Numerical Investigation On Heat Transfer Enhancement Using Nanoaerosols

Submitted By

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Numerical Investigation On Heat Transfer Enhancement Using Nanoaerosols

Major Project Report

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF TECHNOLOGY

IN

MECHANICAL ENGINEERING
(Thermal Engineering)

By

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May 2018

Declaration

This is to certify that,

- The thesis comprises of my original work towards the Degree of Masters of Technology in Mechanical Engineering (Thermal Engineering) at Nirma University and has not been submitted elsewhere for a degree.

- Due acknowledgment has been made in the text to all other material used.

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Certificate

This is to certify that the major project entitled **"Numerical Investigation On Heat Transfer Enhancement Using Nanoaerosols"** submitted by **Gaurav Rajput (Roll No: 16MMET20)**, towards the partial fulfillment of the requirements for the award of degree of Master of Technology in Mechanical Engineering of Nirma University, Ahmedabad, is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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Statement of Originality

I, **Gaurav Rajput**, Roll. No. **16MMET20**, give undertaking that the Major Project entitled "**Numerical investigation on heat transfer enhancement using Nano aerosols**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Thermal Engineering** of Institute of Technology, Nirma University, Ahmedabad, contains no material that has been awarded for any degree or diploma in any university or school in any territory to the best of my knowledge. It is the original work carried out by me and I give assurance that no attempt of plagiarism has been made.It contains no material that is previously published or written, except where reference has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Abstract

Cooling constrains in modern appliances and devices necessitate enhancement in conventional heat transfer methods. This could be achieved by number of different techniques and one of them is mixing nano-particles with the base fluid. Nano-particles improve the properties of fluids. The literature study suggest that there are different kind of models for the enhancement of heat transfer in nano-fluids, but very few for Nano aerosols. In this project work numerical investigation on enhancement of the heat transfer by Nano fluids and Nano aerosol is carried out with the help of Fluent software in which simple scheme solution method is used. This numerical study is on laminar flow of a water-Al_2O_3 in a circular tube, for constant heat flux at the wall and numerical investigation on Air-Al_2O_3, Air-SiO_2, Air-TiO_2 and Air-MgO. The investigation for appropriate property model is done by theoretical study of the most used models and they are then compared with the existing experimental results. The effective properties are calculated from the available model. The different Numerical results are calculated in the form of Nusselt number by varying the Reynolds number. Simulation results are validated by comparing them with existing experimental and numerical results. Results of this numerical investigation conclude that by varying the nano-particle and flow parameter, there is enhancement in Nusselt number of 36.23%, 39.09% and 41.27% for Air-Al_2O_3 with Reynolds number of 600, 750 and 90. While Air-SiO_2 shows 6.71%, 8.58% and 5.31% improvement, Air-TiO_2 shows 10.01%, 7.1% and 4.62% improvement and Air-MgO shows 13.44%, 29.04% and 34.61% improvement for same set of Reynolds number.

Abbreviations

HTC	Heat Transfer Coefficient
EG	Ethylene Glycol
HC	Hamilton and Crosser
VOF	Volume of Fluid
SP	Single-phase
MP	Multiphase

Nomenclature

C_p	Specific Heat
m	mass
x	Water content
Q	Heat Load
A	Area
V	Velocity
ρ	Density
D_o	Outer diameter
D_i	Inner diameter
G	Mass Velocity
Nu	Nusselt No
Pr	Prandtl No
h	Heat Transfer Coefficient
k	Thermal Conductivity
f_m	Friction Factor
Re	Reynolds No
k_f	Pierre's Boiling No
g	Acceleration due to gravity

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Chapter 1

Introduction

This is the modern era in which we are completely dependent and surrounded by the computers, electronic equipment, compact equipment. This is a very fast changing and growing sector in which competition lies not only for high speed capacity of gadgets but for space constrains. Today there are two main requirements in the market, high speed as well as reduced size and both of these development comes with more energy requirement and hence dissipation of this consumed energy in the form of heat. Generally, this heat transfer takes place through convection and according to newtons law of cooling it depends on heat transfer coefficient and heat transfer area. But with reducing size of equipment heat transfer coefficient also decreases. So we need alternate method to enhance heat transfer. All the previous researchers are research on to the the improvement of the transport process and very less amount of focus is done on to the improvement of the cooling process in the heat transfer. So from that need to generate the nano fluids for the heat transfer process and its enhancement.

1.1 Complexity involved in Cooling

Cooling is one of the challenges facing high-tech industries like microelectronics, transportation, manufacturing, metrology and defense. Cooling process is very important according to the many application and for heat transfer process but for maintaining the desired performance and reliability of different products like computers, radiators, laptops, automobile engines, heat exchangers, high powered x-rays and lasers. In some of cases heating or cooling loads may reach up to the 25 kW and heat fluxes 2500 W/cm2.

Due to the compactness of the product heat transfer problems occurs and in that product large power is required due to the heat load. In small heat fluxes products like 100 W/cm2 the air cooling is sufficient but more than that the liquid cooling is required.

Generally the microchannel heat sink is the part of the single phase liquid cooling technique and in the two phase liquid cooling techniques spray cooling, thermosyphen, heat pipes and direct immersion cooling is done. All these methods are facing the bottle neck conditions. So in this condition the further improvement is very dicult. Nanotechnologies creates the more opportunities because it can change the properties of the material so it can help for effective and very much compact cooling system.

1.1.1 Conventional Heat Transfer Enhancement Methods and their Limitations

Conventional heat transfer enhancement can be categorized as the following [1]:

Extended surface cooling:

In the extended surface cooling method the commonly extended surfaces are like microchannels and fins. In air or liquid cooling to increase the heat transfer micochannels and reduce the size of that heat exchangers named as microscale heat exchanger.

Microscale heat exchanger has many advantage due to its compact size, low in weight, can change its design, high heat transfer. Due to this kind of advantage many industries are interests into this like refrigeration industry, heating ventilation and air-conditioning industry, automobile industry. Now die to the very compactness and high heat transfer it has limited.

Conventional Solid-Liquid Suspensions:

In the conventional solid- liquid method micro sized particles are suspended in the base fluid like water, oil etc. In this method the main problem is due to the rapid settlement of the micro sized particles if it is prevented by circulation into the fluids than it would wear in pipes,pumps and bearings. If that fluid is used into the micro channel than it would clog the channel. Due to the clogging into the pipes the pressure and pimping power is also increasing.

1.2 Nanofluids

The base fluids have many properties but to enhance its properties the small amount of nanoparticles are suspended with the stability and uniformly into that base fluid, it can give the great enhancement into the properties of the that fluids. In 1873, J.C. Maxwell [2] has first told that base fluid can increase its properties like thermal conductivity and convective heat transfer with the use of micro sized particles into the base fluid. But due to the some draw backs like high pressure drop, sedimentation, clogging, erosion it is not used into the practical work.

1995, Stephen U. S. Choi [3] has first introduce the term Nanofluids (i.e. nanoparticle fluid In suspxensions) at Argonne National Laboratory of USA. when the nanoparticles having a mean size of around 100 nm and that nanoparticles make nanofluids with the help of the base fluids like water, oils, ethylene glycol, etc. In the nanofluids the amount of nanoparticles are generally not more than 6 of that host liquid. There are different kind nanoparticles and have their different properties like thermal, mechanical, electrical and optical properties.

1.2.1 Development of the Concept of Nanofluids:

There are different kind heat transfer fluids like water, oils, ethylene glycol. All these heat transfer fluids have different thermal conductivity and different capacity to heat transfer. But the solid particles are far better than these heat transfer fluids because they good thermal conductivity compare to base fluids. For example, the thermal conductivity of the metallic liquids is better than the non-metallic liquids. The thermal conductivity of copper is 700 times greater than water and 3000 times greater than engine oils [1]. According to this table the thermal conductivities of solid-liquid suspension have more thermal conductivity than that of heat transfer fluids(base fluids).

Table 1.1: Thermal Conductivity of various materials at 300K [4]

	Material	**Thermal Conductivity (W=mK)**
Metallic solids	Aluminum	401
	silver	429
	Copper	237
Non-metallic solids	Silicon	148
	Alumina(Al_2O_3)	40
	Diamond	3300
	Carbon nanotubes (CNTs)	3000
Metallic liquids	Sodium (at 644K)	72.3
	Water	0.613
	Ethylene glycol(EG)	0.253
	Engine oil	0.145

Maxwell introduced about the thermal conductivity of the solid-liquid mixture from that the theoretical and experimental investigation are carried out on to the solid-liquid mixture. But in this approach there is two main problems (1) thermal conductivity is high at the high particle concentration and thermal conductivity is low at low concentration but in case of high the erosion of pipe is high. (2) micro particles are settle very rapidly.

Now the production of metallic and non-metallic particles with mean size around 100 nm is possible due to the advanced nano technology. The nanoparticles have many advantage compare to the micro sized particles and the other particles. The nanoparticles have high mechanical, thermal, electrical and optical properties.

1.2.2 Importance of Nanosize

According to the theory the solid particles are better than the heat transfer fluids into the heat transfer. But there are some problems into the micron sized particles so that particles may not work properly in many cooling application. The nano sized particles can easily solve these kind of problems. Nanoparticles have some very good properties like nanoparticles can stay suspended in longer duration than micron and bigger sized particles and nanoparticles have more surface area compare to the micro particles. The nanoaprticles have more stability and thermal conductivity because it have high surface area so it increases the convective heat transfer of nanofluids. The ratio of surface area to volume of nanoparticles is 1000 times larger than that of microparticles [1]. The size nanoparticles is small compare to the microparticles so it can reduce the erosion and clogging. From this it concluded that there is low pressure drop and low pimping power is required which save the large amount of energy.

In the nanofluids the nanoparticles are the main material from which the enhancement of heat transfer is possible. Due to the advanced nanotechnology it is possible to develop the nanofluids. In the Nanotechnology the very ultra fine particles have the good thermal properties and stability. Table 1.2 [1] shows the difference and comparison of micro particles and nanoparticles.

Table 1.2: Comparison of micro particles and nanoparticles [1]

	Micro particles	Nano particles
Stability	Settle	Stable
Surface/Volume ratio	1	1000 times larger than micro particles
Conductivity	Low	High
Erosion?	Yes	No
Clog in micro channel	Yes	No
Nanoscale phenomena?	No	Yes
Pumping power	More	Less

1.3 Production of Nanofluids

Production of nanofluids is done by the single step method and two step method. By both of this method high heat transfer and stable nanofluids is produced. But in both of this method the agglomeration is the common issue.

1.3.1 Nanoparticles and Fluids Materials

There are different kind of solid material and the properties of that solid material are also different according to their critical length scale. With the help of advance technology the material can also measure into the nanoscale. So, the general solid material have the different properties than the 100 nm solid particles. Nanoparticles have a better magnetic, optical, electrical, thermal and mechanical, electrical properties. Due to this kind of enhancement into the heat transfer and nanoscale many researchers are interested into this topic. Nanofluids contains two main material, solid- nanoparticle and base fluid.

