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# Photonic Sintering Techniques for Nano Tubes

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## ABSTRACT

Photonic sintering is a low ADVANCED MANUFATURING SYSTEMS exposure sintering method developed to sinter nanoparticle thin films. The process involves using a xenon flash lamp to deliver a high intensity, short duration (< 1 ms), pulse of light to the deposited nanoparticles. Photonic sintering was developed by Nanotechnologies (now NovaCentrix) of Austin, Texas, and was first made public in 2006 (Schroder et al., 2006). As photonic sintering is a new technology it is also known as pulsed ADVANCED MANUFATURING SYSTEMS processing (PTP) (Camm et al., 2006) and intense pulsed light (IPL) sintering (Kim et al., 2009). Conductive thin films composed of nanoparticle depositions, when exposed to a short pulse of high intensity light, are transformed into functional printed circuits.

## INTRODUCTION

Photonic sintering is a low ADVANCED MANUFATURING SYSTEMS exposure sintering method developed to sinternanoparticle thin films. The process involves using a xenon flash lamp to deliver a highintensity, short duration (< 1 ms), pulse of light to the deposited nanoparticles. Photonic sintering was developed by Nanotechnologies (now NovaCentrix) of Austin, Texas, and was first made public in 2006 (Schroder et al., 2006). As photonic sintering is a new technology it is also known as pulsed ADVANCED MANUFATURING SYSTEMS processing (PTP) (Camm et al., 2006) and intense pulsed light (IPL) sintering (Kim et al., 2009). Conductive thin films composed of nanoparticle depositions, when exposed to a short pulse of high intensity light, are transformed intofunctional printed circuits. The printed circuits can be tailored for use as flexible circuit boards, RFID tags, flat panel displays (Carter & Sears, 2007), photovoltaics, smartpackaging (Novacentrix, 2009). One of the primary advantages of the method is that the high intensity pulse of light produces minimal damage on low temperature substrates. This allows the nanoparticles to be deposited and cured on a high variety of low temperature substrates such as cloth, paper, and Mylar (Carter & Sears, 2007; Farnsworth, 2009). Another advantage of using photonic curing is the speed at which nanoparticle depositions can be sintered. Rather than spending hours in an oven or programming a laser to follow the deposition path, the photonic curing process can sinter large areas (~ 200 cm2 per 10 cm long lamp) in < 2 ms (Novacentrix 2009).

One of the main objectives of the work reported here was to determine the effectiveness of photonic sintering of silver

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nanoparticle depositions. This was done by measuring the densification of silver nanoparticles films following photonic sintering. The absorption of light emitted by a flash lamp for varying thicknesses of silver nanoparticle layers was also measured. To determine the amount and depth of sintering, SEM images were taken of a cross section of a sintered film. To better understand the process through which the nanoparticles are sintered, we calculate the absorption of the light emitted by the flash lamp by the silver nanoparticle film using the Bruggeman effective medium theory. Using the heat transfer software package Fluent™ to model the temperature profile of the films during and following sintering, we propose a model for the photonic process.

## 1.1 PHOTONICSINTERING OVERVIEW:

Photonic sintering was first introduced at the 2006 NSTI Nanotechnology Conference andTrade Show (Schroder et al., 2006). It was developed by NovaCentrix for the purpose ofrapidly sintering metal nanoparticle based films (Schroder et al., 2006). The technology allows the nanoparticles to sinter without significantly raising the temperature of the substrate. This is accomplished by using a flash lamp. Two main parameters control the degree of sintering: the intensity of the lamp and the duration of the light pulse. The flash lamp is held between 0.5 cm to 20 cm above the deposition and an intense current is run through the flash lamp (Novacentrix, 2007). Due to this intense current, the xenon flash lamp issues a high intensity, broad spectrum pulse of light. This pulse of light is absorbed by the nanoparticles, which heats them to such a degree that they sinter into a single component.

