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Use of Hybrid Nanofluid to Increase Heat Transfer Performance of Double Pipe Heat Exchanger using CFD

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ABSTRACT

In present work, forced convection of a turbulent flow of, Al2O3/water nanofluid and Al-Al2O3/water hybrid nanofluid (a new advanced nanofluid composited of Al and Al2O3 nanoparticles) through a double pipe heat exchanger is numerically analyzed. The solid model of the double pipe heat exchanger is created in design modular and analyzed by the computational software ANSYS 16.0.This work examines the effects of these two fluids as the working fluids, a wide range of Reynolds number ($20000 \le Re \le 60000$) and also the volume concentration (0.25%, and 0.5%) on heat transfer and hydrodynamic performance. The finite volume discretization method is employed to solve the set of the governing equations. The results indicate that employing hybrid nanofluid improves the heat transfer rate with respect to nanofluid. However, the average increase of the average Nusselt number (when compared to nanofluid) in Al-Al2O3/water hybrid nanofluid is 14% and the amount for the average increase of heat transfer coefficient would be 27.5%.

KEYWORDS: *Hybrid nanofluid; forced convection; Reynold's number; heat transfer enhancement; Nusselt number; CFD*

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I. INTRODUCTION:

The function of heat exchanger is to transfer heat between two fluids while keeping them unmixed. The idea of utilizing the nanofluids in heat exchangers uplifted with the demand for compact devices. To extract heat in a controlled manner as needed, researchers must design the devices that can withstand the maximum possible load. For this, investigators suggest the following solutions: increase the heat transfer area by improving the design of the heat exchanging device, develop the material that offers less resistance to heat transfer, and employ the fluids with superior thermal characteristics [1, 2]. Initially, the work conducted on the first two methods and a lot of studies are available on it. But the advancement in technology and demand for compact devices prompted the manufacturers to work on the combination of different techniques (design, material, heat transfer fluid) that can assist them to develop the thermal equilibrium. The investigation on the performance of heat exchangers with nanofluids yielded the great results. Numerical studies have also been conducted to evaluate the heat transfer rate by improving the designs of heat transferring media. Nanofluids performed well and showed satisfactory results that prompted the researchers to think about the suspension of different combinations of nanoparticles in the base fluid, which were later developed and named "hybrid nanofluids" [1-5].

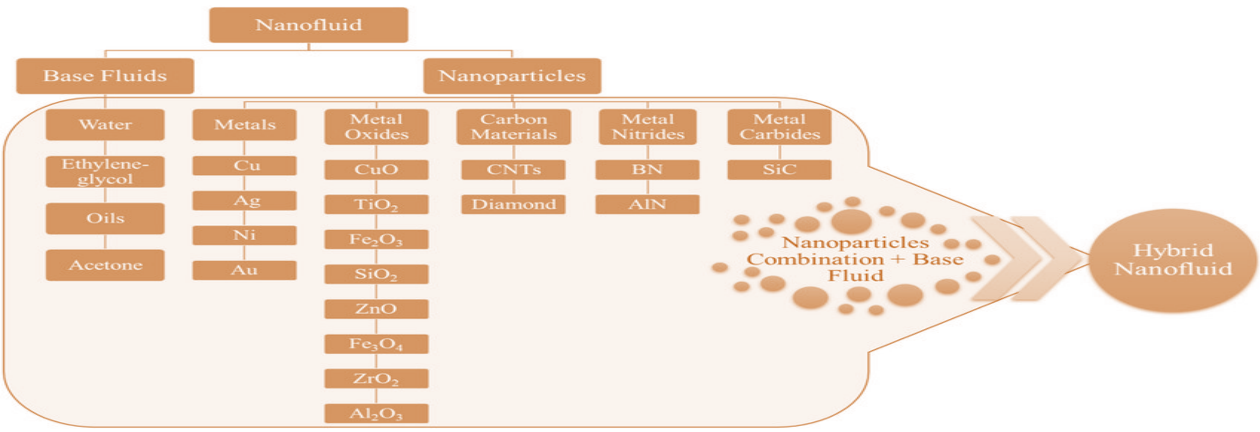


Figure 1 Differentiation between nanofluids and hybrid nanofluids

When two or more materials are mixed so that their combination has a different chemical bond entitled "hybrid metals". In fact, when two or more metals delivered the homogeneous phase with simultaneous mixing named "hybrid nanofluid" [6-8]. This advanced class of nanofluids showed promising enhancement in heat transfer characteristics and thermophysical and hydrodynamic properties compared to unitary nanofluids [9, 10]. The most important exclusivity of hybrid nanofluid refers to composition of two variant types of dispersed nanoparticles in a base fluid. Thus, when materials of particles have been chosen properly, they can enhance the positive features of each other and cover the disadvantages of just one material. For example, alumina (that is a ceramic material) has many beneficial properties such as chemical inertness and a great deal of stability; while Al_2O_3 exhibits lower thermal conductivity with respect to the metallic nanoparticles.

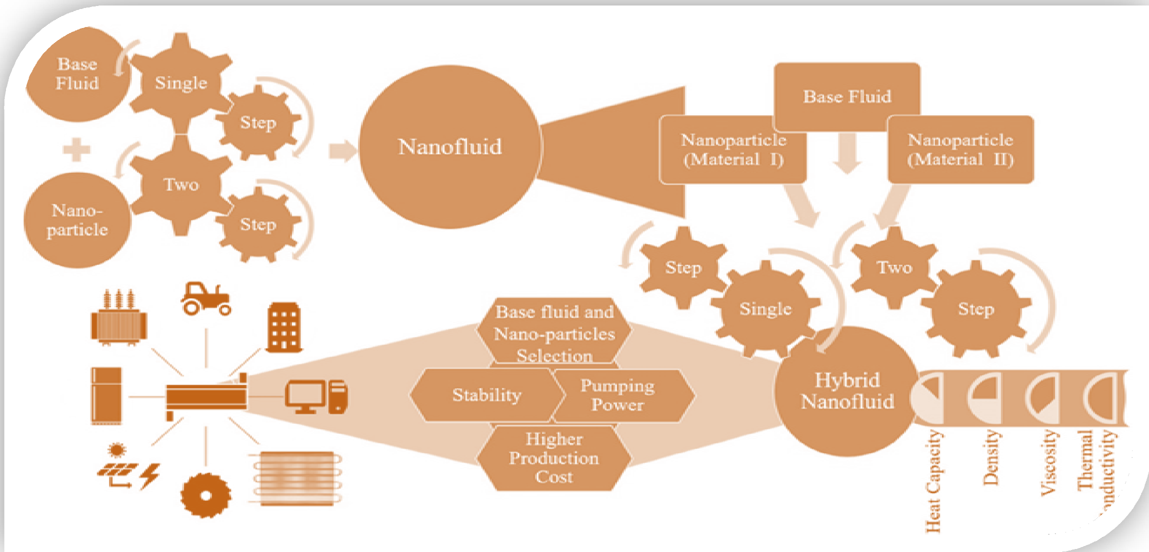


Figure 2 Preparation methods for hybrid nanofluids, application and its impact on thermophysical properties

II. LITERATURE REVIEW

As the need for reliable heat transfer systems has grown, since the mid- 1950s researchers have employed different techniques of heat transfer enhancement. The significant increase in the number of scientific publications dedicated to this subject has shown, to date, that heat transfer technology has advanced considerably.