I. Nanoparticles material There are dierent types of nanoparticles used in nanofluids. Such as metals (Cu, Ag, Au), oxide ceramics (Al_2O_3, CuO), nitride ceramics (AlN, SiN), semiconductors (TiO_2, SiC), carbon nanotubes and composite materials.

II. Base fluid types There are many types of liquids, such as water, ethylene glycol and oil. These liquids are used in nanofluids as host liquids or base fluids.

1.3.2 Manufacturing Methods of Nanoparticles

Generally the chemical process and physical process are the two process for the production of nanoparticles. For manufacturing the nanoparticles there are numbers of method. inert gas condensation and Mechanical grinding are the two methods which involves into the physical process. In the chemical process the methods are more than the physical process. The chemical process are as follows: chemical vapour (CVD), chemical precipitation, thermal spray, spray pyrolysis.

1.3.3 Dispersion of Nanoparticles in Base Fluid

According to the discussion to make the stable suspension of the nanoparticles in the base fluid or in the host liquid two methods are available for this (1) Single step method (2) two step method. In single step method, nanoparticles production and the dispersion of the nanoparticles into the host liquid or base liquid both of these on to the similar time. In the two step method first the nanoparticles are makes and after that nanoparticles are disperse into the host liquid. High shear and ultra sound technique are used into the two step method. For better and successful production of the nanofluid we have to uniformly well mixed the nanofluid.

1.4 Advantages of Nanofluids and its Applications

Nanofluids can be used into the many application in the thermal control system to enhance the heat transfer, cooling application and energy efficiency. In basefluid due to the small amount of nano particles it can helpful into the lighter and compact system, better cooling rates, the capability to achieve thermal control system, reducing the pumping power.

Common area of nanofluids applications are as follows:

Liquid Cooling application: In the many industries due to the heat transfer problems cooling is a major issue of the concern. For example, Defence applications, space and nuclear cooling, vehicle cooling, electronic equipment cooling, transformer cooling.

Tribological applications: In tribological application the oils and lubricants can be developed by using the different kind of nanofluids with their different properties. In the mechanical system there are moving mechanical parts and the other parts which have different kind of properties. By using the nanoparticles into lubricants and oils we can improve properties of lubricants like, friction reducing and antiwear properties into moving mechanical components and load carrying capacity. In the mechanical parts wear can be reduced by using the nanoparticles in lubricants.

Biomedical applications: With the help of nanofluids we can easily change the temperature range according to the requirement like we can provide the cooling around the surgical region. By using the nanofluids We can also provide higher temperature near tumours.

Other potential applications: Generally, the nanofluids are used into the cooling system like electronics and engine cooling. In the Automobile cooling system there are different parts like power electronics for hybrid vehicles, radiators, automatic transmission system, exhaust gas recirculation heat exchangers. There are also other areas in which the nanofluids are very useful and that areas are as follows: new super computers, defence electronic systems, spacecraft and airplanes. In this nanofluids maintain high temperature gradient in thermoelectric.

1.5 Objectives of the Project

- Numerical investigation on laminar flow of air - Al_2O_3 in a circular tube, submitted to a constant heat flux at the wall.

- Study about the thermal conductivity and dynamic viscosity model under the different condition like varying the particle size, particle concentration, fluid temperature.
- Comparison between the results of the air and nanoaerosols.
- Numerical investigation on laminar flow of air - Al_2O_3, air - SiO_2, air - TiO_2 and air - MgO in a circular tube.
- Parametric study by varying the particle concentration, particle size,particle material and flow parameter etc.
- identify the satisfactory results from the CFD compare it with existing results.

Chapter 2

Literature Review

Research work on to the nanofluids can be divided into the three categories according to the research. The research work mainly into these three field numerical, experimental and theoretical (empirical). Since 1993 the most of the research on the nanofluids base on to the experimentals and its results but very few research on the numerical and theoretical basis. many experimental work regarding to nanofluids constantly increasing and still continue. There is only few papers available on to the nanoaerosols.

2.1 Experimental and numerical Investigation

In the experimental research mostly the nanoparticles material were copper oxide and alumina in the experiment. Masuda et al. [5] done first experiment on the heat transfer fluid water-alumina to measure its thermal conductivity. They used the different particles like alumina, silica and other oxides in the water and measure the thermal conductivity and showed that 30 increment into the thermal conductivity by the 4.3 volume fraction. In 1995 the choi introduced the nanofluid for that heat transfer fluid.

Mosavi et al.[6] numerically investigated the developing laminar forced convection flow of a water-Al_2O_3 nanofluid in a circular tube,submitted to a constant and uniform heat flux at the wall.The micro-channel heat sink (MCHS) has the capability to dissipate large amounts of heat from a small area with a very high heat transfer coefficient and less fluid inventory. Using nanofluids as a coolant in the MCHS could further improve its performance.In model the tube with a length(L) of 1.0 m and diameter(D) of 0.01 m. The fluid enters with uniform temperature and axial velocity profiles at the inlet section From the observed results it was clearly seen, that nanofluids have greater potential for heat transfer enhancement and are highly suited to application in practical heat transfer processes. The main reason for the heat transfer enhancement of nanofluids is that the suspended nanoparticles increase the thermal conductivity of the fluids, and the chaotic movement of ultrafine particles increases fluctuation and turbulence of the fluids, which accelerated the energy exchange process. Convective heat transfer is enhanced by increasing the particle concentration and the Reynolds number.

Lee et al. [7] experimented with the different mixtures like Al_2O_3 and water,Al_2O_3 and ethylene glycol (EG), CuO and water, CuO and ethylene glycol. With these kind of mixture they showed the 20% enhance in heat transfer by the 4% of CuO. According to the results they showed that up to the 0.005 volume fraction range the thermal conductivity increase linearly. —

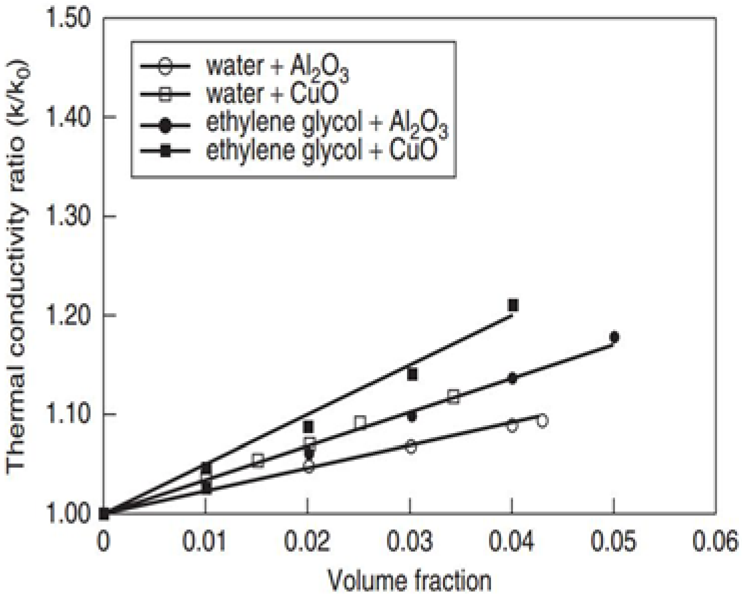

Figure 2.1: Effective thermal conductivity enhancement against volume fraction [7]

Davarnejad et al. [8] numerically investigated the heat transfer characteristics of a nanofluid in a circular tube under constant heat flux in the laminar flow. Two dimensional pipe (with 1 m length and 6 mm inner diameter) was spotted in simulation. The single phase approach was used for nano fluid simulation and effect of nanoparticle concentration on the convective heat transfer coefficient was investigated in the various Reynolds numbers (700 ¡ Re ¡ 2050). The constant heat flux of 1.8 (W/cm2) as a boundary condition at the pipe wall was applied. Al_2O_3 nanoparticles in water with concentrations of 0.5%, 1.0%, 1.5%, 2% and 2.5% were used in this simulation. Two particle sizes with average size of 20 and 50 nm were used in this research. It was concluded that heat transfer coefficient increased by increasing the Reynolds number and the concentration of nanoparticles. The maximum convective heat transfer coefficient was observed at the highest concentration of nano-particles in water (2.5%). The average heat transfer coefficient and Nusselt number increased by increasing the particle concentration and flow rate.

Wang, Xu and Choi [9] experimented with the nanoparticle material as Al_2O_3 and CuO respectively and water and EG as base fluids. They used the size of nanoparticles as 28 and 23 nm. A steady-state parallel-plate technique to measure the thermal conductivity of nanofluids. From the results they concluded that with decreasing particle size the thermal conductivity increases.

Eastman et al. [10] used the Cu as the nanoparticle and EG as the base fluid. The Cu having a size of around 10 nm. From results they showed the 40% increment into the thermal conductivity. They used the Cu nanoparticles of 0.3% as volume fraction.they also concluded that according to the specific surface area the thermal conductivity is also increases it is due to the small particle size.

Saha and Paul [11] numerically investigated the single phase approach on turbulent forced convection flow of water based Al_2O_3 and TiO_2 nanofluids flowing through a horizontal circular pipe under uniform heat flux boundary condition applied to the wall. The effect of volume concentrations, Brownian motion and size diameter of nanoparticles on flow and heat transfer. Reynolds number Re = 10 1000 to 100 1000 , Prandtl number, Pr = 7.04 to 20.29, nanoparticle volume concentration 4% and 6% and nanoparticles size diameter 10, 20, 30 and 40 nm. Nanoparticles were spherical and uniform in size and shape. Radiation effects and viscous dissipation were negligible. The heat transfer rate increases as the particle volume concentration and Reynolds number increase with a decrease of nanoparticles size diameter. Al_2O_3water nanofluid shows a higher heat transfer rate compared to that of TiO_2water nanofluid.

Xuan and Li [12] showed that the eective thermal conductivity of water base nanofluids containing nanoparticles of Cu of size 100nm is almost same as of CuO of size 36nm. They also showed that the appropriate selection of base fluid may increase the stability of nanoparticles in base fluid. As they showed that the Cu particles in transformer oil had better suspension characteristics than Cu particles in water.

