© February 2020 | IJIRT | Volume 6 Issue 9 | ISSN: 2349-6002

# Heat Transfer Enhancement in a Double Pipe Heat Exchanger using Bio-Nano fluid (Mango-Bark) using CFD

Rupesh Kumar Yadav[1], Prof. Animesh Singhai[2]
[1]*Trinity Institute of Technology and Research, Research Scholar, RGPV Bhopal, MP, INDIA*
[2]*Trinity Institute of Technology and Research, Professor, RGPV Bhopal, MP, INDIA*

***Abstract*- 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 "Nano fluids ". Nano fluids have made a significant contribution to the historically utilized heat transfer enriching methods, such as mini-channel assistance and expanded surfaces (fins). But most of the nanoparticles used are considered to be hazardous to humans and the environment. A significant research is therefore performed on bio-nanomaterials to which the atmosphere is inherently subjected.**

**In this study, a numerical investigation into the heat transfer characteristics of mango bark Nano fluids in a double pipe heat exchanger is carried out. 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 physiognomies of a double pipe heat exchanger the simulating software ANSYS 16.0 were used. The main objectives of this research are to analyze the thermal efficiency of Nano-fluid (Mango Bark-Water) relative to Nano-fluid Al2O3-Water. Based on the results obtained by the CFD and the mathematical calculations, this is established; there are great prospects for the use of these Bio-nan fluids as heat transfer fluids it being superior to the base fluid in terms of heat transfer characteristics.**

***Index terms*- Heat Exchanger, Heat Transfer Augmentation, Nano fluid, Bio-Nano fluid, Volume concentration of nanoparticle, Computational fluid dynamics, Thermal conductivity**

## I.INTRODUCTION

The demand for more efficient thermal systems in modern world has increased as a result of numerous environmental regulations and energy saving strategies [1, 2]. The economic reasons are persuading researchers to find new solutions to both reduce the size and energy consumption of industrial equipment [3].

The present science and technology advancement is growing demands for compact high-performance, reliable application and long-life devices with extraordinary functionality. The scientists and academics met to focus on the heat transfer system thermal management [4]. Higher thermal characteristics of solids in comparison to traditional fluids have encouraged scientists to later establish and referred to as "Nano fluids" in the new class of fluids by way of their mixture. The Nano scale development is a relatively new field of science that allows us to change the parameters we want for our designs [5].

Inherently, the Nano fluid is the colloid deposition of rigid Nano components into a fluid framework initially introduced by Choi in 1995[1]. Usually such solids are metallic, non-metallic, polymeric and bio-based. In many scientific fields, Nano fluids can be used for heat transfer procedures, tribology, surfactant / coating industries, pollution cleanup, improved oil recovery[ 2, 3], and new medical practices[ 4]. The presence of Nano-sized solid phase as a thermal transfer fluid improves the thermo physical properties of the fluid and makes it more thermal dissipation / storage efficient compared to its base than that of the operating fluid.

But most of the nanoparticles used are considered to be hazardous to humans and the environment. A significant research is therefore performed on bio-nanomaterial's to which the atmosphere is inherently subjected.

Nano fluid, a basic result of nanotechnology is turn into a point of fascination because of its extraordinary heat transfer execution in different zones including cooling, force era, barrier, atomic, space, microelectronics and numerous biomedical machines. Nano fluids are colloidal suspension of ultra-fine metallic or non-metallic particles in a given base liquid. Alongside different every other property, Nano fluids are surely understood for their high thermal conductivity and better reaction as a heat exchange medium. On expansive characterization, Nano fluids can be of two sorts, for example, metallic Nano fluids and non-metallic Nano fluids and bio-Nano fluids. Metallic Nano fluids are arranged by scattering nano-particles of metals, for example, Aluminium, copper, nickel and so on and non-metallic Nano fluids are made by scattering nano-particles of non-metals i.e. metal oxides, different types of carbon (Graphene, CNT) and so on.

