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Effects of Al_2O_3-Cu/Water Hybrid Nanofluid on Heat Transfer of Double Pipe Heat Exchanger using CFD

Prof. Om Prakash[1], Prabha Shankar Kumar[2]

[1]Assistant Professor, [2]Research Scholar,
[1,2]Corporate Institute of Science and Technology, RGPV, Bhopal, Madhya Pradesh, India

ABSTRACT

The researchers have consistently observed higher heat transfer rates with different kinds of nanofluids (among others, Al_2O_3, Cu, CuO, Fe_3O_4, Fe_2O_3, CNT, nickel, Nano diamond, TiO_2, and SiO_2) flow in a tube under laminar or turbulent flow conditions. The heat transfer enhancement of nanofluids depends on particle concentrations, thermal conductivity of nanoparticles and mass flow rates. The thermal conductivity of nanoparticles may be altered or changed by synthesizing the hybrid (nanocomposite) nanoparticles and it is expected that fluids prepared with hybrid nanoparticles may cause further heat transfer enhancements. The hybrid nanoparticles may be defined as two or more different materials in the nanometer size; hybrid nanoparticles represent an area of nanotechnology, which is experiencing a marked growth due to its potential impact in material science and engineering.

In this Present work, a solid model of a double pipe heat exchanger is built. The main objectives of this research are to analyze the thermal efficiency of hybrid nano-fluid (Cu-Al_2O_3/Water) relative to single nano-fluid (Al_2O_3) and pure water. For which nanofluid and hybrid nanofluid passes through the tube side with 6mm diameter, while the hot fluid flows through the annulus side with a 16mm inside diameter and length 1000mm. For this we considered hot water is supplied to the outer tube at a volume flow rate of 3.5 litre/min at a temperature of 353 K, while Cu-Al_2O_3/Water based hybrid nanofluid of 0.3% volume concentration are supplied to the inner tube at different volume flow rate of 0.2, 0.4, 0.6, 0.8 and 1 litre/min at temperature of 301K. From the present study, it has been found that at 0.2, 0.4, 0.6, 0.8.and 1 liter per minute cold fluid flow rate and 3.5 liters per minute hot fluid flow rate the overall heat transfer coefficient is improved by 12 percent by the use of hybrid nano-fluid (Cu-Al_2O_3/Water) compared to single nano-fluid (Al_2O_3).

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KEYWORDS: *Heat Exchanger, Nanofluids, Hybrid Nanofluids, Heat Transfer, LMTD, Effectiveness, CFD*

I. INRODUCTION

Heat transfer systems have been used for heat transfer and recovery in a variety of commercial and domestic applications. For five decades, significant efforts have been made to improve a design of heat exchangers that can result in a reduction in energy requirements as well as material and other cost savings. Ways to improve heat transfer performance are referred to it as heat transfer enhancement (or increase or intensification). Nowadays, a significant number of thermal engineering investigators are looking for new ways to facilitate the transfer of heat between surfaces and ambient fluids.

Since its inception, nanotechnology has fascinated a number of researchers who have recently begun using nano-fluids in both experimental and theoretical science. The heat transfer characteristics of nanoparticles have allowed industries like the solar synthesis, gas sensing, biological sensing, chemical, nuclear reactors, chemical industries, etc. to include the nanoparticles to improve the heat transfer performance of normal fluids in their respective areas.

Previously, there have been several studies with two forms of nanoparticles embedded in the base fluid called "Hybrid Nanofluid," the cutting-edge nanofluid. The preferred theory of hybrid nanofluid use is that beneficial aspects can be strengthened and drawbacks can be dealt with through their synergistic effects by choosing the correct combination of nanoparticles.

Such hybrid nanofluids are relatively a new class of nanofluids with a range of possible uses in all areas of heat transfer, e.g. micro fluids, processing, shipping, protection, medical, military systems, acoustics, etc. Once nano-sized particles are adequately distributed, hybrid nanoparticles give a collosal gain with an exceptionally high efficient thermal conductivity. In specific, nanofluid flow is well established for high heat transfer compared to normal fluid. To order to improve it even more, a synthetic nanofluid is introduced.