After observing the comparisons to traditional sintering methods, experiments were run to gain insight into the process by which particles are sintered during photonic curing. The densification as a function of the flash lamp voltage and pulse duration was measured to determine the effects of those parameters. Depositions of varying thickness were tested using a UV-Vis spectrometer to measure the absorption of the depositions in the wavelength region produced by the flash lamp. Finally, SEM images were taken of the cross section of a thick sintered sample To determine the depth and amount of sintering in the deposition.

## 1.2 PARAMETRIC STUDY OF DENSIFICATION:

We measured the densification of silver nanoparticles as a function of the pulse duration and flash lamp voltage to find the optimal settings to sinter V2 silver ink. The V2 silver ink consists of Novacentrix 25 nm silver nanoparticles suspended in DMA. The measurements also allow a determination of the effect of lamp voltage and pulse duration on the sintering process.

The process of measuring the densification began by finding the volume fraction of nanoparticles in the deposition prior to sintering. This was accomplished by weighing a clean glass slide and then depositing V2 ink in a square pattern on the slide. The thickness of the deposition was then measured using a Zeiss Imager M1M microscope. The deposition thickness was determined by focusing on the surface of the glass slide and then again on the surface of the deposition. The focal distances were then compared to find the thickness of the deposition.

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**Figure 1.1 Optical cross section of the V2 silver on a glass slide in an epoxy mold.**

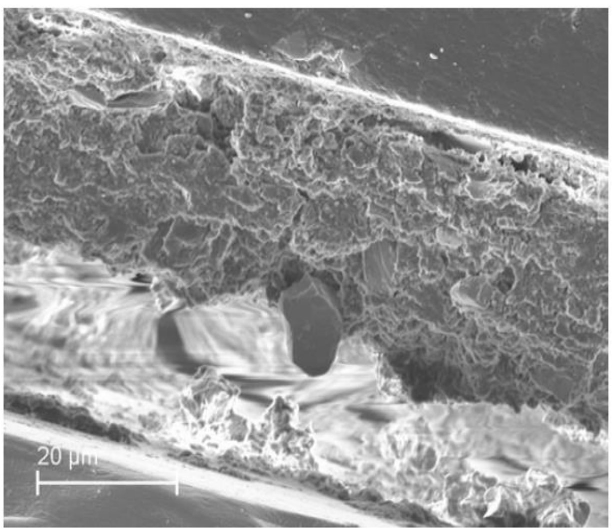
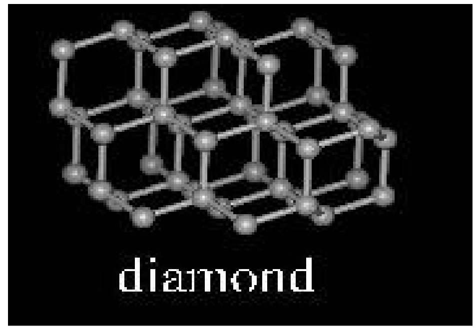


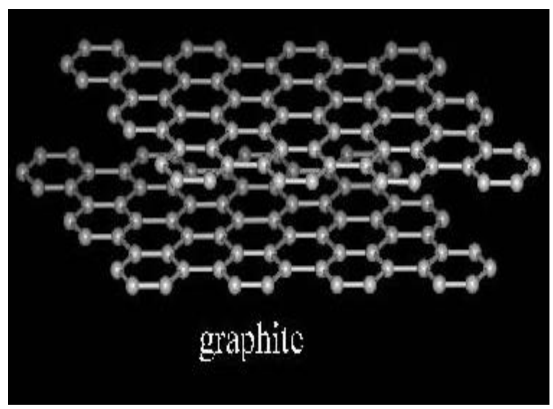

**Figure 1.2 SEM image of silver deposition cross section.**

**BACKGROUND LEADING UP TO PHOTINIC SINTERING:**

Until the mid-1980's pure solid carbon was thought to exist in only two physical forms, diamond and graphite. Diamond and graphite have different physical structures and properties however their atoms are both arranged in covalently bonded networks. These two different physical forms of carbon atoms are called allotropes.