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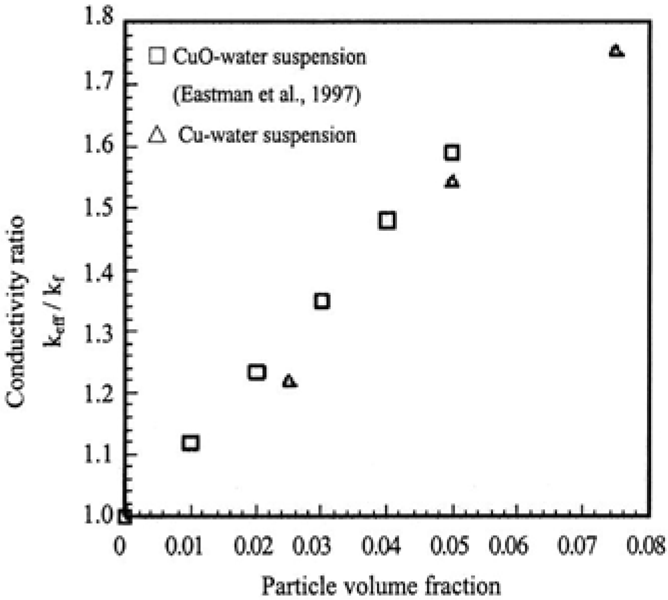

Figure 2.2: Conductivity ratio of water-CuO (36nm) and water-Cu (100nm) against particle volume fraction.[12]

Salman et al. [13] numerically investigated the Eulerian, mixture and single phase models were used to simulate laminar and turbulent forced convective flow of SiO_2-EG nanofluid in a microtube. The simulations are performed for SiO2 with 4% volume fraction and particle diameter of 25 nm with EG as a base fluid. Reynolds numbers in the range of 40 Re 1200 were used. The microtube used in this simulation has a hydraulic diameter of 500 m and a length of 100,000 m.It is assumed that the nanofluid enters the channel with 301 K and a constant heat flux 50,000 W/m2. The flow and heat transfer are assumed to be fully developed. The numerical simulation is performed for three different approaches which were, single-phase (homogenous) and two-phase (mixture and Eulerian). The single phase model was more precise and the two phase (mixture and Eulerian) model has the same results. The deviation between the correlation equations and the single-phase and two-phase models at different ranges of Reynolds number was 19% and 23%, respectively. The deviation was high because of the small size of the microtube.

Pak and Cho [14] investigated about the behaviour of nanofluids containing gAl_2O_3 and TiO_2 of size 13 and 27 nm respectively. They found that the nanofluids behave as Newtonian fluid. This is true only for Al_2O_3 -water containing 3% volume fraction and for T iO2 -water it is up to 10 vol%. They also showed that with increase in nanoparticles con-centration viscosity increases and cannot predicted by standard empirical correlation for solid- liquid suspensions. Results also showed that as the temperature increases apparent viscosity of nanofluids decreases.

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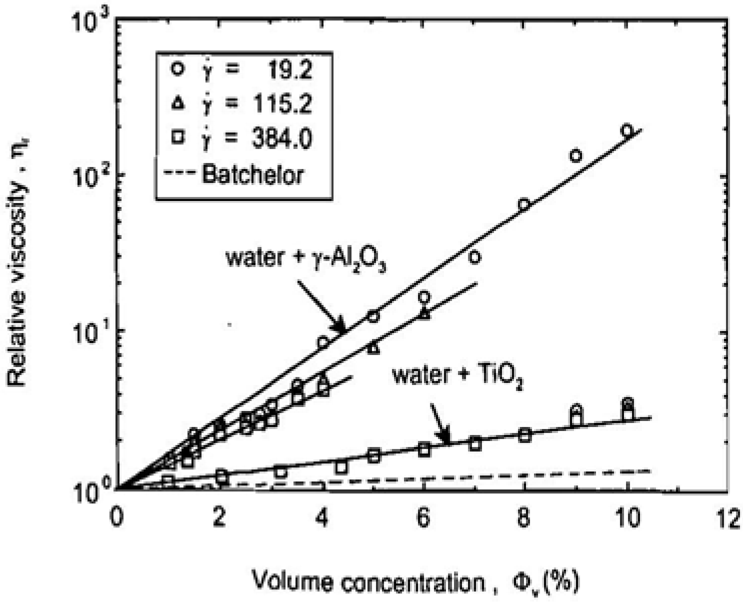

Figure 2.3: Relative viscosity at different shear rates [14]

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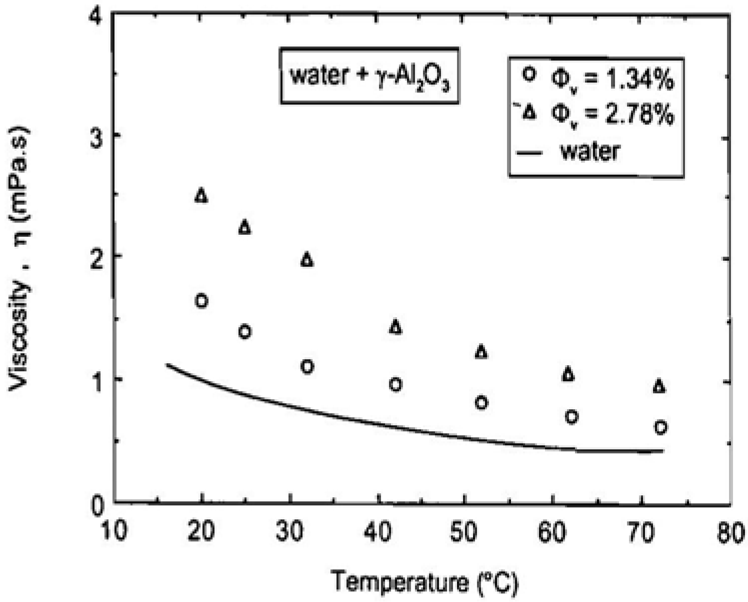

Figure 2.4: Viscosity at different temperature [14]

Ding et al. [15] measured dynamic viscosity of carbon nanotubes (CNTs) in water based nanofluids. They found also found the similar trend about viscosity increment with particle concentration and decrement with increase in temperature.

Abdolbaqi et al. [16] numerically investigated the heat transfer enhancement of nanofluids under turbulent flow through a straight square channel under constant heat flux conditions at the upper and lower walls. the nanofluids are prepared as solid nanoparticles of CuO, TiO_2 and Al_2O_3 suspended in water. The boundary conditions of these study assumed steady state, incompressible and Newtonian turbulent fluid flow, constant thermophysical properties of nanofluids, no effect of gravity, heat conduction in the axial direction and neglecting the wall thickness. The Nusselt number and friction factor were obtained through the numerical simulation. The study concluded that the enhancement of the friction factor and the Nusselt number is 2% and 21%. The 4% volume concentration of nanofluid has the highest friction factor values, followed by 3, 2 and 1%.The Nusselt number of CuO has the highest value followed by TiO_2 and Al_2O_3.

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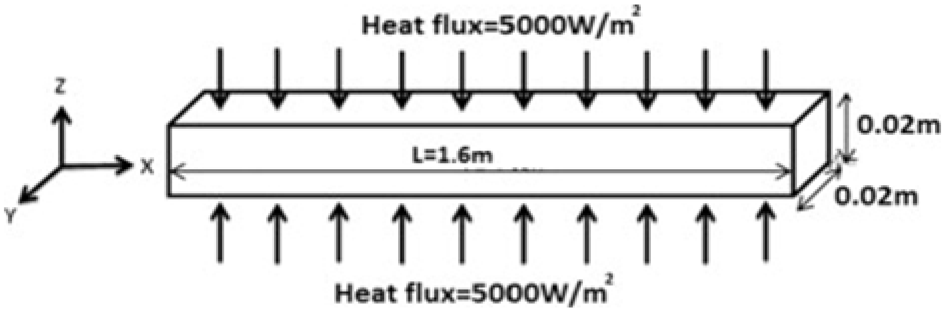

Figure 2.5: Straight square channel [16]

Pak and Cho [14] were the first to do experiment to investigate convection in nanofluids. They showed the large enhancement in heat transfer coecient in the turbulent flow condition with water as base fluid and nanoparticles containing gAl_2O_3 and TiO_2 of size 13 and 27 nm respectively. They showed that the 45% increment in heat transfer coecient with 1.34 vol%. Results also showed that with increase in Reynolds number heat transfer coecient increase.

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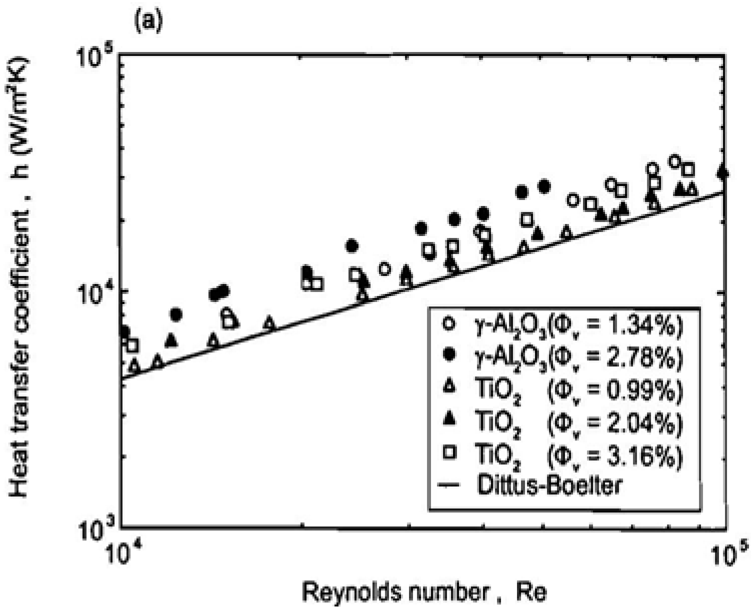

Figure 2.6: Heat transfer coefficient at different Reynolds number [19]

pak and Choi [14] investigated heat transfer enhancement in micro channel heat exchanger with nanofluids as a coolant and then compared with water as coolant and liquid nitrogen as coolant. Results showed that heat transfer is better with nanofluids as coolant the possible reason could be reduction in boundary layer, intensification of turbulence and dispersion of nanoparticles.

Trivedi et al. [17] experimentally investigated the effect of nanoparticles suspended in air on rate of convective heat transfer. A hotwire experiment were conducted using nano particles of aluminium oxide (Al_2O_3) having diameter of 112 nm. The Experimental setup includes a compressor, pressure gauge, pressure control valve, a tube for passing of compressed air, particle injector, thermistors, hotwire and particle collector. The particle injector was a costumed glass hour. Magnification of nanoparticle was done at 3000x and 30,000x to calculate average particle size.

- Properties Of the nanoparticle used (Al_2O_3): Density : 3970 kg/m3 Specific Heat: 880 J/Kg K Thermal Conductivity: 30W/m k
- Experimental Setup Dimensions: Tube Length: 510mm Nichrome Wire: 80% Nickel and 20% Hot Wire Diameter: 1mm

Wire is Heated at temperature range of 500-750 Degree Celsius using Sorensen DCR 40-20A Power Supply. Configuration of flow used Is cross flow. 0.1 Ohm shunt resistor is used to accurately measure the current. Downstream and upstream temperature measurement is done by NTC thermistors.

Mass Flow rate was calculated by filtering nanoparticles in 753mm3 collection tank located at 240mm downstream from final thermistor.