1.1. Hybrid Nanofluid

Hybrid nanoparticles are classified as nanoparticles made up of two or more separate nanometer-sized materials. Fluids formed with hybrid nanoparticles are known as hybrid nanofluids.

Essential fluids such as water ethylene glycol, engine oil, and ethylene/water mixtures are widely used fluids for the preparation of hybrid nanofluids. The scale of the hybrid nanoparticles is very necessary and should be less than 100 nm in order to achieve stable hybrid nanofluids. The use of hybrid nanofluids is still quite limited; nevertheless, hybrid nanofluids may become the heat transfer fluid of the future for multiple potential applications.

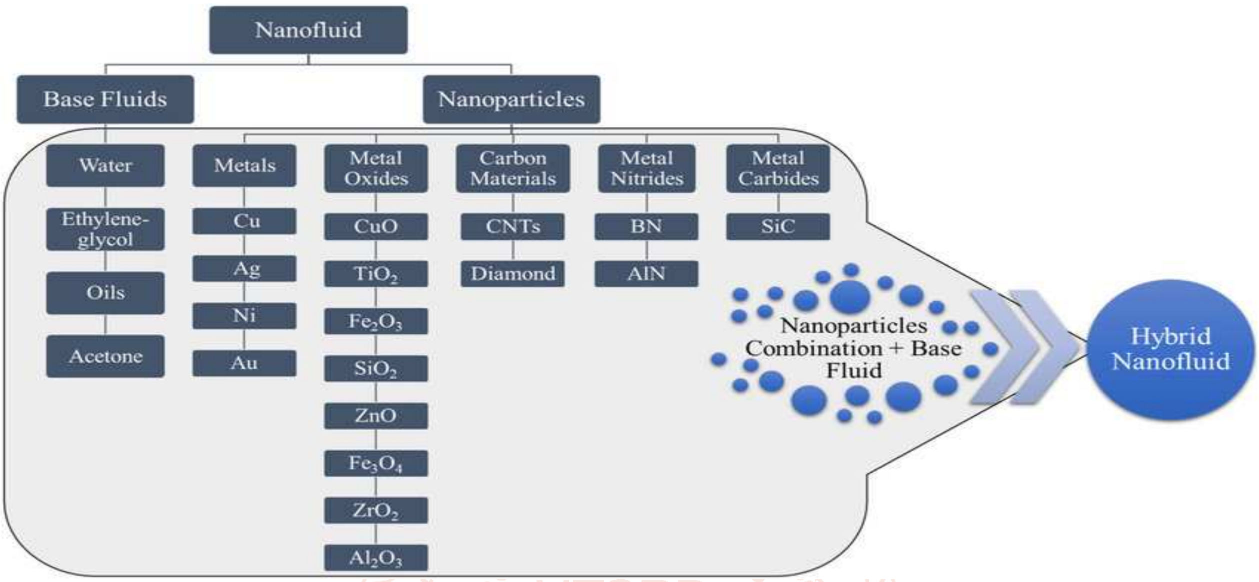

Figure1: Combination available for Hybrid Nano-fluid preparation.

II. LITERATURE REVIEW

Increased heat transfer has played a very important role in achieving significant cost and energy savings. Today's developments in science and technology are fueling the demand for exceptionally featured compact devices with the best performance, accurate functioning and long lifespan. As a consequence, researchers and scientists met to focus on the thermal management of heat transfer devices.

Superior thermal transfer properties of solids compared to traditional fluids allowed the investigators to introduce a new type of fluids with a mixture that was eventually formulated and referred to as "nanofluids”. Nanofluids have made a significant contribution to the historically utilized heat transfer enriching methods, such as mini-channel assistance and expanded surfaces (fins).

The revolutionary technique to improve the thermal properties of operating fluids includes the accumulation of Nanometric metallic and non-metallic particles of a dimension not approaching 100 nm in the base fluid.

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 into 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 into 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].

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 [20].

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

Guo et al. (2008) used sonication and sol-gel chemistry technique for the synthesis of silica (Si) coated carbon nanotube (CNTs) coaxial nano cables [24].