Even though diamond and graphite are made of the same carbon atoms, they obviously have different physical properties. Diamond is very hard and graphite is very soft. Use the two pictures to help you explain why this difference occurs.




Graphite is composed of graphene sheets of carbon atoms. This is the material that is in our "lead"

**LITERTURE REVIEW:**

Heat transfer plays an important role in numerous applications. For example, in vehicles, heat generated by the prime mover needs to be removed for proper operation. Similarly, electronic equipments dissipate heat, which requires a cooling system. Heating, ventilating, and air conditioning systems also include various heat transfer processes. Heat transfer is the key process in ADVANCED MANUFATURING

SYSTEMS power stations. In addition to these, many production processes include heat transfer in various forms; it might be the cooling of a machine tool, pasteurization of food, or the temperature adjustment for triggering a chemical process. In most of these applications, heat transfer is realized through some heat transfer devices; such as, heat exchangers, evaporators, condensers, and heat sinks. Increasing the heat transfer efficiency of these devices is desirable, because by increasing efficiency, the space occupied by the device can be minimized, which is important for applications with compactness requirements. Furthermore, in most of the heat transfer systems, the working fluid is circulated by a pump, and improvements in heat transfer efficiency can minimize the associated power consumption.

There are several methods to improve the heat transfer efficiency. Some methods are utilization of extended surfaces, application of vibration to the heat transfer surfaces, and usage of pipes. Heat transfer efficiency can also be improved by increasing the ADVANCED MANUFATURING SYSTEMS conductivity of the working fluid. Commonly used heat transfer fluids such as water, ethylene glycol, and engine oil have relatively low ADVANCED MANUFATURING SYSTEMS conductivities, when compared to the ADVANCED MANUFATURING SYSTEMS conductivity of solids. High ADVANCED MANUFATURING SYSTEMS conductivity of solids can be used to increase the ADVANCED MANUFATURING SYSTEMS conductivity of a fluid by adding small solid particles to that fluid. The feasibility of the usage of such suspensions of solid particles with sizes on the order of millimeters or micrometers was previously investigated by several researchers and significant drawbacks were observed. These drawbacks are sedimentation of particles, clogging of channels and erosion in channel walls, which prevented the practical application of suspensions of solid particles in base fluids as advanced working fluids in heat transfer applications [1, 2].

To obtain higher heat transfer properties, numerous theoretical and experimental studies of the effective ADVANCED MANUFATURING SYSTEMS conductivity of solid-particle suspensions have been conducted dated back to the classic work of Maxwell (1873).

**Ahuja 1975**, Liu et al. 1988]. Although such suspensions show higher heat transfer properties, they suffer from stability problems. In particular, particles tend to settle down very quickly and thereby causing severe clogging. Choi, in 1991, developed a pipe heat exchanger where micro-sized particles suspended in liquids were used for cooling. It showed excellent heat transfer behavior but at a high cost of pumping power.

**Masuda et al.(1993)** for the first time demonstrated that the ADVANCED MANUFATURING SYSTEMS conductivity of ultra fine suspensions of alumina, silica and other oxides in water increased by up to 30% for a volume fraction of 4.3%.

In 1995, Choi [Choi 1995] reported a possibility of doubling convection heat transfer coefficients by using nanoparticles suspended in liquids, a result that would otherwise require a tenfold increase in pumping power.

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This new class of nanotechnology based heat transfer fluids that exhibit ADVANCED MANUFATURING SYSTEMS properties superior to those of their host fluids were termed as nanofluids.

Thus, nanofluids are engineered by suspending nanoparticles with average sizes below 100nm in traditional heat transfer fluids such as water, ethylene glycol and oil.