1.1 Nano fluid Synthesis

Planning of Nano fluids is the first stride to the exploratory investigations of Nano fluids . The best possible use of the capability of Nano fluids relies on upon the planning of Nano fluids . There are two principle routines to set up a Nano fluid: The single-step planning procedure and the two-stage arrangement process.

1.1.1 Single-step synthesis process

The single-step readiness procedure demonstrates the blend of Nano fluids in one-stage. A few single-step systems have been touched base for Nano fluid readiness. Akoh et al. investigated and built up a solitary step direct dissipation technique. In this technique the vaporized metal is dense and after that scattered by deionized water to deliver Nano fluids . Leverage of blend by one-stage strategy is that Nano-particles agglomeration is minimized. Be that as it may, prime issue is that just low vapor weight liquids are good with such a procedure. One-stage arrangement process (chemical procedure) of Nano fluids is given in the Figure 1.7.

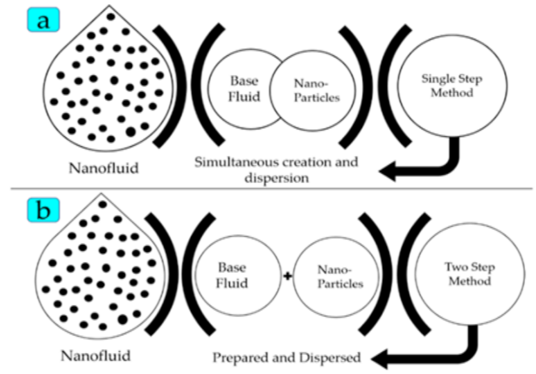


Figure 1: (a) One-step preparation, (b) two-step process of Nano-fluids.

1.1.2 Two-step preparation process

Two-stage arrangement procedure is broadly utilized as a part of the union of Nano fluids by blending base liquids with industrially accessible Nano powders got from diverse mechanical, physical and substance procedures, for example, processing, crushing, and vapor stage techniques. An ultrasonic vibrator or higher shear blending gadget is for the most part used to blend Nano Powders with host liquids. Incessant utilization of Ultra Sonication blending is obliged to lessen molecule agglomeration. A few writers proposed that two-stage procedure is exceptionally suitable for get ready Nano fluids containing oxide Nano-particles than those containing metallic Nano-particles. Steadiness is a major issue that intrinsically identified with this operation as the powders effectively combine because of solid van-der-wall forces among Nano-particles. Regardless of such weaknesses this procedure is still prominent as the most financial procedure for Nano fluids generation. The most widely recognized two -step strategy is indicated in Figure1.

1.2. Stability of Nano fluids

Nano fluids have an undesirable propensity which influences their capability to exchange heat because of their inclination to coagulation. Subsequently, investigation on steadiness is an unavoidable issue that can change the thermo-physical properties of Nano fluids for application furthermore essential to dissect the compelling variables to the dependability of such suspensions. Underneath said is a brief talk on the strength development routines and dependability upgrade forms alongside a brief about the steadiness instruments identified with Nano fluids.

1.3 Advantages of Nano fluids

Nano fluids cause drastic change in the properties of the base fluid so, the following benefits are expected to get on.

- Due to nano size particles, pressure drop is minimum.
- Higher thermal conductivity of nanoparticles will increase the heat transfer rate.
- Successful employment of Nano fluid will lead to lighter and smaller heat exchanger.
- Heat transfer rate increases due to large surface area of the nanoparticles in the base fluid.
- Nano fluids are most suitable for rapid heating and cooling systems.
- Due to nano size particles, fluid is considered as integral fluid.
- Good mixture Nano fluids will give better heat transfer.
- Microchannel cooling without clogging. Nano fluids are not only a better medium for heat transfer in general but they are also ideal for microchannel applications where high heat loads are needed.
- Cost and energy saving. Successful employment of Nano fluids will result in significant energy and cost savings because heat exchange systems can be made smaller and lighter.

1.4 Bio based Nano fluids

Given the advantages of using these Nano fluids, there are real health and environmental issues associated with their use. The use of Nano fluids is therefore restricted due to the fact that most commonly available Nano fluids are poisonous, dangerous and unsafe to humans and animals, either by inhalation, absorption and penetration or otherwise, and are also harmful to the environment as stated by researchers.