Li et al. (2009) prepared CNT/SiO_2 and CNT//SiO_2/Ag hybrid nanoparticles using plasma treatment [25].

Sundar et al. (2014) prepared Nano diamond-nickel (ND-Ni) nanocomposite (hybrid) nanofluids and determined experimentally the thermal conductivity and viscosity [26].

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 [27].

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 [28].

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 [29].

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.

III. RESEARCH OBJECTIVES

The present work deals with hybrid nanofluids, which have the ability to make a significant contribution to reducing the cost of heat exchange equipment by growing its performance and thus rendering it smaller and lighter. In fact, increased efficiency will lead to significant energy savings worldwide. The main objective of the current work is to investigate how heat transfer can be improved by variations in the thermodynamic properties of fluids with the aid of suspended hybrid nanofluids.

As we know, Nowadays, CFD is applicable to many manufacturing and technological issues, and nano-fluid heat transfer efficiency is no exception. So to analyze the heat transfer characteristics of a double pipe heat exchanger the simulating software ANSYS 14.5 were used.

The main objectives of the present work are as follows:

A. The main objectives of this research are to analyze the thermal efficiency of hybrid nano-fluid (Cu-Al_2O_3/Water) relative to single nano-fluid (Al_2O_3) and pure water.
B. To develop model of double pipe heat exchanger and Validation will be carried on CFD model with comparison of previous experimental model.
C. To improve LMTD as effect of increased heat transfer and to evaluate the enhancement of the overall heat transfer coefficient.
D. To improve Nusselt number as effect of increased heat transfer

IV. GEOMETRY SETUP AND MODELLING

The geometric dimension of the double pipe counter flow heat exchanger is shown in the Table 1and 2.

Table1: Geometric Dimension of Outer Tube

MATERIAL	STEEL
INTERNAL DIAMETER	16mm
OUTER DIAMETER	20mm
LENGTH	1000mm

Table2: Geometric Dimension of Inner Tube

MATERIAL	STEEL
INTERNAL DIAMETER	6 mm
OUTER DIAMETER	8 mm
LENGTH	1100mm

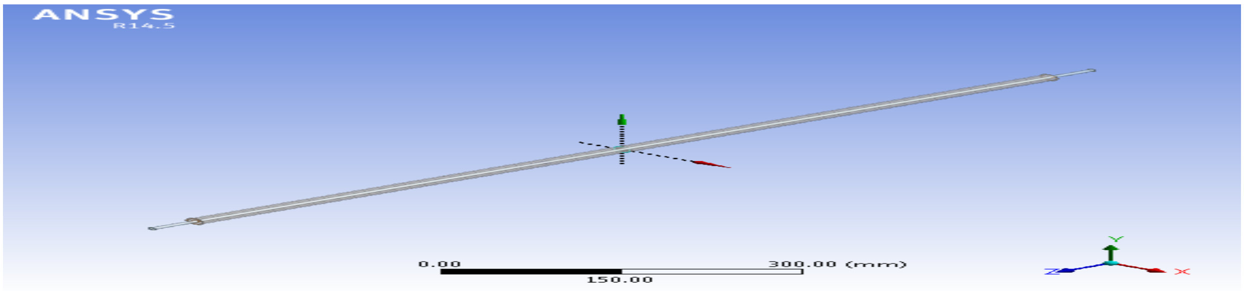

Figure2 Isometric view of double pipe heat exchanger

The CFD analysis of the heat exchanger is performed in the ANSYS Fluent module. The solid model of the heat exchanger m eshing is created. The use of ANSYS tools in meshing edge sizing has been achieved. Inflation is also a good contact net. Mesh comprises mixed cells per unit area (ICEM Tetrahedral cells) with tetrahedral and quadrilateral meshing at the boundary. Therefore, for the current problem, a mesh containing 768043 nodes and 2116626 elements has been developed. Increasing the node and item number would confuse the analysis unduly and will require heavy simulation software to help it. Boundary is taken as no slip boundary and the fine meshing is preferred for modes.