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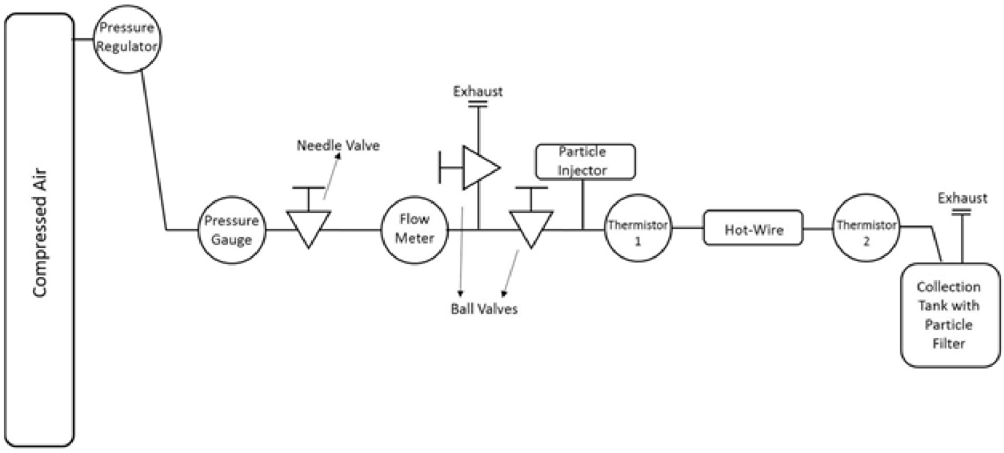

Figure 2.7: Experimental setup of the nanoaerosols experiment [17]

In the experiment first we measure the starting and ending temperature without any air flow rate so from that we can ensure about system was at thermal equilibrium. After the system thermal equilibrium 30 s test of the air with the different flow rates were completed to check the accuracy of the experimental setup. The gas density was compute from the measured value of the pressure and temperature used it with the ideal gas law.

The measured pressure and temperature was used with the ideal gas law to compute the gas density. The mean velocity and the Reynolds number can calculate using the value of mass flow rate, tube dimensions and density. Using the Reynolds number range of 1,400 < ReD < 11,000 the air only test were completed. Then after using the cross-flow Reynolds number ranged from 140 < Rew < 1100 with the hot wire. All the calculations on the basis of the cross-flow Reynolds number.

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on the basis of the cross-flow Reynolds number.

The tests were conducted with the air and the air and nanoparticles mixture. In both the cases they were calculate the Nusselt number for the comparison. In comparison they using Reynolds number range 600-900 and particle mass loading 0.35 with this parameter they observed the heat transfer enhancement of 20-37%.

Chapter 3

Selection of Property Model

3.1 Selection of Thermal Conductivity Model

There are different property model and here the thermal conductivity model is selected according to the its range and factors that effect the property like particle size, particle concentration, and fluid temperature. There are different conductivity model but the selected model have to check the effect of the factors.

3.1.1 Comparison with Particle Concentration

According the figure 3.1 there are different kind of results are available in this diagram the thermal conductivity is measured according to the particle concentration and compared this results by experimental results of Kyo et al. [18]. In the results the particle concentration is low (0.01% - 0.3%). The nanofluid is mixture of water- Al_2O_3. The nanoparticles diameter is around (30 5 nm) and the temperature is 21 C. According to the figure thermal conductivity increase with increase of particle concentration. But some of the model are not working on this low particle concentration. —

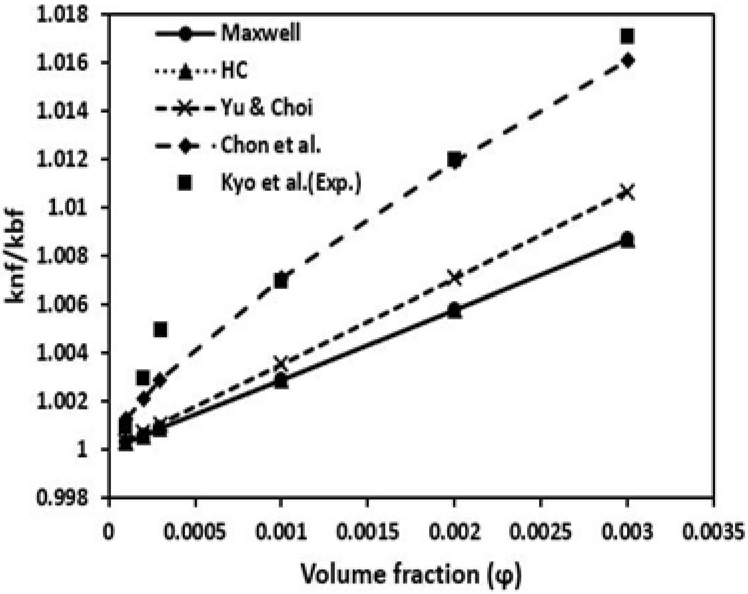

Figure 3.1: Thermal conductivity ratio for water- Al_2O_3 (30 nm) at 21 C [18]

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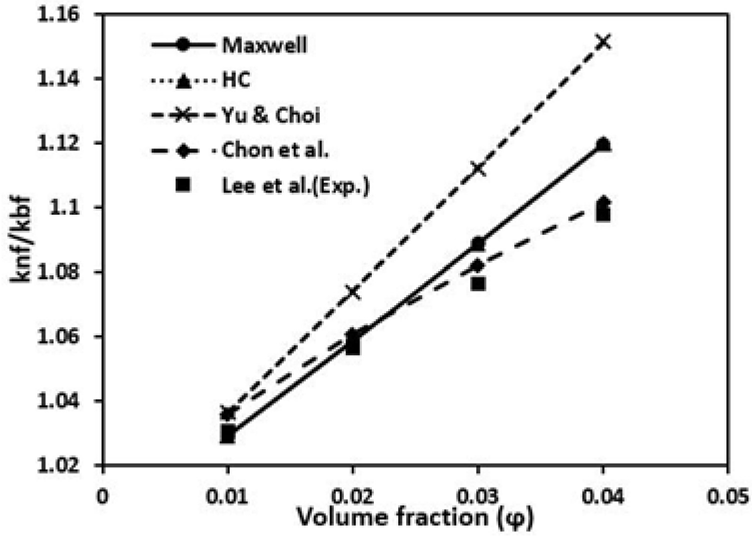

Figure 3.2: Thermal conductivity ratio for water- Al_2O_3 (38.4 nm) at 21 C [11]

According the figure 3.2 there are different kind of results are available in this diagram the thermal conductivity is measured according to the particle concentration and compared this results by experimental results of Lee et al. [7]. In the results the particle concentration is (1% - 4%). The nanofluid is mixture of water- Al_2O_3. The nanoparticles diameter is around (38.4 2 nm) and the temperature is 21 C. According to the figure at high particle concentration (2-4%) only the Chon et al [19] showing the better results than the others And the (0-2%) particle concentration all results gives a better results so from that it proved that Chon et al [19] results are good for low and high particles concentration.

3.1.2 Comparison with Fluid Temperature

According the figure 3.3 there are different kind of results are available in this diagram the thermal conductivity is measured according to the fluid temperature and compared this results by experimental results of Chon et al. [19]. In the results the particle concentration is 1%. The nanofluid is mixture of water- Al_2O_3. The nanoparticles diameter is around 47 nm and the temperature is 21 C.

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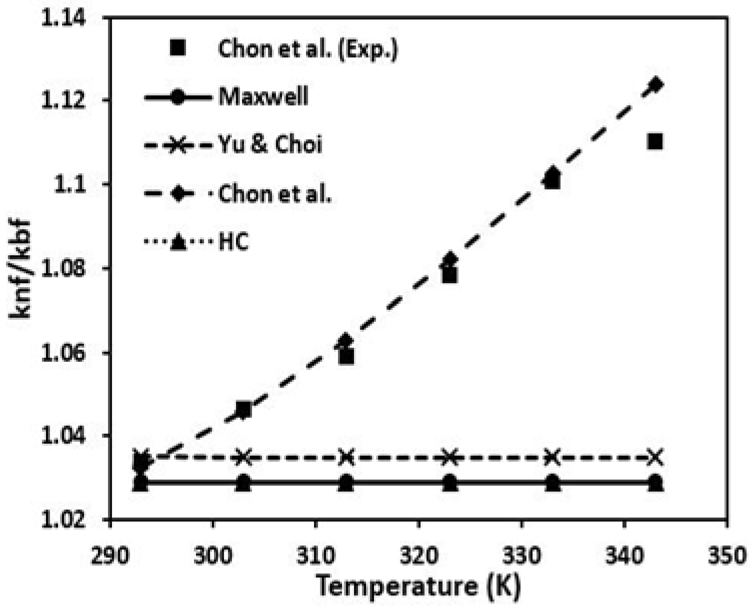

Figure 3.3: Thermal conductivity ratio for water- Al_2O_3 (1 vol.%) of 47 nm diameter.[19]

According to the figure the experimental results are matches with results of Chon et al [19] compare to the other results. In the Chon et al [19] model the results are very similar due to the direct effect of fluid temperature. In the other models results are not according to the experimental results because the thermal conductivity ratio is constant with respect to the temperature

3.1.3 Comparison with Particle Size

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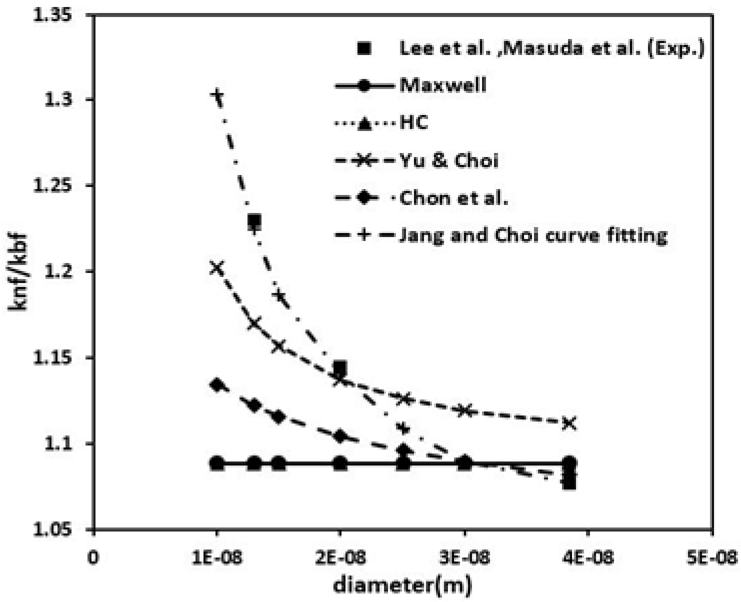

Figure 3.4: Thermal conductivity ratio for water- Al2O3 (3 vol.%) of dierent diameter.[7]

According the figure 3.4 there are different kind of results are available in this diagram the thermal conductivity is measured according to the particle size. In the results the particle concentration is 3%. The nanofluid is mixture of water- Al_2O_3. The temperature is 21 C. According to the models it is clear that very few models are available for the same particle size with the similar nanofluids and same paricle concentration at same temperature. So due to that curve is fitted by the results of the Masuda et al. [5] and Lee et al [7] at 13 and 38.4 nm diameter respectively According to the figure it is clear that for diameter up to 20 nm the Yu and Choi [20] model is better and diameter above 25 nm the Choi et al [19] is better.