**Table 2.1 ADVANCED MANUFATURING SYSTEMS conductivities of various materials**

| Material | Thermal conductivity at room temperature (W/m-K) |
|---|---|
| Silver | 429 |
| Copper | 401 |
| Aluminum | 237 |
| Diamond | 3300 |
| Silicon | 148 |
| Alumina | 40 |
| Water | 0.61 |
| Ethylene glycol | 0.25 |
| Motor oil | 0.15 |

## SIMULATION OF SINGLE PHASE FLUID FLOW

It is well known that nanoparticles have very high ADVANCED MANUFATURING SYSTEMS conductivity compared to commonly used coolant. Thus, the ADVANCED MANUFATURING SYSTEMS conductivity and other fluid properties are changed by mixing the particle in fluid. The changed properties of the nanofluids determine the heat transfer performance of the straightpipe with nanofluids. This point is illustrated in this chapter by doing the computational fluid dynamics (CFD) analysis of the hydrodynamics and ADVANCED MANUFATURING SYSTEMS behaviour of the single phase flow through a circular Pipe (Lee and Mudawar, 2007).

## SPECIFICATION OF PROBLEM

Consider a steady state fluid flowing through a circular pipe of constant cross section as shown in Fig. 3.The diameter and length of circular channel are 0.014 m and 1.7 m respectively. The inlet velocity is *u* (m/s), which is constant over the inlet cross-section. The fluid exhausts into the ambient atmosphere which is at a pressure of 1 atm.

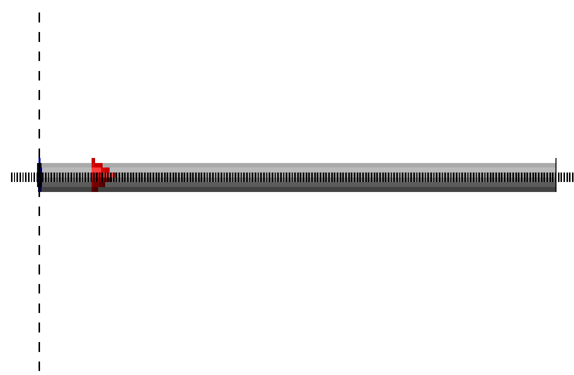

**Figure 3 circular pipe geometry**

As fluid flows through in a pipe at both hydraulic and ADVANCED MANUFATURING SYSTEMSly fully developedcondition, the Nusselt number is constant for laminar flow and it follows the Dittius-Boelter equation for turbulent flow.

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**MESHING OF GEOMETRY:**

Structured meshing method done in ANSYS Workbench was used for meshing thegeometry. Nodes were created. The 2D geometry of circular channel withstructured mesh is shown in Fig. 4.