Just three parameters are used for model selection and the remaining parameter is the default value. The three parameters are: – Multiphase – Eulerian, Energy – On and Viscous – Standard k-ε Standard Wall Fn, Mixture.

CFD Computational equations can be listed below:-

Equation for Mass Conservation:-

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0.$$

Equation for change in rate of Momentum:-

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial p}{\partial x_j}.$$

Energy Equation:-

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_j}{\partial x_i}\right).$$

Where vector u (with elements of such velocity u, v, and w in x, y, and z directions), pressure P, viscosity μ, temperature T, as well as thermal conductivity k. Changes during these given liquid properties will happen. It project deals with only a steady state condition.

Table3: Material Properties

Specification	Water	Al_2O_3	Cu
Density (Kg/m³)	998	3970	8933
Specific Heat(J/Kg-K)	4182	750	385
Thermal conductivity(W/m-K)	0.598	46	400
Dynamic Viscosity(N-s/m²)	0.0007978	-------	-------

Table4: Al_2O_3/water based nanofluid thermophysical property.

Nanofluid Concentration / 3% volume	Thermal conductivity (W/m-K)	Density (Kg/m³)	Specific Heat(J/Kg-K)	Dynamic Viscosity (N-s/m²)
Al_2O_3 -Water	0.65131	1087.16	3806.1928	0.0008609

Now for defining the density, thermal conductivity, specific heat and viscosity of hybrid nanofluids **Suresh et. al. [33]** suggested the following equations:

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

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

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

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

Table5: $Cu\text{-}Al_2O_3$/water based hybrid nanofluid thermophysical property.

Nanofluid Concentration/ 3% volume(1.5%Alumina+1.5%Copper)	Density (Kg/m^3)	Specific Heat(J/Kg-K)	Thermal conductivity (W/m-K)	Dynamic Viscosity ($N\text{-}s/m^2$)
$Cu\text{-}Al_2O_3$/water	1161.605	3568.06	0.6532	0.0008609

Here in the analysis the boundary condition is same as considered by scholar's **Rohit S. Khedkar et al. [19]** during the experimental work. Some of the conditions are shown in the Table 6.

Table6: Boundary condition of different parameters

	Mass Flow rate(Litre/minute)	Temperature(K)
Cold Fluid ($Cu\text{-}Al_2O_3$/water based hybrid nanofluid)	0.2,0.4,0.6,0.8,1	301
Hot Fluid(water)	3.5	353

Flow is turbulent and counter flow conditions.

V. RESULTS AND DISCUSSIONS

We analyze the thermal efficiency of hybrid nano-fluid ($Cu\text{-}Al_2O_3$/Water). For this we considered hot water is supplied to the outer tube at a volume flow rate of 3.5 litre/min at a temperature of 353 K, while $Cu\text{-}Al_2O_3$/Water based hybrid nanofluid of 0.3% volume concentration are supplied to the inner tube at different volume flow rate of 0.2, 0.4, 0.6, 0.8 and 1 litre/min at temperature of 301K.

5.1. Temperature contour for $Cu\text{-}Al_2O_3$/Water based hybrid nanofluid of 0.3% volume concentration at flow rate of 0.2 Litre/min.

Here in this section cold fluid i.e. $Cu\text{-}Al_2O_3$/Water based hybrid nanofluid is flowing at a flow rate of 0.2 litre/min. Whereas the hot fluid is flowing at a flow rate of 3.5 litre/min. the temperature contour of heat exchanger for this flow rate is shown in the below fig.