Additionally, environmental concerns due to use of non-biodegradable materials have been raised: researchers reported that there is amplified toxicological pollution on the environment due to the shape, size and chemical compositions of some of the nanotechnology products. They suggest that choosing less toxic materials will make huge positive impacts on the environment. Laboratory studies have shown that many nanoparticles, specifically those made of silver, copper, and zinc, have anti-microbial properties. While they may be useful for some medical applications, the introduction of such particles into the natural environment could pose a threat to beneficial microbial communities (bacteria, fungi, and archaea) such as those found in the soil.

Bio-nanoparticles which may be gotten from leaves, wood char and seeds could be environmentally friendly since humans are naturally exposed to these nanoparticles.

## II. LITERATURE REVIEW

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 [7]. 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 [8]. 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 [9].

In 1995, the work of Choi revolutionized the field of heat carrying fluids when first time fabricated the Nano fluids that exhibited enhanced thermal transport properties with better stability in comparison of fluids containing the milli and micro sized solid particles [10].

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

Pak and Cho (1998) conducted heat transfer and friction factor experiments for Al2O3/water and TiO2/water Nano fluids 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 [11].

Later on, Xuan and Li (2001) used Cu/water and Cu/transformer oil Nano fluids 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 Nano fluid flowing in a tube at a Reynolds number of 25000 and they report separated Nusselt number correlations for laminar and turbulent flow, respectively [12,12].

Wen and Din (2004) conducted heat transfer experiments for Al2O3/water Nano fluid 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) [14].

Heris et al. (2007) also used Al2O3/water Nano fluids in a tube under laminar flow and observed heat transfer enhancement using constant wall temperature boundary conditions [15].

Williams et al. (2008) reported convective heat transfer enhancement with alumina/water and zirconia/water Nano fluids flow in a horizontal tube under turbulent flow [16].

Duangthongsuk and Wongwises (2010) found heat transfer enhancement of 20% and 32% for 1.0% vol of TiO2/water Nano fluid flowing in a tube at Reynolds numbers of 3000-18000, respectively [17].

Moraveji et al. (2011) simulated water-Al2O3 Nano fluid 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 [18].

Ghozatloo et al. (2014) obtained heat transfer enhancement of 35.6% at a temperature of 38 °C for 0.1 wt% of graphene/water Nano fluids flow in a tube under laminar flow [19].

Sundar et al. (2012) found heat transfer enhancement of 30.96% with a pumping penalty of 10.01% for 0.6% vol of Fe3O4/water Nano fluid flow in a tube at a Reynolds number of 22000 [20].

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 Nano fluid flow in a tube at a Reynolds number of 22000 [21].

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 [22].

Chandrasekhar et al. (2017) experimentally investigated and theoretically validated the behavior of Al2O3/water Nano fluid that was prepared by chemical precipitation method. For their investigation, Al2O3/water at different volume concentrations was studied. They concluded that the increase in viscosity of the Nano fluid 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 [23].

Hady et al. (2017) experimentally investigated the performance on the effect of alumina water (Al2O3/H2O) Nano fluid in a chilled water air conditioning unit. They made use of various concentrations ranging from 0.1-1 wt % and the Nano fluid 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 [24].

Rohit S. Khedkar et al. (2017): experimental study on concentric tube heat exchanger for water to Nano fluids heat transfer with various concentrations of nanoparticles in to base fluids and application of Nano fluids as working fluid. Overall heat transfer coefficient was experimentally determined for a fixed heat transfer surface area with different volume fraction of Al2O3 nanoparticles in to base fluids and results were compared with pure water. It observed that, 3 % Nano fluids shown optimum performance with overall heat transfer coefficient 16% higher than water [25].

Akyürek et al. (2018) experimentally investigated the effects of Al2O3/Water Nano fluids at various concentrations in a concentric tube heat exchanger having a turbulator inside the inner tube. Comparisons were done with and without Nano fluid 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 Nano fluid at various volume concentrations, changes in heat transfer coefficient, effect of the difference of pitch of turbulators on the heat transfer of Nano fluid 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 [26].