Significant theoretical and analytical and computational studies to enhance heat transfer have been performed. The following chapter offers a short summary of the relevant literature showing the degree to which work has already been published in the publication on the growth, the application of nano fluids, their use in different heat exchangers and numerous methods available of hybrid nanofluid preparation to allow for the synthesis of hybrid nanoparticles.

2.1. Previous Work

Maxwell (1873) was the first to report the thermal conductivity enrichment of conventional fluids with the challenges of sedimentation, clogging and erosion in flow tracks [1]. Afterward, **Masuda et al. (1993)** examined the thermal conductivity enhancement with the addition of micro-sized solid particles into the base fluid (single phase), but also encountered the same problems of sedimentation, enhanced pumping power, erosion and clogging [2]. **Hamilton-Crosses (1962)** also contributed by extending the work of Maxwell and provided the more accurate model to predict the thermophysical properties of the particles suspended fluids [3].

In 1995, the work of **Choi** revolutionized the field of heat carrying fluids when first time fabricated the nanofluids that exhibited enhanced thermal transport properties with better stability in comparison of fluids containing the milli and micro sized solid particles [4].

With this invention, researchers started to investigate the nanofluids with great interest.

Pak and Cho (1998) conducted heat transfer and friction factor experiments for Al_2O_3/water and TiO_2/water nanofluids in the Reynolds number range from 104 to 105 and the particle concentration ranging from 0% to 3% and observed heat transfer enhancement compared to the base fluid (water); they also propose newly-developed Nusselt number correlation [5].

Later on, **Xuan and Li (2001)** used Cu/water and Cu/transformer oil nanofluids and observed heat transfer enhancements as compared to the base fluids. In another study, **Xuan and Li(2002)** observed heat transfer enhancement of 60% for 2.0% volume concentration of Cu/water nanofluid flowing in a tube at a Reynolds number of 25000 and they report separated Nusselt number correlations for laminar and turbulent flow, respectively [6,7].

Wen and Din (2004) conducted heat transfer experiments for Al_2O_3/water nanofluid in a tube under laminar flow and they observed heat transfer enhancement of 47% at 1.6% volume fraction as compared to the base fluid (water) [8].

Heris et al. (2007) also used Al_2O_3/water nanofluids in a tube under laminar flow and observed heat transfer enhancement using constant wall temperature boundary conditions [9].

Williams et al. (2008) reported convective heat transfer enhancement with alumina/water and zirconia/water nanofluids flow in a horizontal tube under turbulent flow [10].

Duangthongsuk and Wongwises (2010) found heat transfer enhancement of 20% and 32% for 1.0% vol of TiO_2/water nanofluid flowing in a tube at Reynolds numbers of 3000-18000, respectively [11].

Moraveji et al. (2011) simulated water-Al_2O_3 nanofluid through a tube under a constant heat flux. They found that the heat transfer coefficient rises by increasing the nanoparticle concentration and Reynolds number. Furthermore, the heat transfer coefficient increases by particle diameter reduction [12].

Ghozatloo et al. (2014) obtained heat transfer enhancement of 35.6% at a temperature of 38 °C for 0.1 wt% of graphene/water nanofluids flow in a tube under laminar flow [13].

Sundar et al. (2012) found heat transfer enhancement of 30.96% with a pumping penalty of 10.01% for 0.6% vol of Fe_3O_4/water nanofluid flow in a tube at a Reynolds number of 22000 [14].

Sundar et al. (2014) observed heat transfer enhancement of 39.18% with a pumping penalty of 19.12% for 0.6% vol of Ni/water nanofluid flow in a tube at a Reynolds number of 22000 [15].

Delavari et al. (2014) numerically simulated the heat transfer in a flat tube of a car radiator at laminar and turbulent regimes. They showed the ability of CFD to simulate the flow field and temperature distribution profile well and reported an increment of Nusselt number with increasing the nanoparticle concentration [16].

Chandrasekhar et al. (2017) experimentally investigated and theoretically validated the behavior of Al_2O_3/water nanofluid that was prepared by chemical precipitation method. For their investigation, Al_2O_3/water at different volume concentrations was studied. They concluded that the increase in viscosity of the nanofluid is higher than that of the effective thermal conductivity. Although both viscosity and thermal conductivity increases as the volume concentration is increased, increase in viscosity predominate the increase in thermal conductivity. Also various other theoretical models were also proposed in their paper [17].

Hady et al. (2017) experimentally investigated the performance on the effect of alumina water (Al_2O_3/H_2O) nanofluid in a chilled water air conditioning unit. They made use of various concentrations ranging from 0.1-1 wt % and the nanofluid was supplied at different flow rates. Their results showed that less time was required to achieve desired chilled fluid temperature as compared to pure water. Also reported was a lesser consumption of power which showed an increase in the cooling capacity of the unit. Moreover the COP of the unit was enhanced by 5 % at a volume concentration of 0.1 %, and an increase of 17 % at a volume concentration of 1 % respectively [18].

Rohit S. Khedkar et al. (2017) experimental study on concentric tube heat exchanger for water to nanofluids heat transfer with various concentrations of nanoparticles in to base fluids and application of nanofluids as working fluid. Overall heat transfer coefficient was experimentally determined for a fixed heat transfer surface area with different volume fraction of Al_2O_3 nanoparticles in to base fluids and results were compared with pure water. It observed that, 3 % nanofluids shown optimum performance with overall heat transfer coefficient 16% higher than water [19].

Han et al. (2017) in double tube heat exchanger flow turbulent and counter examine the enhancement of heat transfer by using nanoparticles aluminum oxide in water. They examine the rate of heat transfer with 0.25% and 0.5% by volume concentration at various inlet temperatures. In pipe flow the Reynold's number should be greater than 4000 for turbulent flow, as we know with higher turbulence the rate of heat transfer is high so with the various concentration and inlet temperature they also examine the rate of heat transfer at various Reynold's number i.e., 20000, 30000, 40000, 50000, and 60000. After the experiment they analyze that by using different concentration of Al_2O_3 that include 0.25% and 0.5% by volume concentration with Reynold's number varies from 20000 to 60000 maximum increase in heat transfer coefficient is about 9.7% and 19.6% respectively at 40^0C, and with same volumetric concentration and also Reynold's number varies from 20000 to 60000 the maximum increase in heat transfer coefficient is about 15% and 29% for volume concentration 0.25% and 0.5% respectively at 50^0C. Comparing the result at 40^0C and 50^0 with the volume concentration of 0.25% and 0.50%, the increase in heat transfer coefficient is about 5.3% and 9.4% respectively. The main conclusion is that at same nanoparticles concentration we can increase the rate of heat transfer with the increase in inlet temperature of nanofluid, which shows that nanofluid dependency on temperature. Nusselt number is also deal with heat transfer, by using nanofluid the Nusselt number also increases about 8.5% and 17% at the volumetric concentration of 0.25% and 0.50% respectively [20].