3.2 Selection of Dynamic Viscosity Model

3.2.1 Comparison with Particle Concentration

According the figure 3.5 there are different kind of results are available in this diagram the dynamic viscosity is measured according to the particle concentration and compared this results by experimental results of Kyo et al. [17]. In the results the particle concentration is (0.01% - 0.3%). The nanofluid is mixture of water- Al2O3. The nanoparticles diameter is around (30 5 nm) and the temperature is 21 C.

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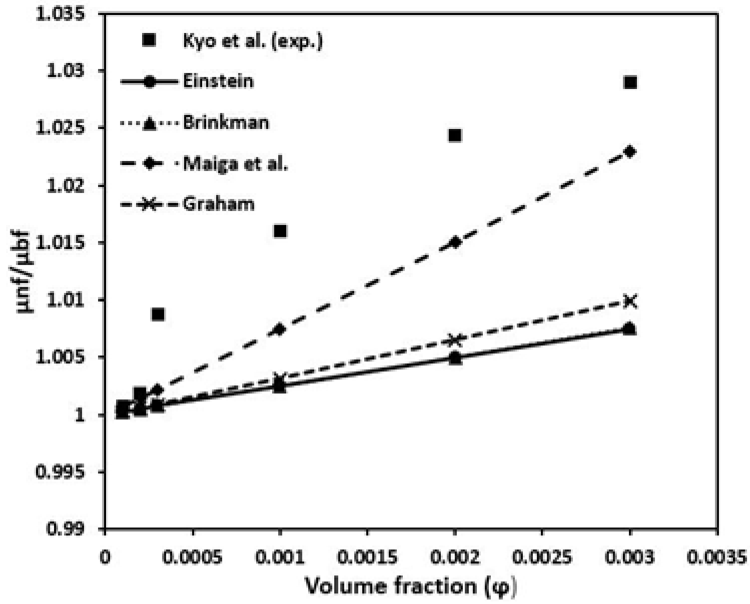

Figure 3.5: Dynamic viscosity ratio for water- Al_2O_3 (0.01 0.3%) at 21 C.[17]

According to figure 3.6 the viscosity increases with the particle concentration. there are different models into the figure but the Maiga et al [21] gives the better results than the other models. In the figure 3.6 there are also the different models and the results of different models are compared to the models. the paticle concentration is (1-2%). The nanofluid as a water-alumina and the temperature is 21C.

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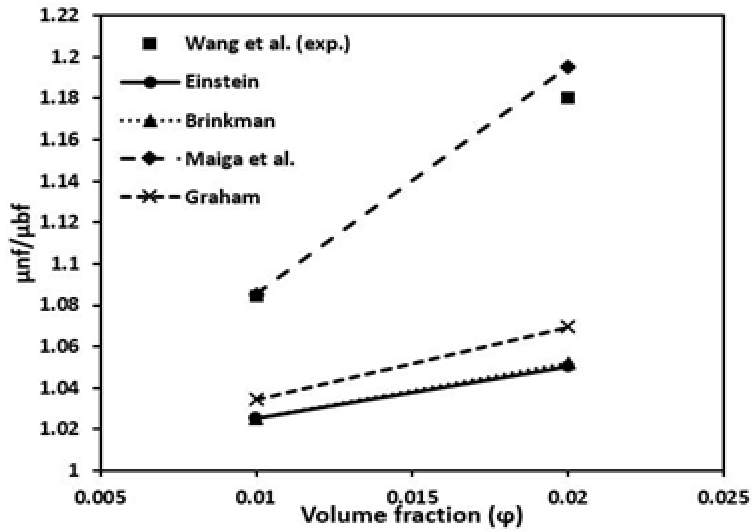

Figure 3.6: Dynamic viscosity ratio for water- Al_2O_3 (1 2%) at 21 C [21]

3.2.2 Comparison with Fluid Temperature

It is known that with increase in temperature dynamic viscosity of any fluid is decreasing. The eect of fluid mean temperature on eective dynamic viscosity is compared with the existing experimental results of Pak and Cho [14] for 1.34 and 2.78 vol.% particle concentration of water- Al_2O_3.

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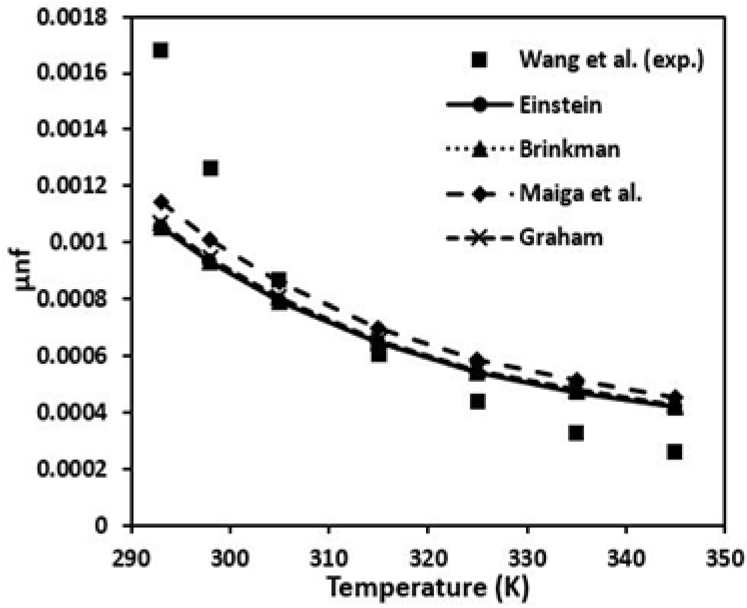

Figure 3.7: Dynamic viscosity for water- Al_2O_3 (1.34%). [14]

From figure 3.8 it is clear that none of the models can predict value correctly. But in the temperature range of 305 K to 315 K, Maiga et al. [21] model predict better values than other two models. So, it is required to find a dierent model which predicts accurate value for dierent temperature range.

Chapter 4

Analysis work

Analysis work involves modelling and numerical investigation on heat transfer enhancement in nanofluids and nanoaerosols using FLUENT software. Analysis is done according to the different condition.

4.1 Modelling

The size of nanoparticles are very small so it can be considered as ultrafine particles and can be easily fluidized in base fluid. So, the mixture of solid particle and base fluid can be treated as single phase and the effective thermophysical properties of nanofluid show the effect of nano particle.

4.1.1 Properties of Water

These are the properties of water used in present work [22]

Density = 998.2 kg/m3

Specific heat = 4182 J/kgK

Thermal conductivity = 0.6 w/m*k

Dynamic viscosity = 0.001003 kg/m*s

4.1.2 Properties of Nanoparticles

Table 4.1: Properties of nanoparticles

	Al_2O_3
Density (kg=m3)	3880
Specific heat (J=kgK)	729
Conductivity (W=mK)	42.34

4.1.3 Properties of Nanofluids

Density:

Pak and Cho [23] proposed correlation to find effective density of nanofluids. In most of the studies this correlation is used for density estimation.

$$\rho_{eff} = (1 - \Phi_p)\,\rho_g + \Phi_p\rho_p \tag{4.1}$$

Where, Density of nanofluids,

Denisty of base fluid,

Density of nanoparticles,

Nanoparticle volume fraction

All values of density are taken in kg=m3

Specific heat:

Similar to density correlation, specific heat correlation is also proposed by Pak and Cho [23]. This model is also widely used for calculating nanofluid specific heat.

$$C_{p_{eff}} = \frac{(1 - \Phi_p)\,\rho_g C_{pg} + \Phi_p\rho_p C_{pg}}{\rho_{eff}} \tag{4.2}$$

Where Specific heat of nanofluid,

Specific heat of base fluid,

Specific heat of nanoparticles

All values of specific heat are taken in J=kgK

4.2 Heat Transfer Enhancement in nanofluids

The study of nanofluids carried out for forced convection in a circular tube under constant heat flux condition.this numerical study is on to the laminar flow.

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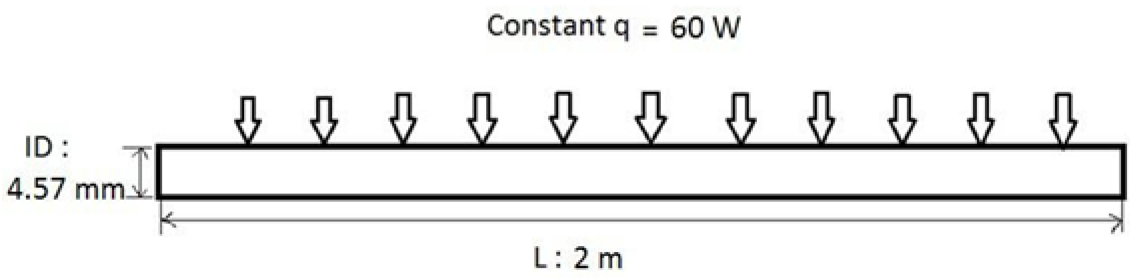

Figure 4.1: Dimensions of test section and its scheme [23]

4.2.1 Modelling of geometry

the modelling of geometry and mesh is generated by inbuilt modules of ANSYS. The details of geometry and cross section are as follows:

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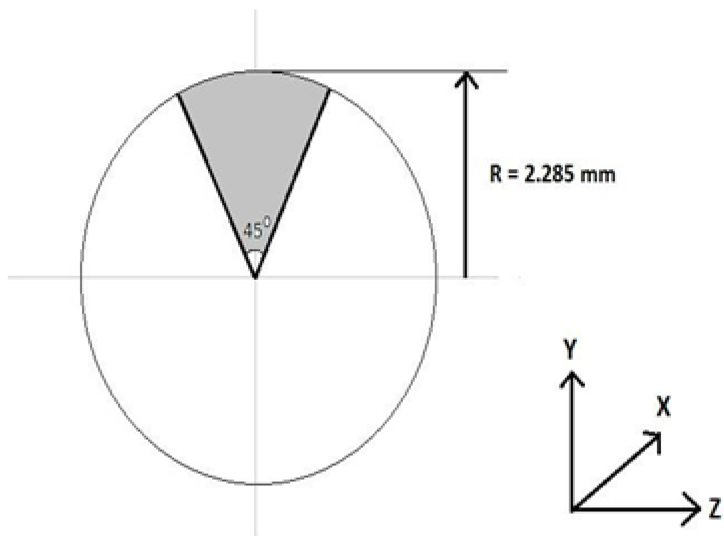

Figure 4.2: Cross section of horizontal tube and coordinate system

As shown in above figure 4.3 only the above shaded area of cross-section of circular tube is taken for computational fluid domain. The shaded portion is small compare to the circular tube. This is done to reduce computational time and energy.