The researchers have constantly observed higher heat transfer rates with different varieties of Nano fluids (among others, Al2O3, Cu, CuO, Fe3O4, Fe2O3, CNT, nickel, Nano diamond, TiO2, and SiO2) flow in a tube under laminar or turbulent flow conditions. The increase in the heat transfer of Nano fluids depends on the concentration of particles, thermal conductivity of nanoparticles and the rate of mass flow.

The above-mentioned researchers had studied various aspects of Nano fluids and various methods to implemented Nano fluids to enhance heat transfer rate in various heat exchangers.

In some research papers, the study is focused on an increase in the effectiveness of Nano fluid. However, in some paper study is focused on Nano fluid and their effect on, effectiveness, Heat transfer and overall heat transfer coefficient. There was no significant work found using biomaterial nanoparticles in double pipe heat exchanger for heat transfer enhancement.

The use of biomaterial nanoparticles in a base fluid under forced convection in a heat exchanger has not been addressed thoroughly in the literature. Thus, there is a gap in the literature that address the forced convection heat transfer of biomaterial Nano fluid.

In this study, a numerical investigation into the heat transfer characteristics of mango bark Nano fluids in a double pipe heat exchanger is carried out. 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 physiognomies of a double pipe heat exchanger the simulating software ANSYS 16.0 were used. The main objectives of this research are to analyze the thermal efficiency of nano-fluid (Mango Bark-Water) relative to nano-fluid Al2O3-Water.

## III.METHODOLOGY

To create a CFD model with a double pipe heat exchanger, a solid heat exchanger model must be developed first. In this study, a solid model of a double pipe heat exchanger is built on the basis of different geometric parameters of heat exchanger. The geometric dimension of the double pipe counter flow heat exchanger is shown in the Table 1.

Table 1. Value of different geometric parameters of heat exchanger

| Parameters | Values |
|---|---|
| Tube length | 1.3 m |
| Inner tube diameter | 12 mm |
| Tube wall thickness | 2 mm |
| Outer tube diameter | 33 mm |
| Pitch of turbulator | 39 mm |

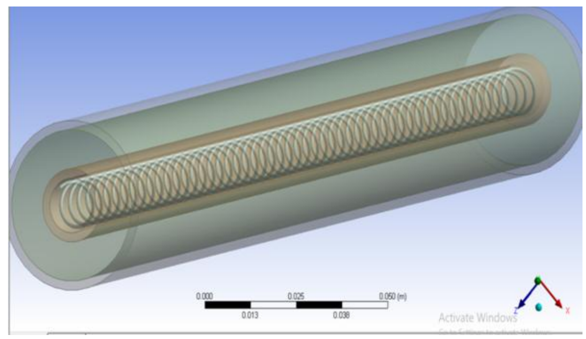

Figure 2. Solid model of heat exchanger with helical turbulator

The CFD analysis of the heat exchanger is performed in the ANSYS Fluent module. The solid model of the heat exchanger meshing is created.For the current problem, a mesh containing 768043 nodes and 2116626 elements has been developed. For model selection three parameters are: – Multiphase – Eulerian, Energy – On and Viscous – Standard k-ε Standard Wall Fn, Mixture.

Table 2: Material Properties

| Specification | Water | $Al_2O_3$ | Mango-Bark |
|---|---|---|---|
| Density (Kg/m$^3$ ) | 998 | 2719 | 1589 |
| Specific Heat(J/Kg-K) | 4182 | 871 | 2310 |
| Thermal conductivity(W/m -K) | 0.598 | 37.14 | 0.873 |
| Dynamic Viscosity(N-s/m$^2$) | 0.00100 2 | ------- | ------- |

Pak and cho [27], Patel [28] suggested the below equations for determining density, thermal conductivity, specific heat and viscosity of nanofluids.