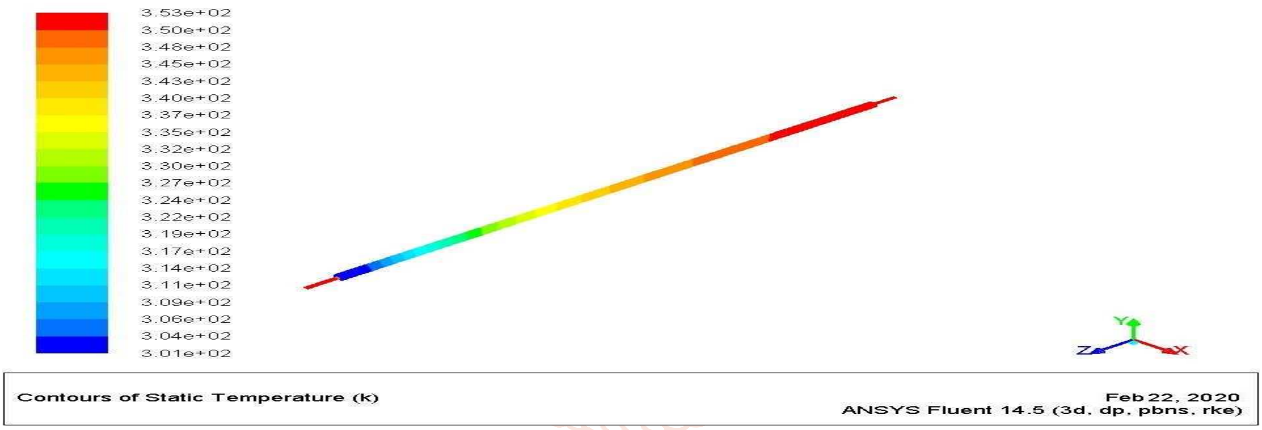

Figure3. Contours of static Temperature for $Cu\text{-}Al_2O_3$/Water based hybrid nanofluid of 0.3% volume concentration at 0.2 litre/min flow rate.

5.2. Temperature contour for $Cu\text{-}Al_2O_3$/Water based hybrid nanofluid of 0.3% volume concentration at flow rate of 0.4 Litre/min.

Here in this section cold fluid i.e. $Cu\text{-}Al_2O_3$/Water based hybrid nanofluid is flowing at a flow rate of 0.4 litre/min. Whereas the hot fluid is flowing at a flow rate of 3.5 litre/min. the temperature contour of heat exchanger for this flow rate is shown in the below fig.

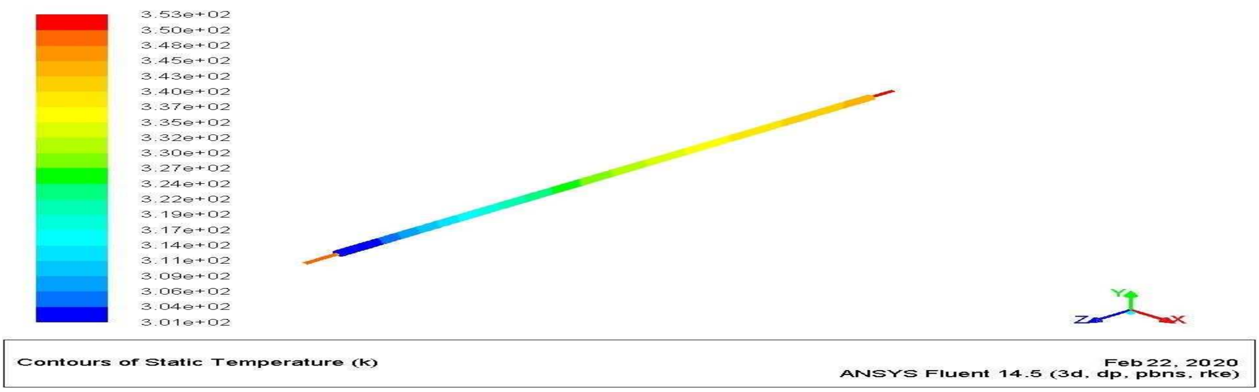

Figure4. Contours of static Temperature for $Cu\text{-}Al_2O_3$/Water based hybrid nanofluid of 0.3% volume concentration at 0.4 litre/min flow rate.

5.3. Temperature contour for Cu-Al_2O_3/Water based hybrid nanofluid of 0.3% volume concentration at flow rate of 1.0 Litre/min.

Here in this section cold fluid i.e. Cu-Al_2O_3/Water based hybrid nanofluid is flowing at a flow rate of 1.0 litre/min. Whereas the hot fluid is flowing at a flow rate of 3.5 litre/min. the temperature contour of heat exchanger for this flow rate is shown in the below fig.