Akyürek et al. (2018) experimentally investigated the effects of Al_2O_3/Water nanofluids at various concentrations in a concentric tube heat exchanger having a turbulator inside the inner tube. Comparisons were done with and without nanofluid in the system as well as with and without turbulators in the system. Results were drawn and a number of heat transfer parameters were calculated on the basis of observed results. Various heat characteristics such as change in Nusselt number and viscosity with respect to Reynolds number, behaviours of nanofluid at various volume concentrations, changes in heat transfer coefficient, effect of the difference of pitch of turbulators on the heat transfer of nanofluid etc. were studied. They concluded that there exists a relationship between the varying pitches and the turbulence in the flow caused i.e. when the pitch is less there is more turbulence and vice versa [21].

For the preparation of hybrid nanofluids there are different available methods, which enable the synthesis of hybrid nanoparticles; the use of the most common methods is succinctly reviewed in what follows.

Jia et al. (2007) used the hydrothermal method [22], **Zhang et al. (2009)** used the solvothermal method [23] and **Shi et al. (2010)** used the polyols method for the synthesis of CNT/Fe_3O_4 hybrid nanoparticles [24].

Guo et al. (2008) used sonication and sol-gel chemistry technique for the synthesis of silica (Si) coated carbon nanotube (CNTs) coaxial nanocables [25].

Li et al. (2009) prepared CNT/SiO_2 and CNT//SiO_2/Ag hybrid nanoparticles using plasma treatment [26].

Sundar et al. (2014) prepared Nano diamond-nickel (ND-Ni) nanocomposite (hybrid) nanofluids and determined experimentally the thermal conductivity and viscosity [27].

Sundar et al. (2014) also prepared MWCNT-Fe_3O_4 hybrid nanofluids and found heat transfer enhancement of 31.10% with a pumping penalty of 18% for 0.3% vol at a Reynolds number of 22000. His studies clearly indicate that hybrid nanofluids yield higher heat transfer enhancement than single nanoparticles-based nanofluids [28].

According to **Makishima (2016)** when two or more materials are mixed so that their combination has a different chemical bond entitled “hybrid metals”. In fact, when two or more metals delivered the homogeneous phase with simultaneous mixing named “hybrid nanofluid". This advanced class of nanofluids showed promising enhancement in heat transfer characteristics and thermophysical and hydrodynamic properties compared to unitary nanofluids [29].

Hayat and Nadeem (2017) revealed that the hybrid nanofluid performed well with higher heat transfer rate compared to unitary nanofluid even in the presence of heat generation, chemical reaction, and thermal radiation. They observed this while investigating the rotating three-dimensional steady flow of Ag– CuO/water hybrid nanofluid [30].

2.2. Problem Formulation

The above-mentioned researchers had studied various aspects of nanofluids and various methods to implemented nanofluids to enhance heat transfer rate in various heat exchangers. In some research papers, the study is focused on an increase in the effectiveness of nanofluid. However, in some paper study is focused on nanofluid and their effect on, effectiveness, Heat transfer and overall heat transfer coefficient. There was no significant work found using hybrid nanofluids in double pipe heat exchanger for heat transfer enhancement. Therefore this investigation deals with the thermal and flow behavior of double pipe heat exchanger handling Al-Al_2O_3/water hybrid nanofluids at different volume concentrations.

2.3. Research Objectives

In this analysis, the thermal characteristics of an Al-Al_2O_3/water hybrid nanofluids in a double pipe heat exchanger was investigated using a 3-dimensional numerical (3-D) simulation. This investigation deals with handling Al-Al_2O_3/water hybrid nanofluids at two different volume concentrations. The simulation programme ANSYS 16.0 was used for study of the heat transfer physiognomies of a double pipe heat exchanger with an Al-Al_2O_3/water hybrid nanofluids.

The main objectives of the present work are as follows:

- To analyze the thermal characteristics of double pipe heat exchanger using Al-Al_2O_3/water hybrid nanofluids.
- To develop double pipe heat exchanger model and validation on CFD model will be carried out with comparison of previous experimental model.
- Effect of Al-Al_2O_3/water hybrid nanofluids in double heat pipe exchanger, thermal characteristics is analyzed by parameters such as the Nusselt number, Heat transfer rate, and Overall heat transfer coefficient.
- Calculating the effects of various volume concentrations of Al-Al_2O_3 hybrid nanoparticles present in the hybrid nanofluid and their effects on heat transfer.
- Calculating the effects of flow rate variation in the performance of the double heat exchanger.

III. METHODOLOGY

CFD is a computer-efficient, numerical analysis-based method of heat - transfer research. CFD simplifies many experimental method problems and offers comprehensive characterization of 3-dimensional flow fields in the heat exchanger.

CFD simulations can be divided into three major steps:

- **Pre-processing** (description of the region of interest, generation of mesh numbers, definition of initial and boundary conditions, mathematical modelling and description of numerical schemes);
- **Solving of simulations** (numeric solution of the transport equations system);
- **Post-processing** (processing and analysis of results).

3.1. The steps of the study

- Firstly we design the double pipe heat exchanger on Workbench of ANSYS 16.0 Software.
- After designing the model it is transferred to ANSYS for CFD analysis.
- Meshing of model and Name selection is done on CFD pre-processor.
- The boundary conditions are applied on the model and numerical solutions are calculated by using solver.
- The finite volume method is used in solving the problem.
- The solution is calculated by giving iterations to the mathematical and energy equations applied on model.
- The results can be visualized in the form contours and graphs by CFD post processor.
- Applying formulas for calculating heat transfer coefficient, Nusselt Number of double pipe heat exchanger.
- Result analysis.

IV. COMPUTATIONAL MODEL AND NUMERICAL SIMULATION

The study uses the CFD model in this section to investigate the heat transfer characteristics of a double pipe heat exchanger Al-Al_2O_3/water hybrid nanofluids. CFD review involves three major steps. The first step includes the creation of the geometry and mesh generation of the desired model, while the results are seen as expected in the last step. In the execution of the solver (middle) stage, the boundary conditions are fed into the model.

4.1. Geometrical specification of double pipe heat exchanger

The geometry of double pipe heat exchanger using Al-Al_2O_3/water hybrid nanofluids performing the simulation study is taken from the one of the research scholar's **Han et al. (2017)** [20]with exact dimensions.

Table 1 Geometrical specification of double pipe heat exchanger

Parameters	Value
Inner tube diameter	38 mm
Outer tube diameter	100 mm
Tube length	2100 mm
Tube thickness	2 mm

4.2. Solid Model of double pipe heat exchanger

The solid model of the double pipe heat exchanger is created in design modular of ANSYS 16.0.