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

$$(\rho C_p)_{nf} = (1 - \emptyset_p)(\rho C_p)_{bf} + \emptyset_p (\rho C_p)_p$$

$$K_{nf} = K_{bf} \left\{ \frac{K_p + 2K_{bf} - 2\emptyset_p (K_{bf} - K_p)}{K_p + 2K_{bf} + \emptyset_p (K_{bf} - K_p)} \right\}$$

$$\mu_{nf} = \frac{\mu_{bf}}{(1 - \emptyset)^{2.5}}$$

*Where,*

$\emptyset_p$ = Volume concentration of nanoparticle dispersed in water.

$\rho_{nf}$ = Density of nanofluid.

$\rho_{bf}$ = Density of base fluid.

$\rho_p$ = Density of nanoparticle.

$(C_p)_{nf}$ = Specific heat of nanofluid.

$(C_p)_{bf}$ = Specific heat of base fluid.

$(C_p)_p$ = Specific heat of nanoparticle.

$K_{nf}$ = Thermal conductivity of nanofluid.

$K_{bf}$ = Thermal conductivity of base fluid.

$K_p$ = Thermal conductivity of nanoparticle.

$\mu_{nf}$ = Dynamic viscosity of nanofluid.

$\mu_{bf}$ = Dynamic viscosity of base fluid.

Table 3. Properties of $Al_2O_3$-$H_2O$ nanofluid

| Concentration (% by weight) | Density (kg/m$^3$) | Specific heat (J/kg-K) | Thermal Conductivity (W/m-K) | Dynamic viscosity (Pa-s) |
|---|---|---|---|---|
| 0.4 | 1010.008 | 4128.0980 | 0.602 | 0.001120 |
| 0.8 | 1022.016 | 4075.4627 | 0.613 | 0.001260 |
| 1.2 | 1033.664 | 4024.0500 | 0.620 | 0.001440 |
| 1.6 | 1034.024 | 3998.7886 | 0.627 | 0.001580 |

Table 4. Properties of $Al_2O_3$-$H_2O$ nanofluid

| Concentration (% by weight) | Density (kg/m$^3$) | Specific heat (J/kg-K) | Thermal Conductivity (W/m-K) | Dynamic viscosity (Pa-s) |
|---|---|---|---|---|
| 0.4 | 1000.364 | 4170.10 | 0.598 | 0.00103 |
| 0.8 | 1002.728 | 4158.267 | 0.599 | 0.00102 |
| 1.2 | 1005.092 | 4146.48 | 0.600 | 0.00103 |
| 1.6 | 1007.456 | 4134.75 | 0.601 | 0.00104 |

Here in this work hot water is flowing in the outer tube, whereas the cold fluid is flowing in inner tube. The inlet temperature of hot water is 343 K whereas the inlet temperature of cold fluid is 293 K. The velocity of hot fluid is considered as 0.0084 m/s as considered in base paper, calculated at Re=4000, at 343K. The velocity of cold fluid changes as the Reynolds number of cold fluid changes.

## IV. RESULTS AND DISCUSSIONS

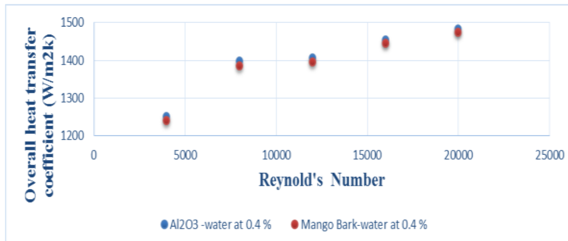


Figure 3. Comparison of overall heat transfer coefficient for (Al2O3)-water and Mango bark-water nano fluids at 0.4 % volume fraction

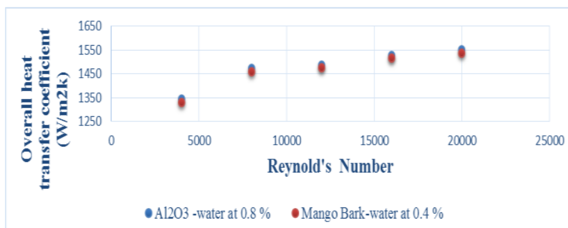


Figure 4. Comparison of overall heat transfer coefficient for (Al2O3)-water and Mango bark-water nano fluids at 0.8 % volume fraction