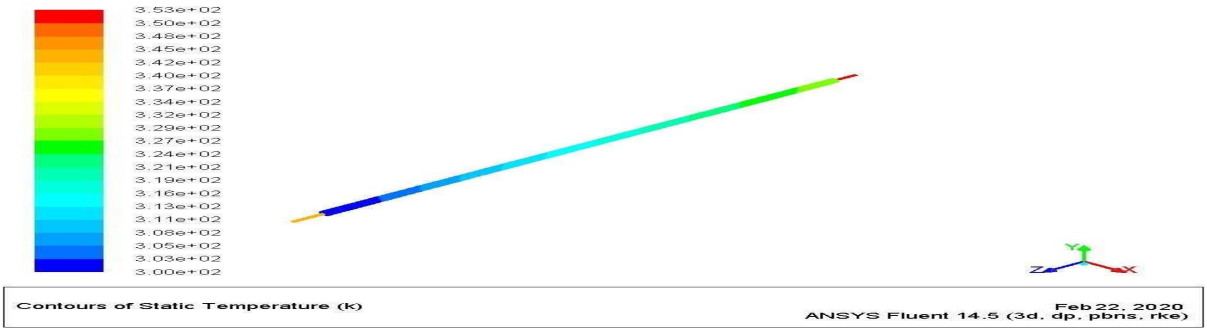

Figure5. Contours of static Temperature for Cu-Al_2O_3/Water based hybrid nanofluid of 0.3% volume concentration at 1.0 litre/min flow rate.

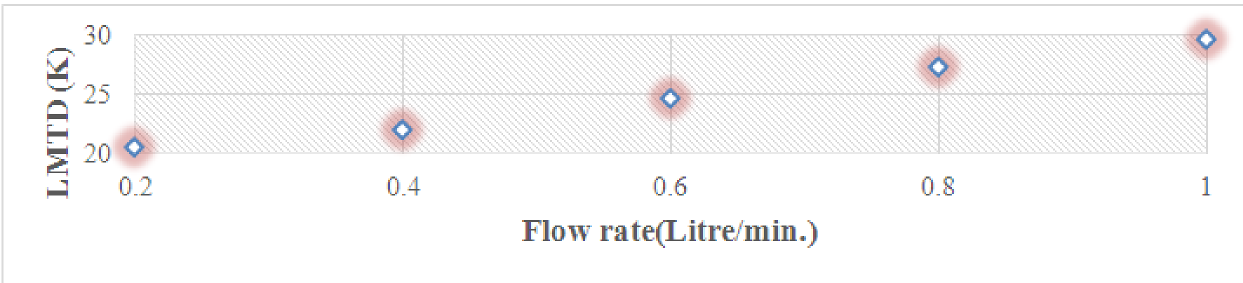

Figure6. Values of LMTD.at different flow rates for Cu-Al_2O_3/Water based hybrid nanofluid of 0.3% volume concentration.