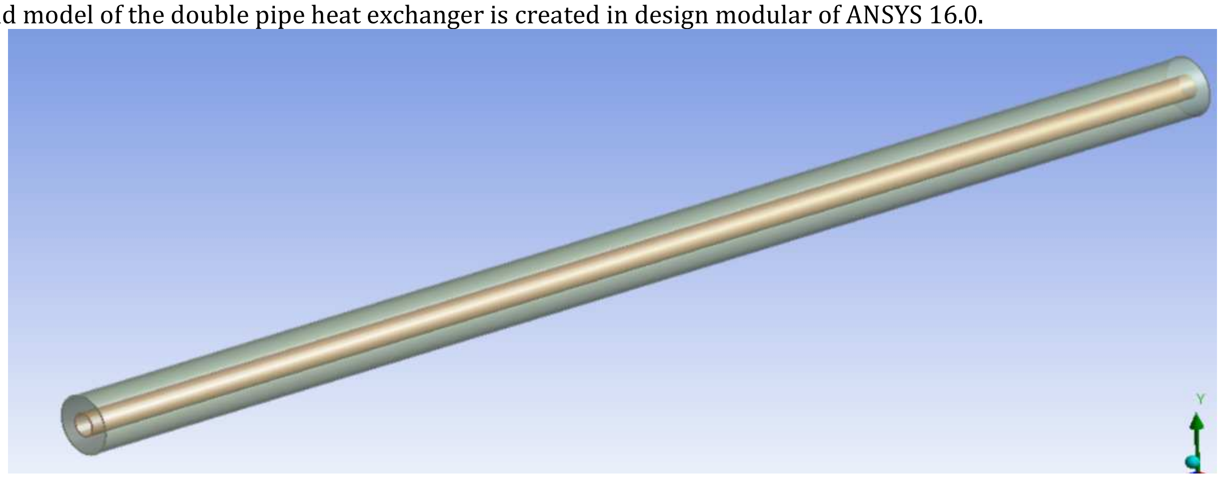
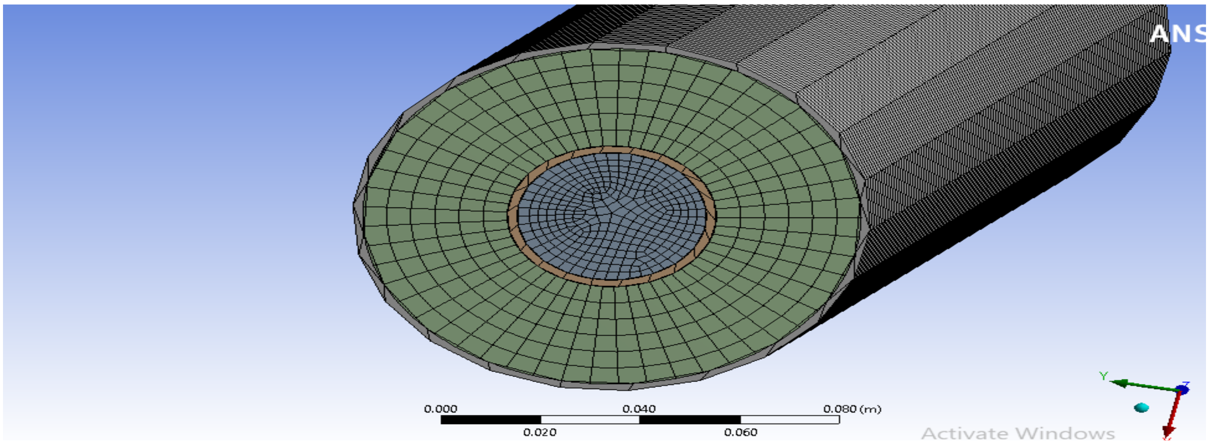


Figure 3 Solid model of double pipe heat exchanger

4.3. Meshing

The modeling of the test section is meshed with ANSYS 16.0. The coarser meshing is created throughout the effective length of the tube. Fig. 5.2 and 5.3 represents the meshing of double pipe heat exchanger used in this CFD analysis. The meshing contains the collaborated cells for triangular and quadrilateral expressions at boundary conditions. Much effort is given to the structured hexahedral cells. The smooth meshing is created, edges, as well as regions of temperature and pressure constraints, meshed.



Figurer 4 Face mesh of heat exchanger

Table 2 Details of Meshing

Domain	Nodes	Elements
Cold_fluid	389108	340938
Hot_fluid	4327200	327825
Inner_pipe	183624	100533
Outer_pipe	253576	139872
All domains	1263508	909168

4.4. Model Selection and Numerical Simulation

To enhance the simulation accuracy of the current three-dimensional and steady analysis, the governing equations are discretized with the SIMPLE pressure-velocity coupling algorithm with the finite volume formulation. In addition, the second-order upwind scheme have been used for momentum, turbulent kinetic energy, turbulent dissipation rate and energy, while the Presto system is used for pressure.

No-slip condition is applied to all solid walls, and as near-wall treatment, standard wall functions are implemented. The fluids were therefore assumed to be incompressible and the thickness of the tube, heat dissipation from the shell's outer surfaces and radiation were insignificant.

The k-epsilon model is chosen for this analysis as the k-epsilon model predicts well far from the boundaries (wall) and k-omega model predicts well near wall. Continuity, energy and Navier Stokes equations are used to find the conditions for flowing fluid in the double pipe with Eqs.

- **Conservation of mass**

$$\frac{1}{r}.\frac{\partial(ru)}{\partial r}+\frac{\partial v}{\partial z}=0$$

- **Conservation of momentum**

In Axial Direction

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial r}+v\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 v}{\partial r^2}+u\frac{\partial v}{r\,\partial r}+v\frac{\partial^2 v}{\partial z^2}\right)+S_z$$

In Radial Direction

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}+v\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu(\frac{\partial^2 u}{\partial r^2}+u\frac{\partial u}{r\,\partial r}-\frac{u}{r^2}+v\frac{\partial^2 u}{\partial z^2})+S_r$$

- **Conservation of energy**

$$\rho Cp\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial r}+v\frac{\partial T}{\partial z}\right)=\frac{\partial}{r\,\partial r}(kr\frac{\partial T}{\partial r})+\frac{\partial}{\partial z}(k\frac{\partial T}{\partial z})+S_e$$

Where z, r, u, v, ρ, p, μ, k, T and Cp are the axial distance, radial distance, radial velocity, axial velocity, density of material, pressure, viscosity of liquid metal, thermal conductivity, temperature of liquid, and specific heat respectively.

The following are the consideration for this CFD analysis:

- The Al-Al_2O_3/water hybrid nanofluids are incompressible fluid and single phase fluid.
- The effect of radiation and net convection are neglected.
- The thermo physical properties are not temperature dependent.
- Uniform dispersion nanoparticles.
- The flow is hydro dynamic.