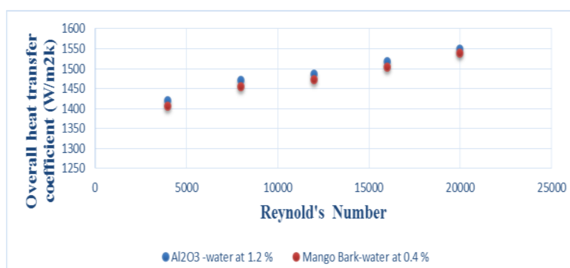


Figure 5. Comparison of overall heat transfer coefficient for (Al2O3)-water and Mango bark-water nano fluids at 1.2 % volume fraction

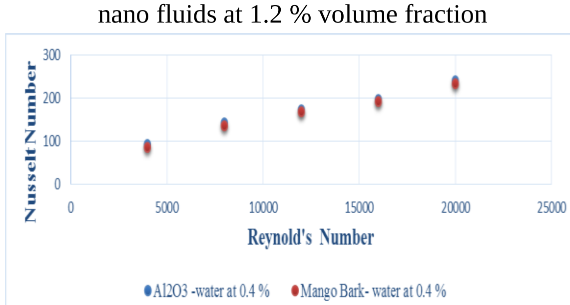


Figure 6 Comparison of Nusselt number for (Al2O3)-

water and Mango bark-water nano fluids at 0.4 % volume fraction

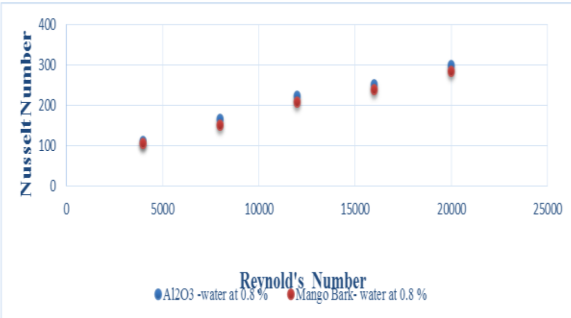


Figure 7. Comparison of Nusselt number for (Al2O3)-water and Mango bark-water nano fluids at 0.8 % volume fraction

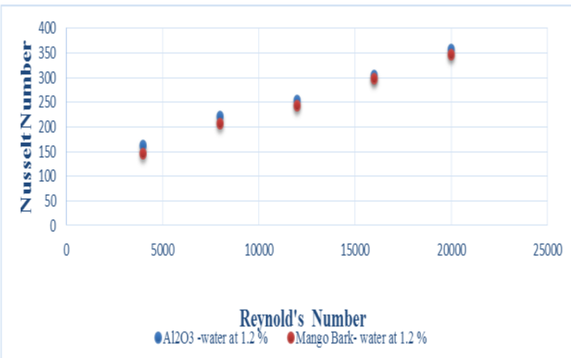


Figure 8. Comparison of Nusselt number for (Al2O3)-water and Mango bark-water nano fluids at 1.2 % volume fraction

## V. CONCLUSIONS

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

- Normally, the presence of Mango-bark nanoparticles in the base fluid improves the property of convective heat transfer. Al2O3-water nanofluid is, however, more effective than Mango-bark nanoparticles nanofluid (at a steady concentration of volume).
- Numerical tests have shown that the average coefficient of heat transfer increases in line with the Reynold's number.
- For Bio-nanofluids flowing in a tube, their increased viscosity is the main cause for the increase in friction.
- From analysis it is found that the value of Nu number and overall heat transfer coefficient is higher in case of Aluminum oxide (Al2O3) as compared to Aluminum oxide Mango-bark by 5%.
- Hence there are great prospects for the use of these Bio-nanofluids as heat transfer fluids it being superior to the base fluid in terms of heat transfer characteristics.

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