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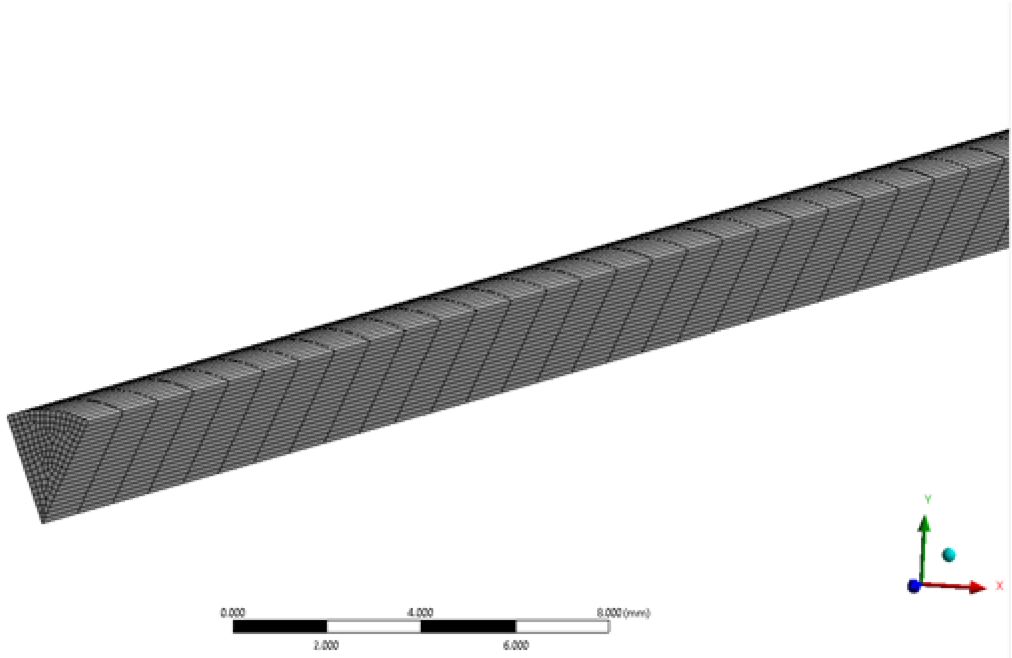

Figure 4.3: Cross section of horizontal tube and coordinate system

Figure 4.3 shows the 3-D mesh of the geometry. Which is use into the analysis.

Table 4.2: GIT

Mesh	**Min. face size**	**Nodes**	**Elements**	**Temp**
Coarse	0.0002	354729	76800	445 k
Fine	0.00017	369140	79200	440.5
Fine	0.00013	547865	120756	440

4.2.2 Setup Parameters and Boundary Conditions

According to the table 4.3, the setup parameter and boundary condition are set in fluent according to the material for modelling approach.

Table 4.3: Detail of setup parameters and Boundary condition for Water-Liquid

Solver type (Steady state)	Pressure based
Model (Single phase)	Viscous-Laminar
Material	Water-Liquid
Inlet	Velocity inlet (value as per Re number)
Outlet	Pressure outlet = 0 Pa (gauge)
Symmetry	Symmetry
Solution method (for pressure velocity coupling)	SIMPLE scheme
Solution method (for convective & diusive term)	Second order upwind method
Convergence criteria	1e-04, 1e-06 (for energy)

In table 4.3 the material is water-liquid so according to the material the properties are taken.

4.2.3 Result and discussion

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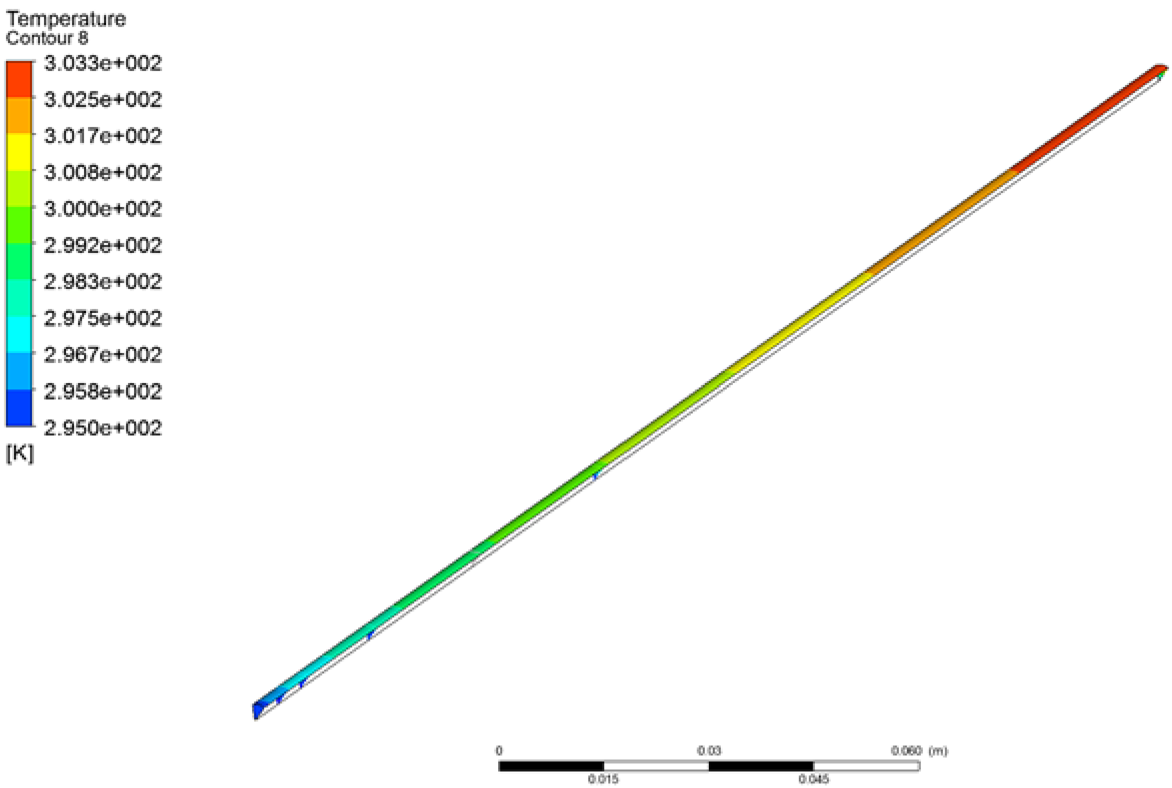

Figure 4.4: Result of water with RE-1460

The above result is for the water with Reynold number 1460, from that we can get the velocity. In result we can see that the temperature is continuous increasing from 295 to 303 k.

Table 4.4: Detail of setup parameters and Boundary condition for Water-Al_2O_3

Solver type (Steady state)	Pressure based
Model (Single phase)	Viscous-Laminar
Material	Water-Al_2O_3
Inlet	Velocity inlet (value as per Re number)
Outlet	Pressure outlet = 0 Pa (gauge)
Symmetry	Symmetry
Solution method (for pressure velocity coupling)	SIMPLE scheme
Solution method (for convective & diusive term)	Second order upwind method
Convergence criteria	1e-04, 1e-06 (for energy)

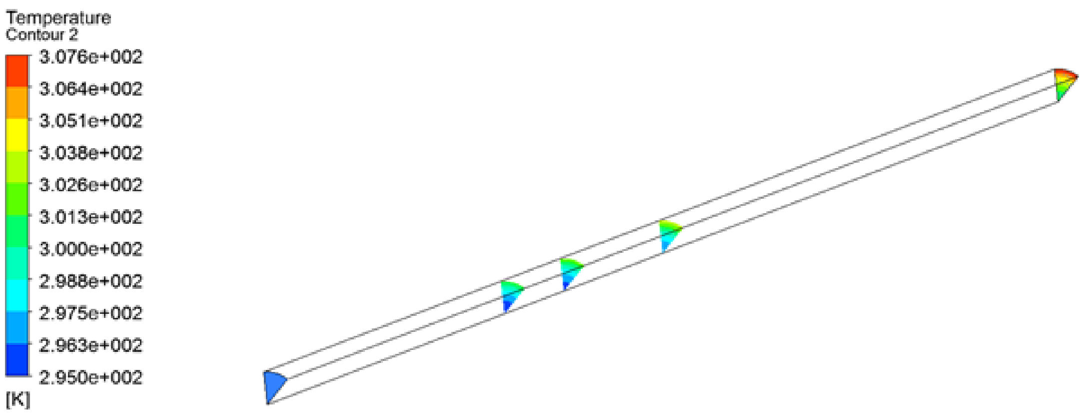

Figure 4.5: Result of water-Al_2O_3 with Re-1460

The above result is for the water with Reynold number 1460, from that we can get the velocity. In result we can see that the temperature is continuous increasing from 295 to 307 k.

Chapter 5

Modelling and analysis

5.1 Geometric Modelling

Geometry and mesh is created utilizing inbuilt modules of ANSYS.

Material:

Pipe : Stainless Steel

Hot wire : Nichrome

The Figure 5.1 shows the geometry of pipe and the hot wire as a heat source.The hot wire outer dia. is 1 mm and the pipe length is 1021 mm.The dia. of the stainless steel pipe is 10.16 mm.

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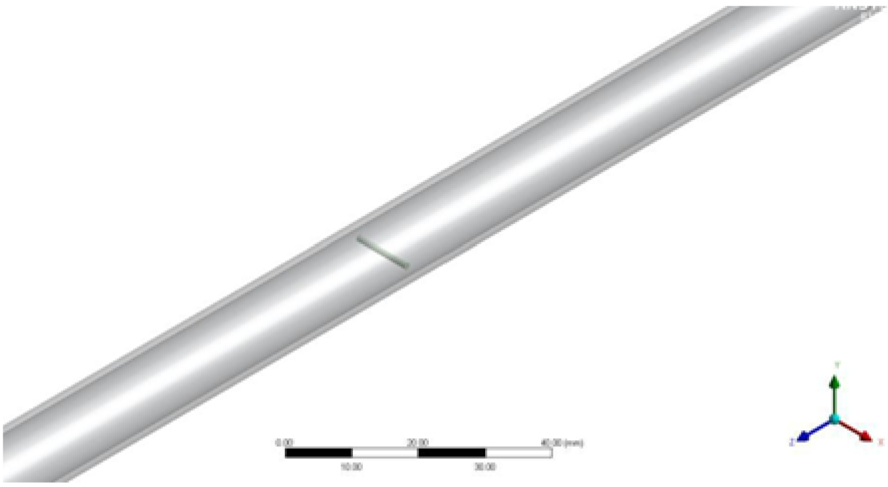

Figure 5.1: Geometry of Pipe and Hot wire

The figure 5.2 shows the front view of the geometry.It shows that the hot wire is placed between the pipe. —