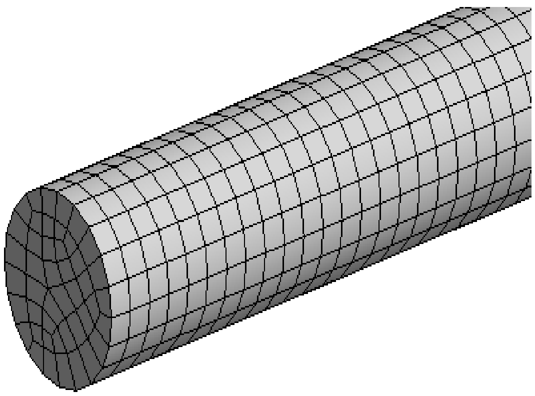

**Figure 4:Meshed model of pipe with zoomed view**

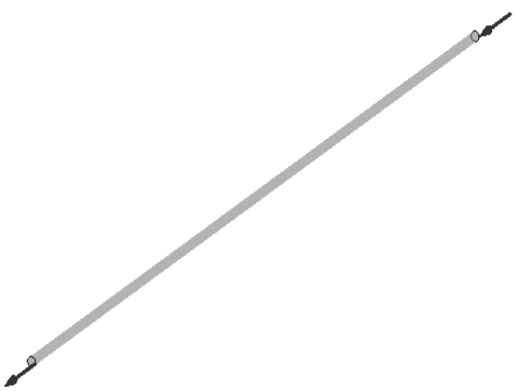

**Figure 5 Boundary conditions**

**RESULTS AND DISCUSSION:**

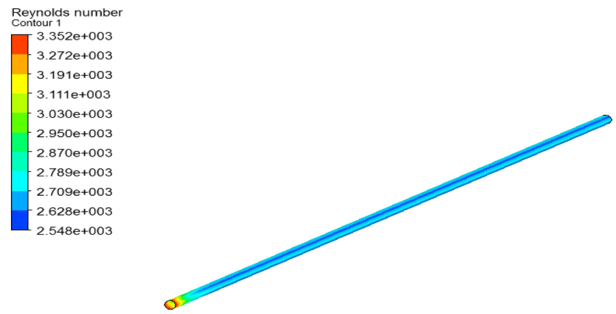


**Figure 5.1 of Nano tube with pure water flow**

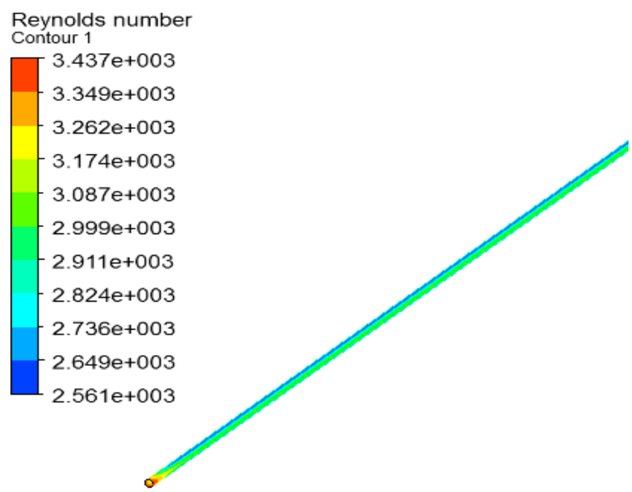


**Figure 5.2 of Nano tube with pure 0.01% Nano fluid**

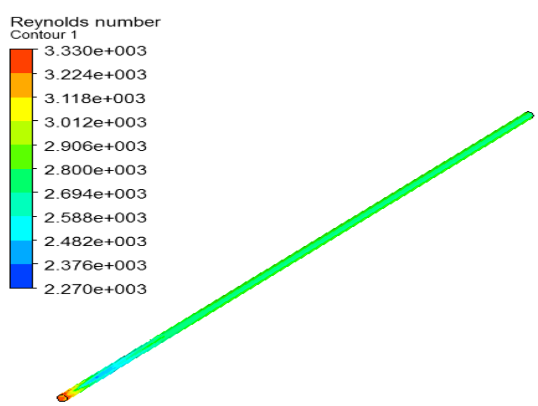

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**Figure 5.3 of Nano tube with pure 0.02% Nano fluid**