4.5. Thermophysical properties

In order to generate hybrid nanofluids, the Al-Al_2O_3 hybrid nanoparticles were dispersed in distilled water at 0.25, and 0.5 percent by volume concentration before conducting the analysis. At the mean bulk temperature the thermophysical properties of hybrid nanofluids were measured. Density, specific heat, viscosity and thermal conductivity values were determined by means of equations:

$$\rho_{hnf} = (1 - \emptyset_{p1} - \emptyset_{p2})\rho_{bf} + \emptyset_{p1}\rho_{p1} + \emptyset_{p2}\rho_{p2}$$

$$(\rho C_p)_{hnf} = (1 - \emptyset_{p1} - \emptyset_{p2})(\rho C_p)_{bf} + \emptyset_{p1}(\rho C_p)_{p1} + \emptyset_{p2}(\rho C_p)_{p2}$$

$$K_{hnf} = K_{bf}\left\{\frac{K_{nc} + 2K_{bf} + 2(\emptyset_{p1} + \emptyset_{p2})(K_{nc} - K_{bf})}{K_{nc} + 2K_{bf} - (\emptyset_{p1} + \emptyset_{p2})(K_{nc} - K_{bf})}\right\}$$

$$\mu_{hnf} = (1 + 2.5\ (1 - \emptyset_1 - \emptyset_2)^{2.5})\mu_{bf}$$

Table 3. Provides the thermophysical properties of Al, Al_2O_3nanoparticles and distilled water used in the present research. The thermophysical characteristics of nanofluids and hybrid nanofluids using the above equations at different concentrations are assessed in Table 4.

Table 3 Thermophysical properties of distilled water and Al, and Al_2O_3 nanoparticles

Substance/nanoparticles	Density (kg/m³)	Thermal conductivity (W/m-K)	Specific heat (kJ/kg-K)	Viscosity (kg/m-s)
Distilled water	1000	0.62	4.187	0.000798
Al_2O_3	3970	46	0.750	-----------
Al	2719	202.4	0.871	-----------

Table 4 Thermophysical properties of nanofluids and hybrid nanofluids at different concentrations

Single Nanofluid and Hybrid nanofluid	Vol.%	Density (kg/m³)	Thermal conductivity (W/m-K)	Specific heat (J/kg-K)	Viscosity (kg/m-s)
Al_2O_3/water	0.25	1007.425	0.6244	4153.139	0.00084548
Al_2O_3/water	0.5	1014.85	0.6289	4119.773	0.00089295
Al-Al_2O_3(50:50)/water	0.25	1005.86	0.6246	4158.84	0.0011
Al-Al_2O_3 (50:50)/water	0.5	1011.7225	0.6299	4131.00	0.0013

Table 5 Thermophysical properties of materials for double pipe heat exchanger

Material	Density (kg/m³)	Thermal conductivity (W/m-K)	Specific heat (J/kg-K)
Inner tube and outer tube (Aluminium)	2800	200	900

4.6. Boundary Conditions

Here in this work, hot water steam is flowing in the outer tube where as cold fluid i.e. Al-Al_2O_3/water hybrid nanofluids is flowing in the inner tube. During the analysis the hot fluid steam is flowing at constant velocity 2.5 m/s as mention in base paper **Han et al. (2017)** [20]. Whereas cold fluid flowing in the inner tube at different Reynolds number (Re) that is 20000, 30000, 40000, 50000, and 60000. The change in Reynolds of cold fluid is used to measure the effect of change in mass flow rate of cold fluid on heat transfer.

Table 6 Details of boundary conditions

Constraints	Range/standards
Inner tube fluid	Cold fluid (Al-Al_2O_3/water hybrid nanofluids)
Flow rate of Al-Al_2O_3/water hybrid nanofluids	At different Reynolds number (Re) i.e. 20000, 30000, 40000, 50000, and 60000.
Inlet temperature of cold fluid	313 K
Volume concentration of hybrid nanofluid	0.25 and 0.5 %
Outer tube fluid	Hot fluid (Water)
Flow rate of hot water	2.5 m/s
Inlet temperature of hot fluid	427 K

V. RESULTS AND DISCUSSIONS

This section is aimed at evaluating the double pipe heat exchanger thermal performance using Al-Al_2O_3/water hybrid nanofluids at different concentration and at different Reynold's number. The variations in the Nusselt number, and overall heat transfer coefficient, are measured at different concentration and different Reynold's number in order to research the performance of the double pipe heat exchanger using Al-Al_2O_3/water hybrid nanofluids subject to flow.

5.1. Data reduction equations

The data reduction of the measured results is summarized in the following procedures:

The Reynolds number is given by,

$$Re = \frac{\rho V D}{\mu}$$

The mass flow rate is calculate on the basis of below formula,

$$\dot{m} = \rho A V$$

Where, ρ is the density of fluid, A is the cross sectional area of the pipe and V is the velocity of fluid.

Therefore, for fluid flows in a concentric tube heat exchanger, the heat transfer rate of the hot fluid in the outer tube can be expressed as:

$$q_h = \dot{m}_h c_{ph}(T_{hi} - T_{ho})$$

Where $\dot{m}_h$ is the mass flow rate of hot fluid, c_{ph} is the specific heat of hot fluid, T_{hi} and T_{ho} are the inlet and outlet temperatures of hot fluid, respectively.

While, the heat transfer rate of the cold fluid in the inner tube can be expressed as:

$$q_c = \dot{m}_c c_{pc}(T_{co} - T_{ci})$$

Average heat transfer rate is given by:

$$Q_{avg} = \frac{q_h + q_c}{2} = UA\theta_m$$

Where, $\theta_m = \frac{\theta_1 - \theta_2}{2}$

θ_m is the logarithmic mean temperature difference.

U is the overall heat transfer coefficient.

5.2. Validation of numerical computations

In this analysis, the validation of CFD data is carried out with the experimental data proposed by **Han et al. (2017)** [20] who conducted an experimental test on convective heat transfer and flow behavior of double pipe heat exchanger in the flow rate of cold fluid i.e. Al_2O_3/water at different Reynold's number ranges from 20000-60000 and hot fluid i.e. water at 2.5m/s.The double pipe heat exchanger geometry that used for validation of numerical computations was considered to be as same as the geometry shown in Fig. 3.

For the initial analysis, here it considered Aluminium oxide (Al_2O_3) as a nanoparticle with two different volume fractions that is 0.25% and 0.5 % at different Reynolds number and measure the value of Nusselt number for different Reynolds number.The values of Nusselt number calculated from the CFD modeling were compared with the values obtained from the analysis performed by **Han et al. (2017)** [20] who conducted an experimental test on convective heat transfer and flow behavior of double pipe heat exchanger.