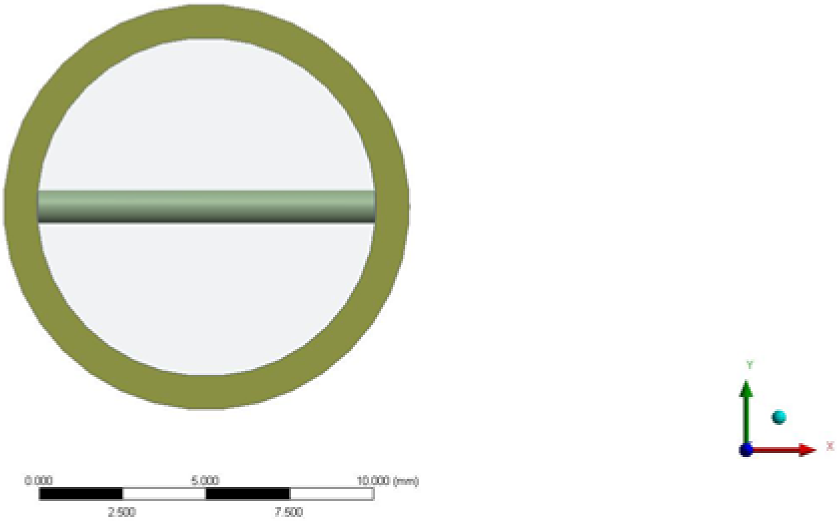

Figure 5.2: Front view of Geometry

5.2 Meshing

The Figure 5.3 shows the meshing of the geometry.It shows that the meshing is very fine throughout the length.The nodes of the meshing is 261312 and element of the meshing is 218598. —

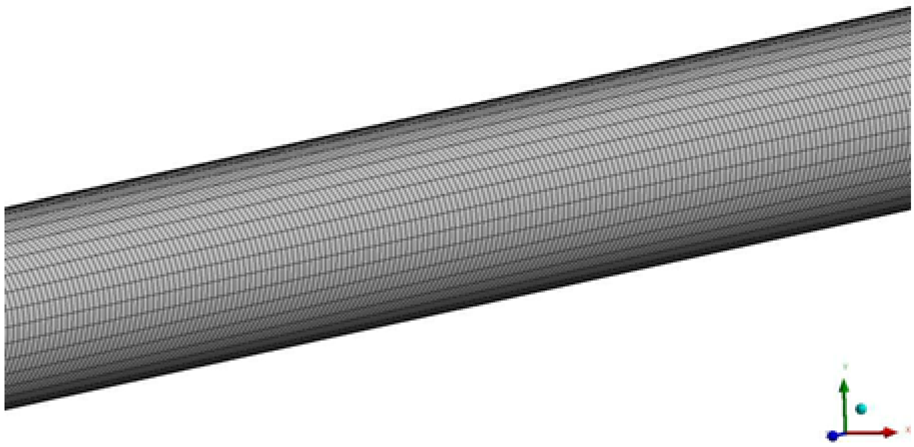

Figure 5.3: Meshing of Pipe

The figure 5.4 shows the wireframe of the geometry.the hot wire which is placed between the pipe is visibile due to the wireframe of pipe.The meshing of the hot wire is very fine.

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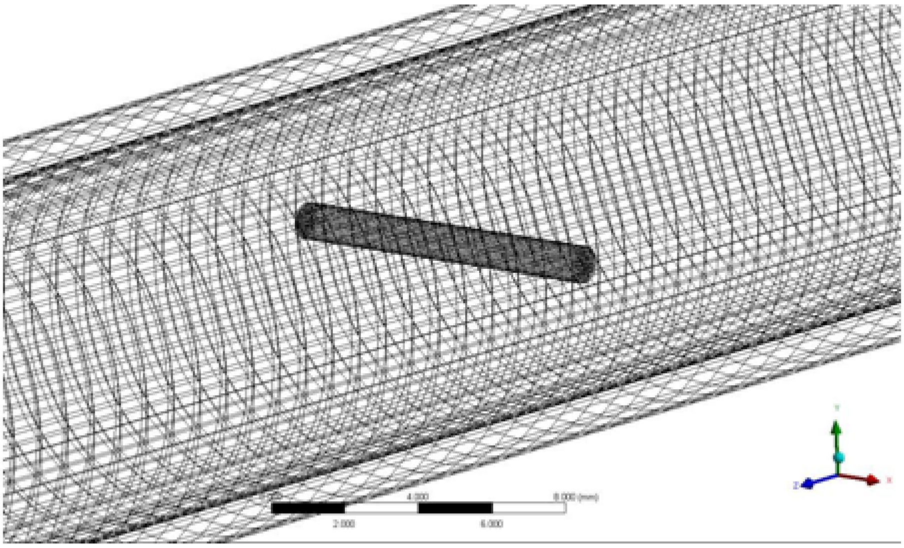

Figure 5.4: Meshing of Pipe and Hot wire

5.3 Property model

Properties of Stainless Steel and Nichrome

Table 5.1: Property of stainless steel and Nichrome

Property	**Stainless Steel**	**Nichrome**
Density	7700 Kg/m3	8400 Kg/m3
Specific Heat	500 J/Kg-K	450 J/Kg-K
Thermal Conductivity	16.2 W/m-K	11.3 W/m-K

$$\rho_{eff} = (1 - \Phi_p)\,\rho_g + \Phi_p \rho_p \tag{5.1}$$

$$C_{p_{eff}} = \frac{(1 - \Phi_p)\,\rho_g C_{pg} + \Phi_p \rho_p C_{pg}}{\rho_{eff}} \tag{5.2}$$

$$\mu_{eff} = \frac{\mu_g}{(1 - \Phi_p)^{2.5}} \tag{5.3}$$

$$k_{eff} = \frac{k_p + (\eta - 1)\,k_g + (\eta - 1)\,\phi_p (k_p - k_g)}{k_p + (\eta - 1)\,k_g - \phi_p\,(k_p - k_g)} k_g \tag{5.4}$$

Properties of air

These are the properties of air used in present work

Density = 1.225 kg/m3

Specific heat = 1006.43 J/kgK

Thermal conductivity = 0.0242 w/m*k

Dynamic viscosity = 0.000017894 kg/m*s

By substituting the required values in the above property model, we get the desired properties of Nano aerosol (Air + Al_2O_3) needed for the simulation. Below are the properties of Nano aerosol in which Al_2O_3 is suspended in the air.

Table 5.2: Effective property of Air + Al_2O_3

Density	120.28825 Kg/m3
Specific Heat	881.248920 J/Kg-K
Viscosity	1.93098 e-05 Kg/m-s
Thermal Conductivity	1.03234 W/m-K

Results are based on the following assumptions:

1. The heat flux of the outer wall is taken to be zero which means that the outer wall does not emit heat to the surroundings and the heat transfer takes place only between the hot wire and flow medium.

2. Area Weighted Average temperature is taken at the outlet of the tube. A plane is constructed at the outlet and area weighted average temperature is taken at that plane.

3. Air flow rate and particle flow rate is taken to be constant.

The simulation is carried out for Reynolds Number 600, 750, 900. First of all the simulation was carried out for Reynolds No. 600 in which initially air was passed and then air with the properties of Nano aerosol found from the property model was passed and the outlet temperature was noted down for both the cases. An increment in the outlet temperature was observed for the later one. Finally, the Nusselt no. was found. And then the simulation was carried out for Reynolds no. 750 and 900.

All the above results were compared with the experimental work.

Following are the results obtained after simulation.

Table 5.3: Experimental data for air and air + Al_2O_3 (Re 600)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	305.53	297	308.8
873	297	306.1	297	309.6
923	297	307.7	297	310.7

In the table 5.4 the comparison of the outlet temperature of Air and Air + Al_2O_3 is given.It shows that outlet temperature of Air + Al_2O_3 is more compare to air at the three different temperature of NIchrome wire and at 600 Reynolds number.

Table 5.4: Numerical data for air and air + Al_2O_3 (Re 600)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	305.95	297	310.05
873	297	306.8	297	311.29
923	297	307.65	297	312.25

Table 5.5: Experimental data for air and air + Al_2O_3 (Re 750)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	304.0	297	305.5
873	297	304.7	297	306.7
923	297	305.3	297	307

In the table 5.6 the comparison of the outlet temperature of Air and Air + Al_2O_3 is given.It shows that outlet temperature of Air + Al_2O_3 is more compare to air at the three different temperature of NIchrome wire and at 750 Reynolds number.In table 5.6 the values of outlet Temperature of Air + Al_2O_3 is small than the values which we get in the Table 5.4

Table 5.6: Numerical data for air and air + Al_2O_3 (Re 750)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	304.70	297	308.74
873	297	305.43	297	309.98
923	297	306.15	297	310.68

Table 5.7: Experimental data for air and air + Al_2O_3 (Re 900)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	303.5	297	304.7
873	297	304.2	297	305.4
923	297	305.6	297	306.5

In the table 5.8 the comparison of the outlet temperature of Air and Air + Al_2O_3 is given.It shows that outlet temperature of Air + Al_2O_3 is more compare to air at the three different temperature of NIchrome wire and at 900 Reynolds number.In table 5.8 the values of outlet Temperature of Air + Al_2O_3 is small than the values which we get in the Table 5.6. This is due to the change in Reynolds number and other flow parameter

Table 5.8: Numerical data for air and air + Al_2O_3 (Re 900)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	305.95	297	307.5
873	297	306.8	297	308.45
923	297	307.65	297	309.41

Now from the outlet temperatures of air and Nano aerosol, we will calculate the Nusselt Number for all the values. Nusselt Number would be calculated by using the below relationships in which the heat transfer equation is written between flow medium and hot wire(Nichrome).

Where Td and Tu stands for downstream and upstream temperatures respectively and Ts stands for surface temperature of hot wire.

Following tables show the Nusselt no. obtained after the simulation.