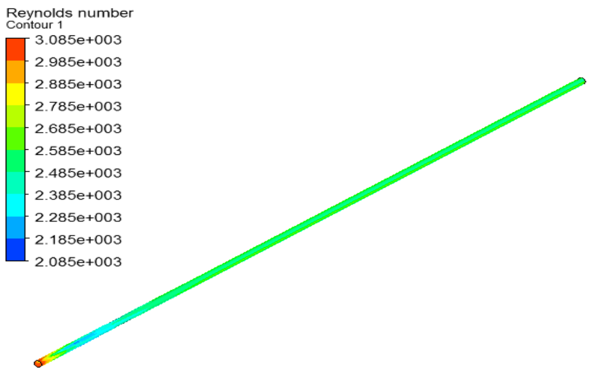



**Figure 5.4 of Nano tube with pure 0.03% Nano fluid**

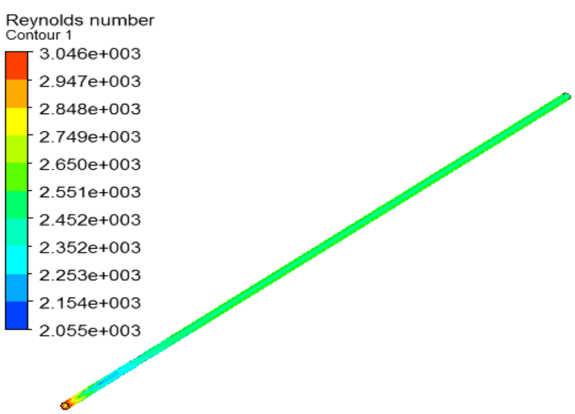
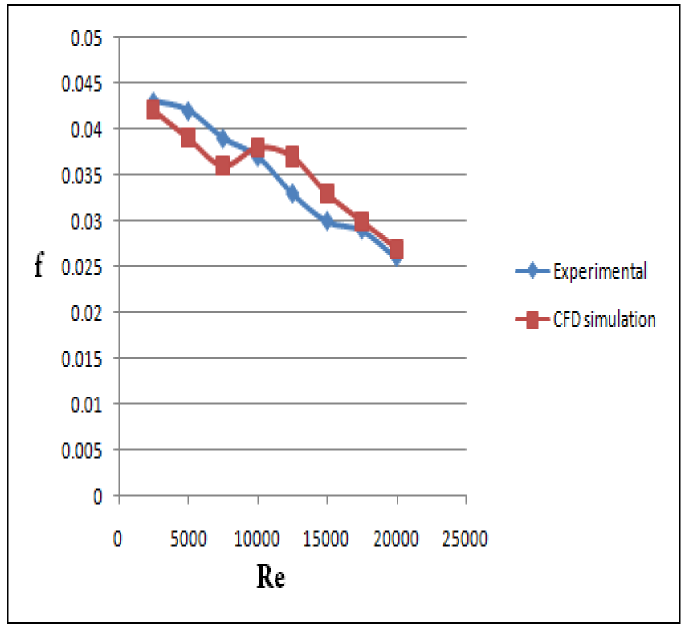
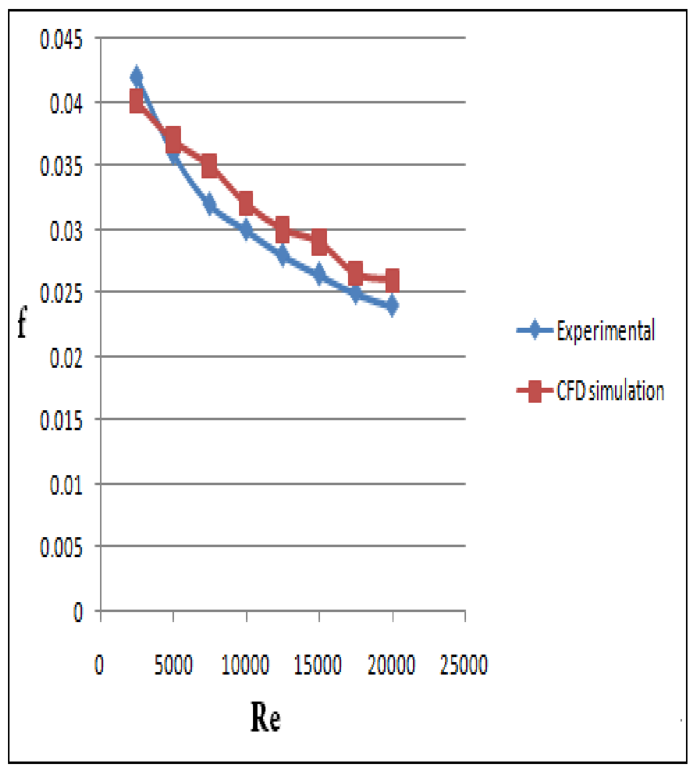