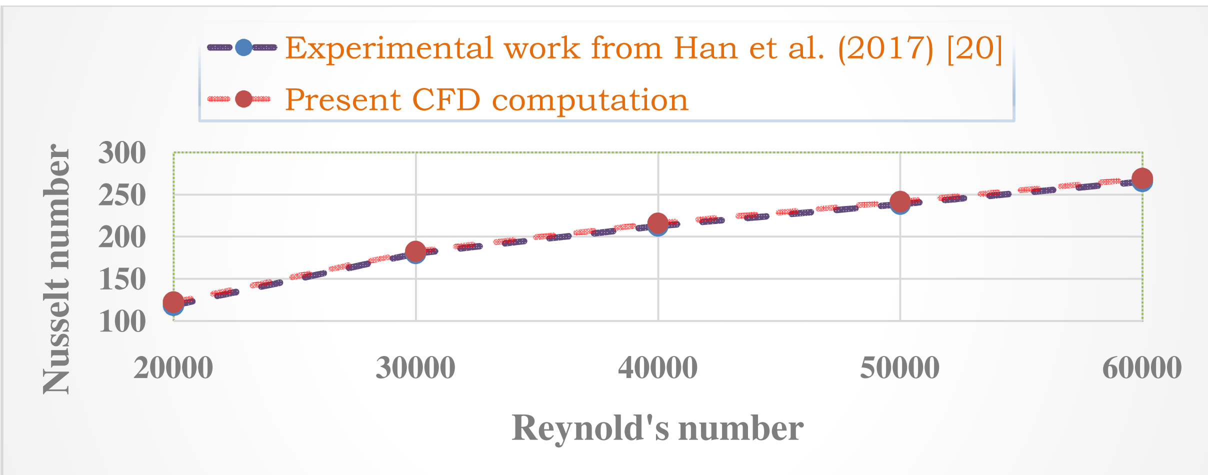


Figure 5. Values of Nusselt number calculated from the CFD modeling compared with the values obtained from the experimental test performed by Han et al. (2017) [20] for double pipe heat exchanger using nanofluid

From the above graph it is found that the value of Nu number calculated from numerical analysis is closer to value of Nu Number obtained from the base paper which means that numerical model of double pipe heat exchanger using nanofluid is correct. There is much lesser difference between experimental and numerical values.

5.3. Effect of suspension of Al-Al_2O_3 hybrid nano-particles in the cold fluid i.e. water of double pipe heat exchanger

From the numerical results and experimental data it is seen that variation tendencies in the values of Nusselt number are qualitatively consistent. So, to analyzing the effect of suspension of Al-Al_2O_3 hybrid nano-particles in the cold fluid to enhance thermal augmentation, we take two volume concentration of hybrid nanofluid i.e. 0.25, and 0.5 %.

- **At 0.25% volume concentration of Al-Al_2O_3/water hybrid nanofluid**

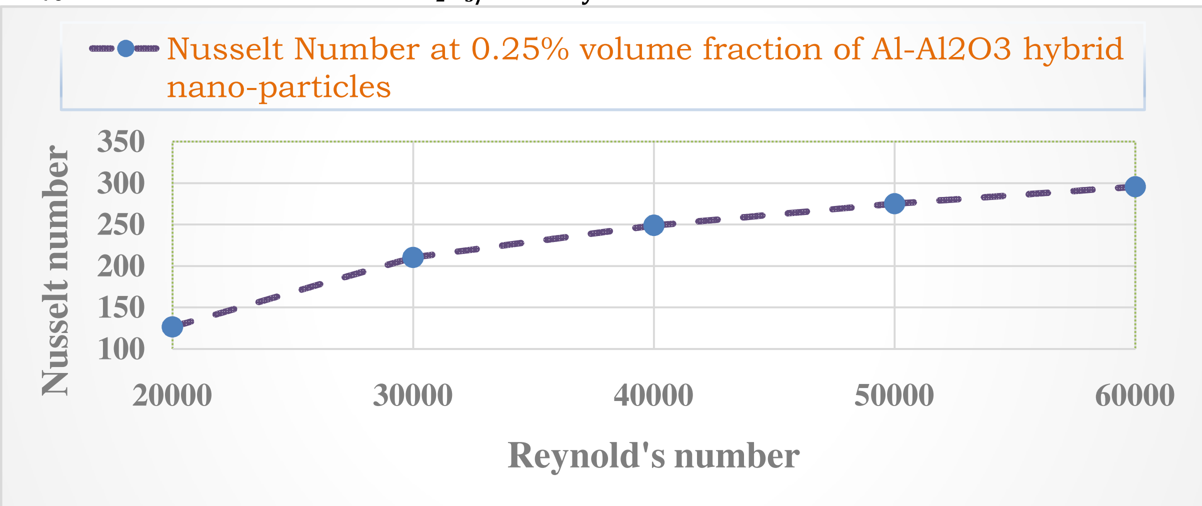


Figure 6. Value of Nusselt number at different Reynold's number for 0.25 percent volume fraction of Al-Al_2O_3 hybrid nano-particles.

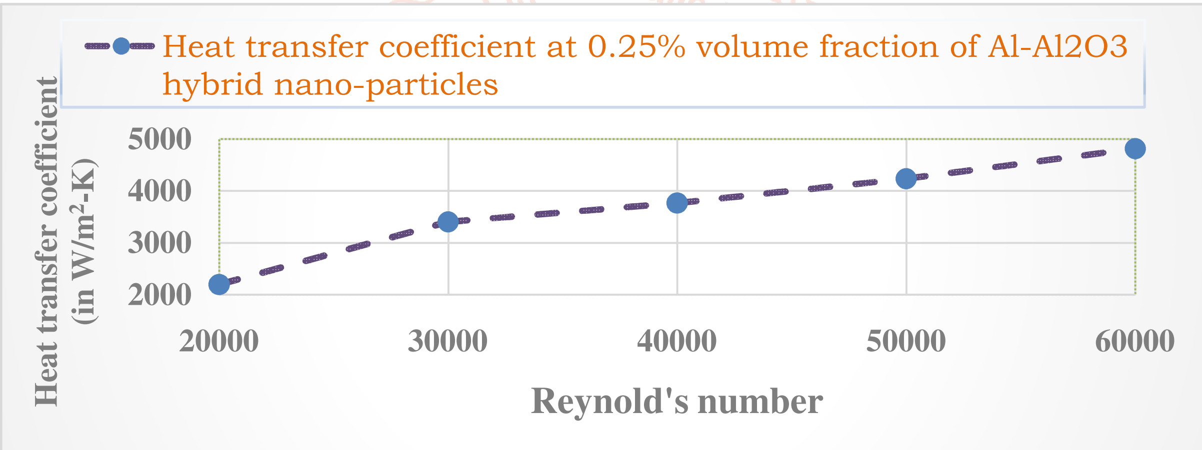


Figure 7. Value of heat transfer coefficient at different Reynold's number for 0.25 percent volume fraction of Al-Al_2O_3 hybrid nano-particles.