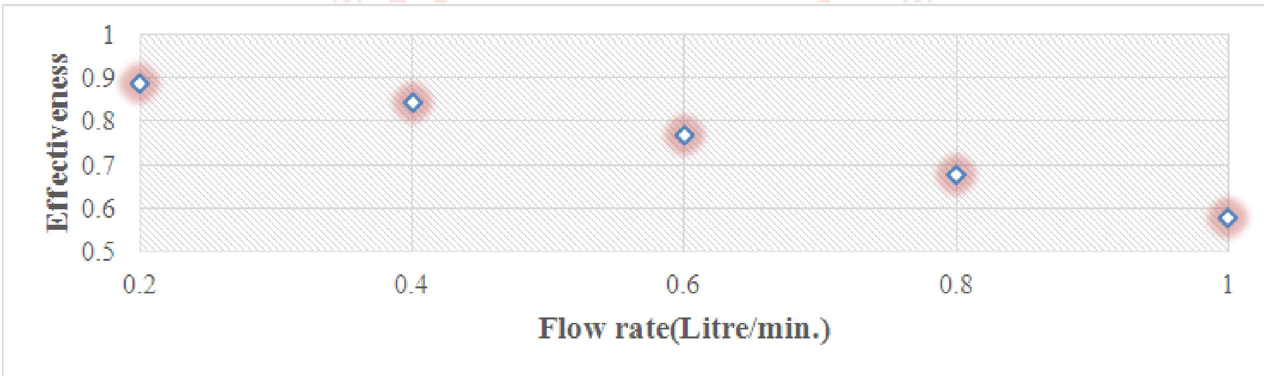

Figure7. Values of Effectiveness calculated for Cu-Al_2O_3/Water based hybrid nanofluid of 0.3% volume concentration.

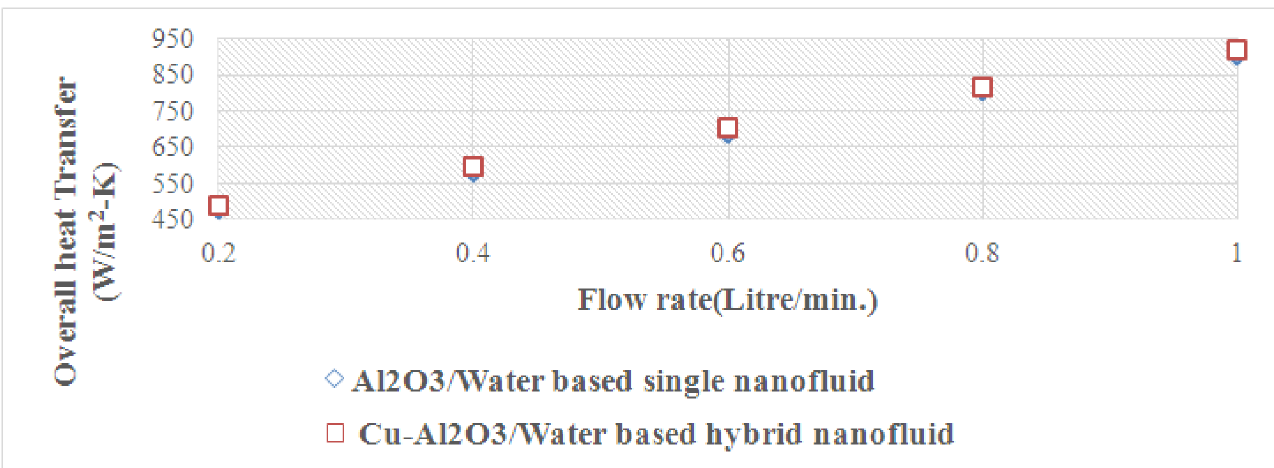

Figure8. Comparison of values of Overall heat transfer coefficient for hybrid nano-fluid (Cu-Al_2O_3/Water) relative to single nano-fluid (Al_2O_3).

VI. CONCLUSIONS

Nano-fluid has been used as a working fluid to improve the characteristics of heat transfer in industrial applications. In the present study, a computational analysis has been performed to establish the thermal and hydrodynamic activity of a new and advanced traditional nano-fluid called \hybrid nano-fluid, compared to today's pure water and popular nano-fluid.

Based on the results obtained by the CFD and the mathematical calculations, this is established;

- Normally, the presence of nanoparticles in the base fluid improves the property of convective heat transfer. Hybrid nanofluid is, however, more effective than nanofluid (at a steady concentration of volume).
- For hybrid nanofluids flowing in a tube, their increased viscosity is the main cause for the increase in friction.
- From the present study, it has been found that at 0.2, 0.4, 0.6, 0.8.and 1 liter per minute cold fluid flow rate and 3.5 liters per minute hot fluid flow rate the overall heat transfer coefficient is improved by 12 percent by the use of hybrid nano-fluid (Cu-Al_2O_3/Water) compared to single nano-fluid (Al_2O_3).
- Normally, the due to the presence of hybrid nanoparticles in the base fluid improves the LMTS with increase in flow rate but effectiveness reduces with increase in flow rate.

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