**Figure 5.5 of Nano tube with pure 0.02% Nano fluid**




**Graph 5.1 flow rate with 0.1% nanaofluid**



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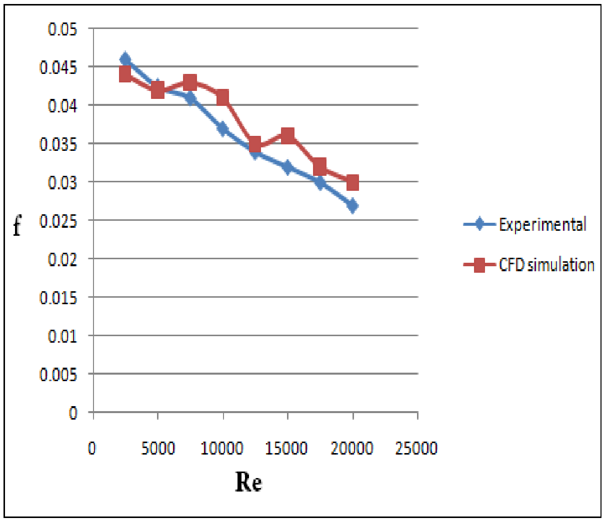
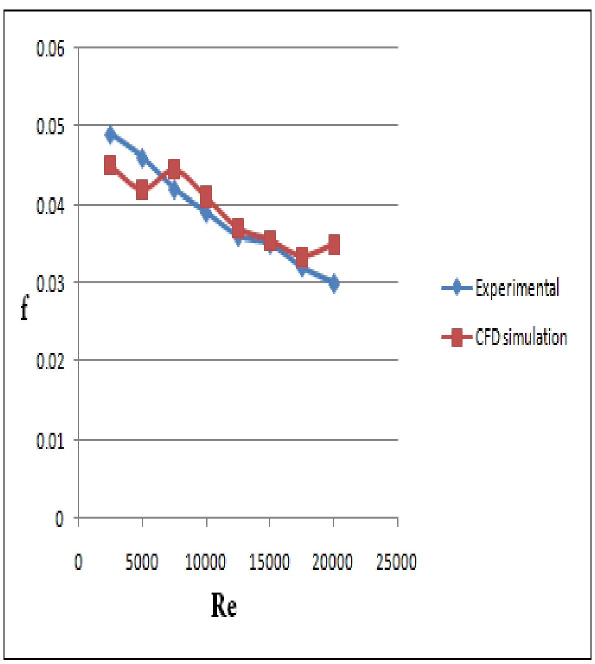
**Graph 5.2 flow rates with 0.2% Nano fluid**




**Graph 5.3 flow rates with 0.3% Nano fluid**




**Graph 5.4 flow rates with 0.6% Nano fluid**

**CONCLUSION:**

In this project, the heat transfer coefficient in the developed region of pipe flow containing $Fe_3O_4$-water nanofluid during the constant heat flux was simulated using CFD. The focal point of investigation was to evaluate the effect of particle volume concentration on convective heat transfer characteristics in the developed region of the tube flow containing water-$Fe_3O_4$ nanofluid. It was observed that 0.6% of nanofluids showed highest heat transfer characteristics than that of the base fluid (water).

In this work the hydrodynamics and ADVANCED MANUFATURING SYSTEMS behavior of circular pipe were studied. Pure water and its nanofluids ($Fe_3O_4$) were considered in pipe channel. A steady state computational fluid dynamics (CFD) models was simulated by ANSYS Fluent 13.0 here. The effect of Reynolds number and Nusselt number on the flow behavior of the pipe was studied.

A numerical study of single phase fluid flow in a pipe was discussed. Water is used s a base fluid and its nanofluids are used as fluid medium. Key conclusion of this chapter can be summarized as follows.

- The computational results successfully validated the analytical data for circular pipe channel.
- Heat transfer coefficient is constant throughout the circular channel due to its fully developed conditions
- As the concentration of nanoparticle increases heat transfer coefficient also increases, with the increase in Nusselt number
- Wall temperature increase within the flow direction of circular channel at very low Re simulation of Single Phase Fluid Flow in a Circular channel

- Wall temperature has negligible variation for higher Reynolds number.

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