- **At 0.5% volume concentration of Al-Al_2O_3/water hybrid nanofluid**

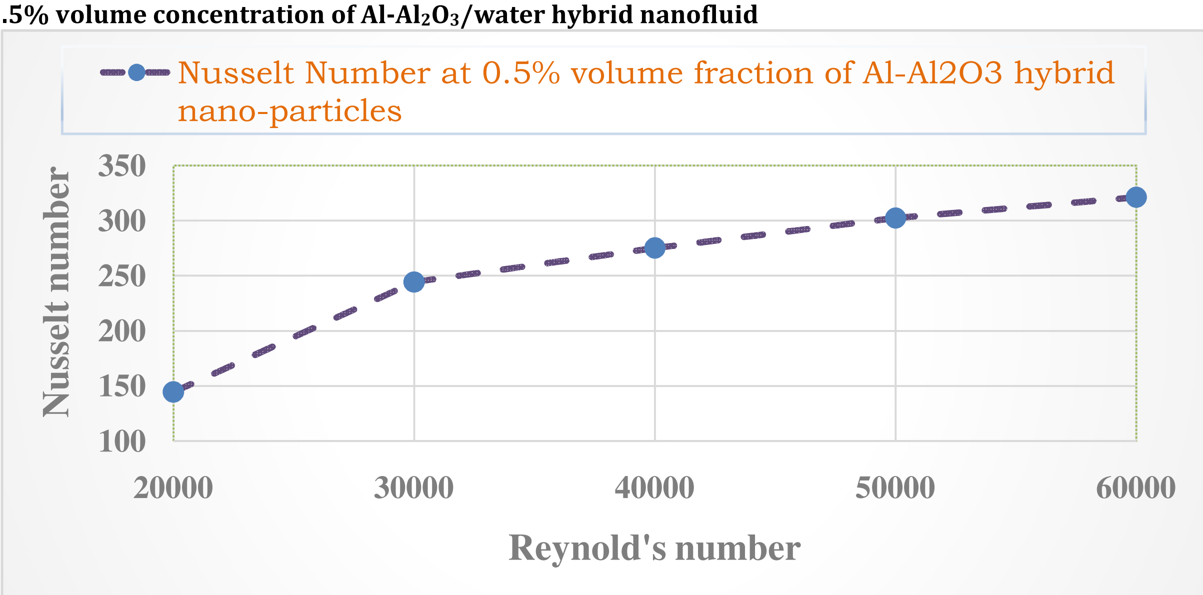


Figure 8. Value of Nusselt number at different Reynold's number for 0.5 percent volume fraction of Al-Al_2O_3 hybrid nano-particles.

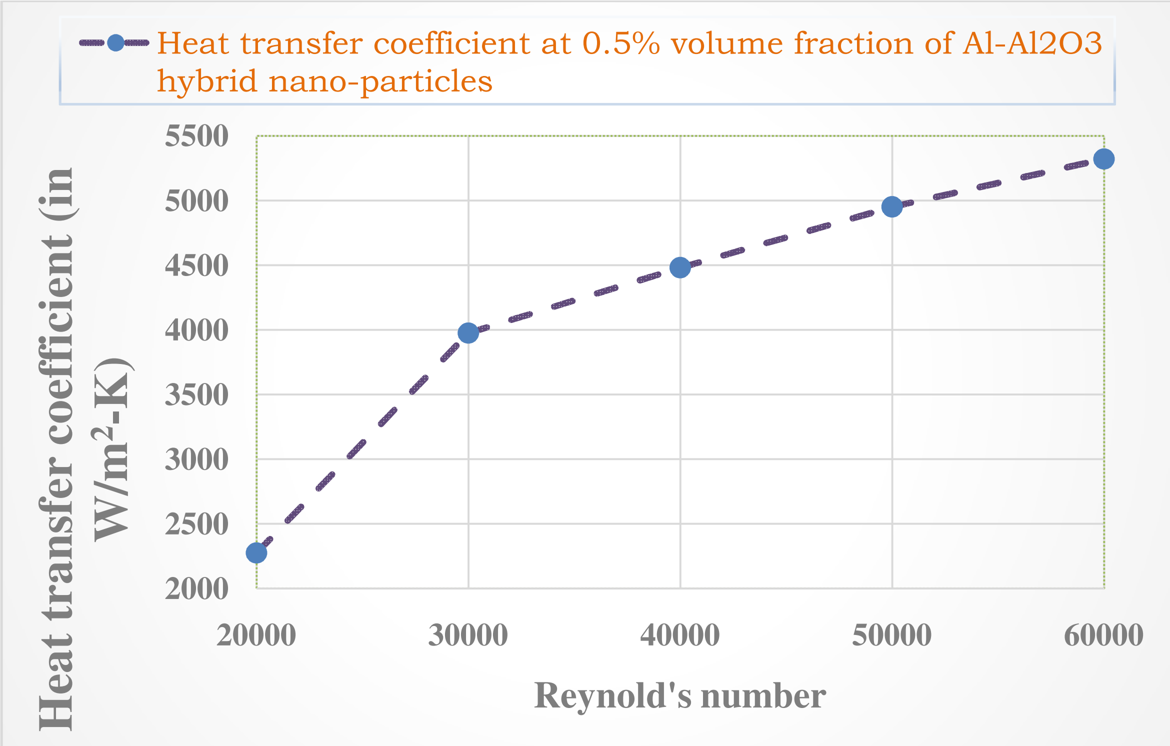


Figure 9. Value of heat transfer coefficient at different Reynold's number for 0.25 percent volume fraction of Al-Al_2O_3 hybrid nano-particles.

5.4. Comparison between Nanofluid fluid i.e. Al_2O_3/Water and Hybrid Nanofluid i.e. Al-Al_2O_3/water of different concentration at different Reynold's number

Table 7 Comparison of Nusselt number values for Nanofluid fluid i.e. Al_2O_3/Water and Hybrid Nanofluid i.e. Al-Al_2O_3/water of different concentration at different Reynold's number

Reynold's number	Nusselt Number			
	0.25% Al_2O_3	0.5% Al_2O_3	0.25% Al-Al_2O_3	0.5% Al-Al_2O_3
20000	118.50	135.62	126.44	144.51
30000	180.00	211.93	210.110	244.250
40000	212.65	231.29	248.84	275.146
50000	238.50	264.58	274.91	302.35
60000	265.64	288.74	295.518	321.11

