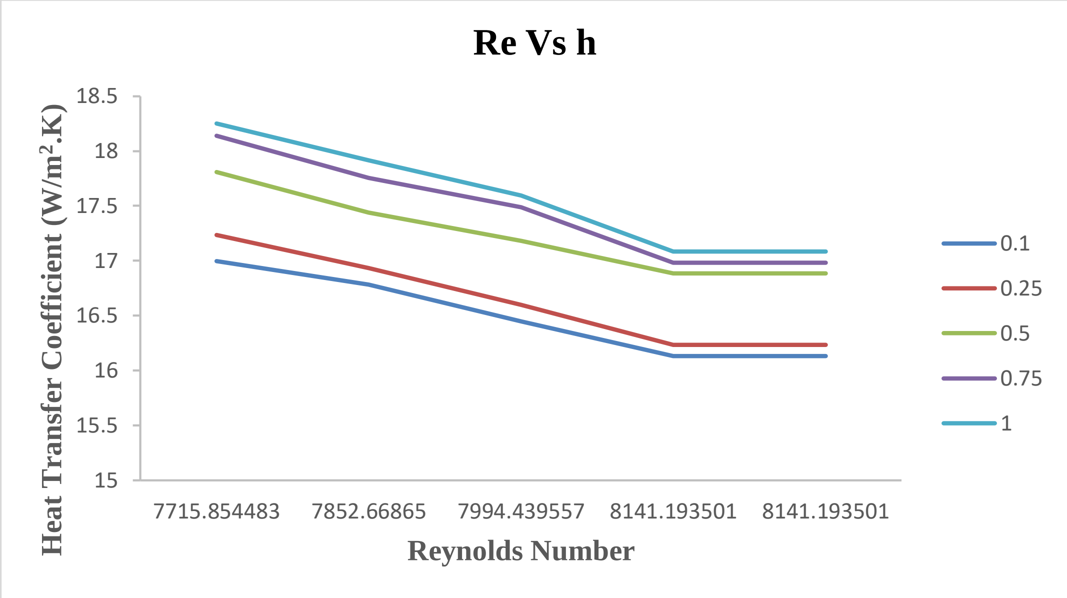

Figure: 8 Graph between Reynolds number and Heat transfer coefficient

The graphical representation effectively illustrates the correlation between the heat transfer coefficient and Reynolds number. In this context, it is noteworthy that Copper oxide consistently outperforms other fluids in each scenario examined. These findings underscore Copper Oxide superior performance when it comes to enhancing the heat transfer coefficient across various flow rates.

Validation:

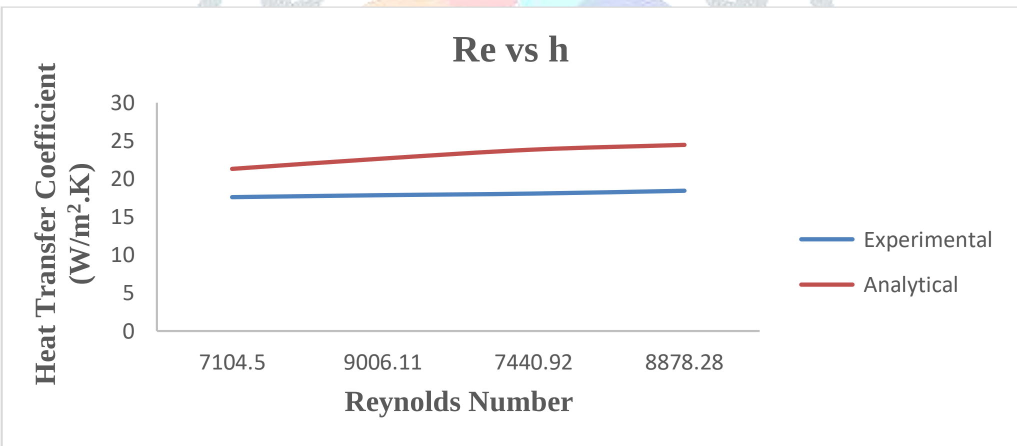

Figure: 9 Graph between Reynolds Number Vs Heat Transfer Coefficient

Figure 9 represents the Graph is plotted between Reynolds number and Heat transfer coefficient of analytical and experimental values. The graph shows that error percentage about 7% to 10% varying between the heat transfer coefficient values of experimental and analytical values. Thus, the experimental results can be validated through the analytical results. Hence, significant increase in the heat transfer coefficient of CuO/water nano fluid is observed that the performance of the car radiator is better than Al_2O_3/water nano fluid.

5. Conclusion:

The experimental findings indicate that Nano fluids with 1% Al_2O_3 and CuO in water exhibit slightly elevated heat transfer coefficient values in comparison to different volume concentrations. Additionally, the performance metrics outperform those associated with other volume concentrations and flow rates. Empirical correlations developed to analyze the Nusselt number and friction factor closely match the experimental data, offering valuable insights into the heat transfer characteristics of these Nano fluids.

Through Computational Fluid Dynamics (CFD) analysis, the study comprehensively dissects temperature fluctuations, pressure distributions, and velocity profiles. These factors are intricately interrelated, and their coordinated optimization plays a vital role in enhancing a car's radiator performance. In essence, CFD analysis serves as an essential tool, acting as a linchpin in the pursuit of improving the cooling capabilities of automotive radiators. It is through a meticulous examination of temperature, pressure, and velocity distributions that the overall effectiveness of the car's radiator system is carefully examined and enhanced

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