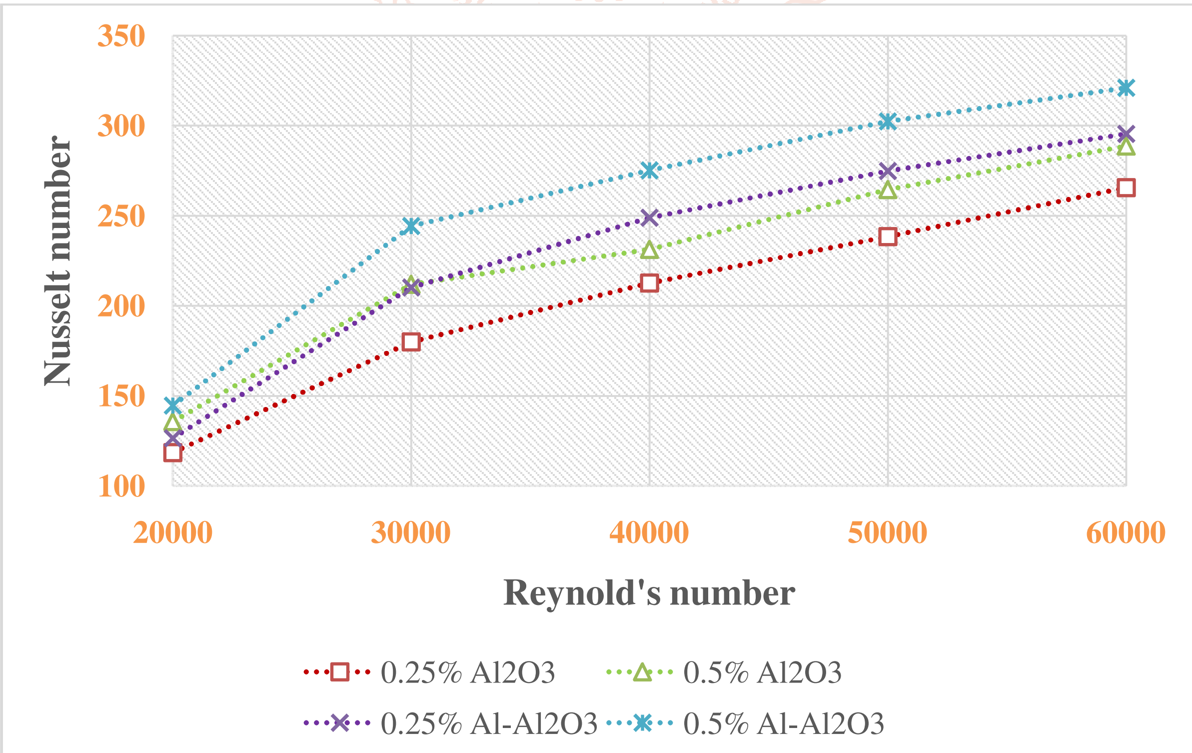


Figure 10. Comparison of Nusselt number values for Nanofluid fluid i.e. Al_2O_3/Water and Hybrid Nanofluid i.e. Al-Al_2O_3/water of different concentration at different Reynold's number.

Table 8 Comparison of Nusselt number values for Nanofluid fluid i.e. Al_2O_3/Water and Hybrid Nanofluid i.e. Al-Al_2O_3/water of different concentration at different Reynold's number

Reynold's number	Heat Transfer coefficient (in W/m^2-K)			
	0.25% Al_2O_3	0.5% Al_2O_3	0.25% Al-Al_2O_3	0.5% Al-Al_2O_3
20000	2022.63	2123.7	2192.143	2275.361
30000	3238.45	3501.39	3401.57	3974.49
40000	3632.87	4059.29	3766.473	4480.559
50000	3759.84	4672.911	4233.97	4950.773
60000	4573.87	5184.38	4814.47	5320.56

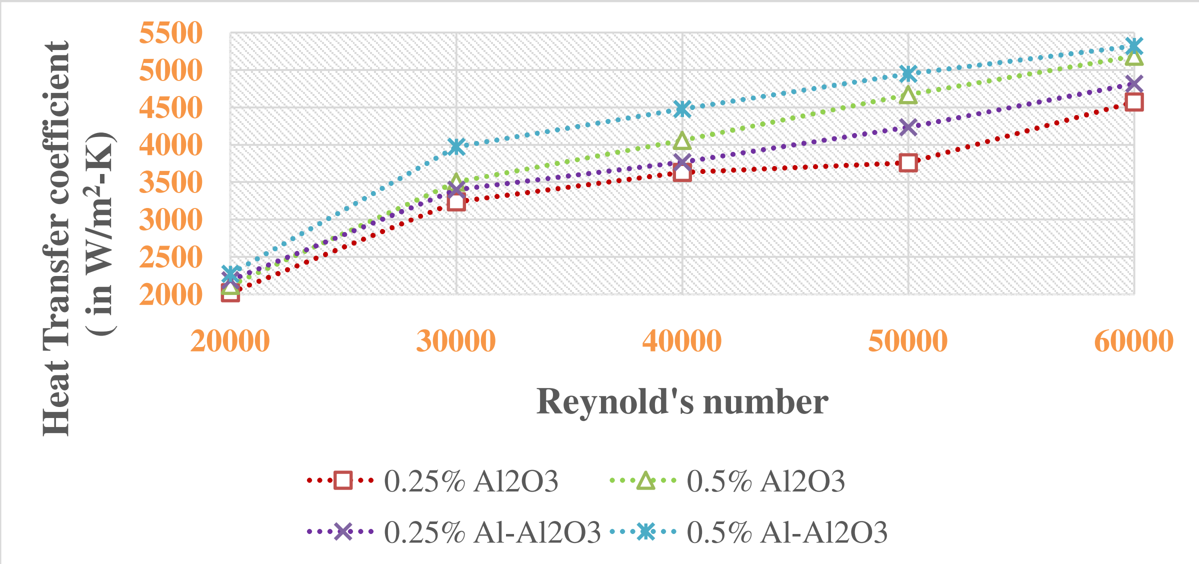


Figure 11 Comparison of Heat transfer coefficient values for Nanofluid fluid i.e. Al_2O_3/Water and Hybrid Nanofluid i.e. Al-Al_2O_3/water of different concentration at different Reynold's number

VI. CONCLUSIONS

This CFD research explores the impact on the performance of double pipe heat exchanger from Al-Al_2O_3/water hybrid nanofluid flow. The Al-Al_2O_3/water hybrid nanofluids with two volume concentrations of nanoparticles (i.e. 0.25, and 0.5 percent) were used.A strong agreement has been seen in the comparison of the findings of this research with the existing experimental results of the literature. The effect of Al-Al_2O_3/water hybrid nanofluid were measured and observed to influence the heat transfer and flow of fluids in a double pipe heat exchanger.The following conclusions can be drawn based on the provided results:

- The heat transfer coefficient of Al-Al_2O_3/water hybrid nanofluid is found to be 20%, and 35% at 0.25%, and 0.5% volume concentrations respectively higher than that of Al_2O_3/water nanofluid at the Reynold's number range of 20000–60000.
- This is simply because of the higher thermal conductivity of hybrid nanofluids and intensification of secondary flow formation leading to lower the residence time dispersion of hybrid nanoparticles and base fluids.
- The Nusselt number of Al-Al_2O_3/water hybrid nanofluid is found to be 11%, and 18% at 0.25%, and 0.5% volume concentrations respectively higher than that of Al_2O_3/water nanofluid at the Reynold's number range of 20000–60000.
- It is studied that the application 0.5% Al-Al_2O_3/water hybrid nanofluid in double pipe heat exchanger, the secondary flow generation becomes very strong and the Al-Al_2O_3 particles are thrown out towards the tube wall and resulting higher pressure drop than Al_2O_3 particles.
- These enhancements in overall heat transfer coefficient and Nusselt number are due to the improved higher thermal conductivity of hybrid nanofluids and generating stronger secondary flow.

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