Table 5.9: Variation in Nusselt number of air and air + Al_2O_3 with Reynolds number

Reynolds number	**Air only (Nu)**	**Air + Al_2O_3 (Nu)**	**Change in Nu**
600	7.59	10.34	2.75
750	8.16	11.35	3.19
900	8.65	12.22	3.57

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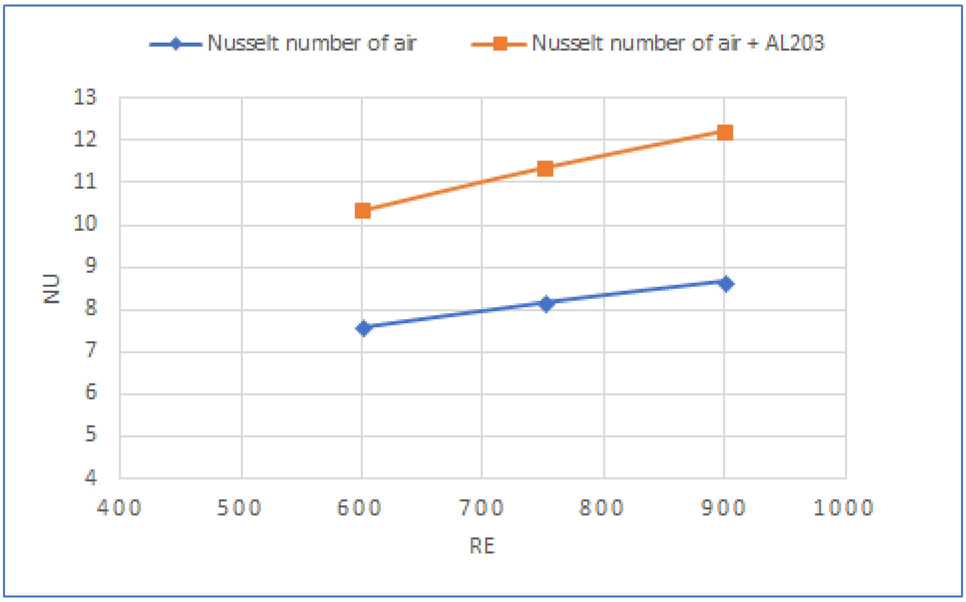

Figure 5.5: Re Vs Nu graph of air and air + Al_2O_3

Table 5.10: Comparison betwen Experimental and Numerical data

Re	**enhancement in (air + Al_2O_3) % NU(exp)**	**enhancement in (Air + Al_2O_3) % NU(num)**
600	35.54	36.23
750	38.53	39.09
900	40.21	41.27

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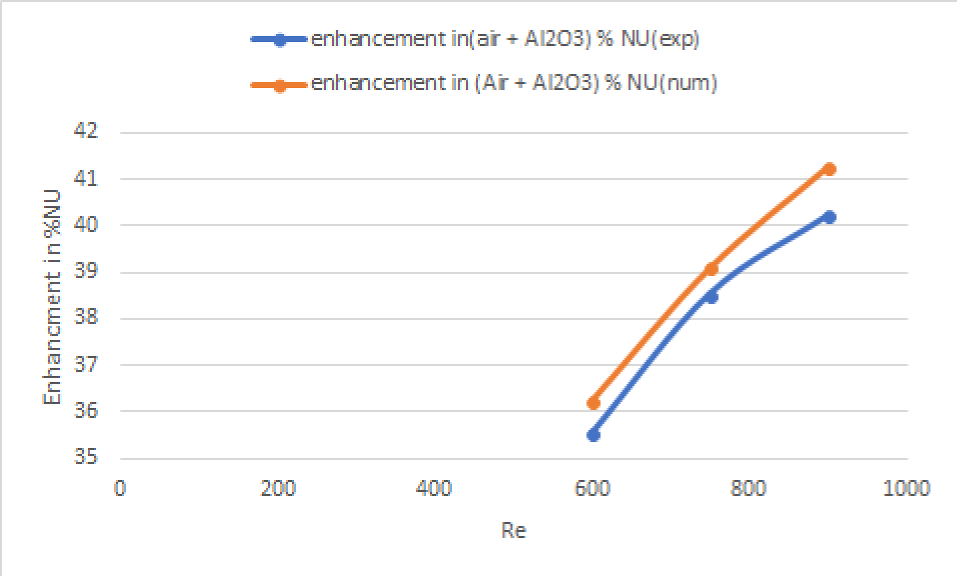

Figure 5.6: Re Vs Nu graph of air and air + Al_2O_3

Chapter 6

Numerical Results

In the Numerical Results there are mainly three different nano aerosols mixtures are taken and they are as follows: Air + SiO_2, Air + TiO_2, Air + MgO.

6.1 Setup Parameters and Boundary Conditions for Air + SiO_2

In the Air + SiO_2 Nano aerosol all the properties are calculated by using the property model. By using these Properties all the flow parameter are calculated Which is use into the setup and Boundary conditions.

Table 6.1: Detail of setup parameters and Boundary condition for Air + SiO_2

Solver type (Steady state)	Pressure based
Model (Single phase)	Viscous-Laminar
Material	Air-SiO_2
Inlet	Velocity inlet (value as per Re number)
Outlet	Pressure outlet = 0 Pa (gauge)
Symmetry	Symmetry
Solution method (for pressure velocity coupling)	SIMPLE scheme
Solution method (for convective & diusive term)	Second order upwind method
Convergence criteria	1e-04, 1e-06 (for energy)

Table 6.2: Effective property of Air + SiO_2

Density	209.6882 Kg/m3
Specific Heat	49.7521 J/Kg-K
Viscosity	1.93098 e-05 Kg/m-s
Thermal Conductivity	0.026321 W/m-K

Table 6.3: Numerical data for air and air + SiO_2 (Re 600)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	305.95	297	331.01
873	297	306.8	297	334.24
923	297	307.65	297	337.47

In the table 6.3 the comparison of the outlet temperature of Air and Air + SiO_2 is given.It shows that outlet temperature of Air + SiO_2 is more compare to air at the three different temperature of NIchrome wire and at 600 Reynolds number.

Table 6.4: Numerical data for air and air + SiO_2 (Re 750)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	304.70	297	325.50
873	297	305.43	297	328.21
923	297	306.15	297	330.92

In the table 6.4 the comparison of the outlet temperature of Air and Air + SiO_2 is given.It shows that outlet temperature of Air + SiO_2 is more compare to air at the three different temperature of NIchrome wire and at 750 Reynolds number.In table 6.4 the values of outlet Temperature of Air + SiO_2 is small than the values which we get in the Table 6.3

Table 6.5: Numerical data for air and air + SiO_2 (Re 900)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	303.80	297	324.57
873	297	304.44	297	327.19
923	297	305.09	297	329.81

In the table 6.5 the comparison of the outlet temperature of Air and Air + SiO_2 is given.It shows that outlet temperature of Air + SiO_2 is more compare to air at the three different temperature of NIchrome wire and at 900 Reynolds number.In table 6.5 the values of outlet Temperature of Air + SiO_2 is small than the values which we get in the Table 6.4. This is due to the change in Reynolds number and other flow parameter.

Table 6.6: Variation in Nusselt number of air and air + SiO_2 with Reynolds number

Reynolds number	**Air only (Nu)**	**Air + SiO_2 (Nu)**	**Change in Nu**
600	7.59	8.10	0.51
750	8.16	8.86	0.70
900	8.65	9.11	0.46

Table 6.6 Shows the Variation in the Nusselt number of Air and Air + SiO_2 corresponding to Reynolds number.

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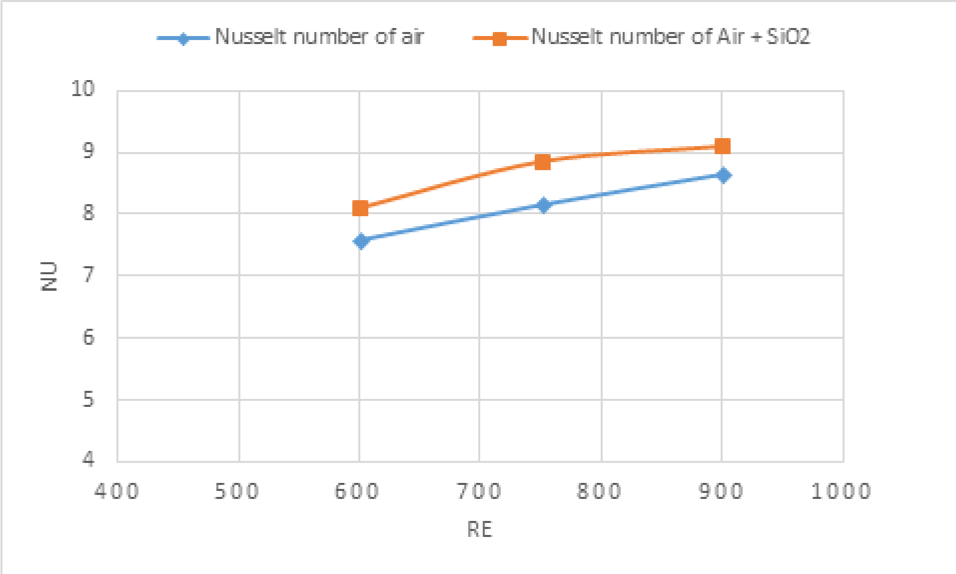

Figure 6.1: Re Vs Nu graph of air and air + SiO_2

The figure 6.1 shows the graph of Re Vs Nu of Air and Air + SiO_2.Figure shows that there is a enhancement in the Nusselt Number of Air + SiO_2 according to the Reynolds Number

6.2 Setup Parameters and Boundary Conditions for Air + TiO_2

In the Air +TiO_2 Nano aerosol all the properties are calculated by using the Equation number 5.1, 5.2, 5.3, 5.4.By using these Properties all the flow parameter are calculated Which is use intothe setup and Boundary conditions

Table 6.7: Detail of setup parameters and Boundary condition for Air + TiO_2

Solver type (Steady state)	Pressure based
Model (Single phase)	Viscous-Laminar
Material	Air-TiO_2
Inlet	Velocity inlet (value as per Re number)
Outlet	Pressure outlet = 0 Pa (gauge)
Symmetry	Symmetry
Solution method (for pressure velocity coupling)	SIMPLE scheme
Solution method (for convective & diusive term)	Second order upwind method
Convergence criteria	1e-04, 1e-06 (for energy)

Table 6.8: Effective property of Air + TiO_2

Density	209.6882 Kg/m3
Specific Heat	49.7521 J/Kg-K
Viscosity	1.93098 e-05 Kg/m-s
Thermal Conductivity	0.026321 W/m-K

Table 6.9: Numerical data for air and air + TiO_2 (Re 600)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	305.95	297	310.67
873	297	306.8	297	311.97
923	297	307.65	297	313.27

In the table 6.9 the comparison of the outlet temperature of Air and Air + TiO_2 is given.It shows that outlet temperature of Air + SiO_2 is more compare to air at the three different temperature of NIchrome wire and at 600 Reynolds number.

Table 6.10: Numerical data for air and air + TiO_2 (Re 750)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	304.70	297	308.45
873	297	305.43	297	309.54
923	297	306.15	297	310.63

In the table 6.10 the comparison of the outlet temperature of Air and Air + TiO_2 is given.It shows that outlet temperature of Air + TiO_2 is more compare to air at the three different temperature of NIchrome wire and at 750 Reynolds number.In table 6.10 the values of outlet Temperature of Air + TiO_2 is small than the values which we get in the Table 6.9

Table 6.11: Numerical data for air and air + TiO_2 (Re 900)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	303.80	297	307.10
873	297	304.44	297	307.81
923	297	305.09	297	308.75

In the table 6.11 the comparison of the outlet temperature of Air and Air + TiO_2 is given.It shows that outlet temperature of Air + TiO_2 is more compare to air at the three different temperature of NIchrome wire and at 900 Reynolds number.In table 6.11 the values of outlet Temperature of Air + TiO_2 is small than the values which we get in the Table 6.10 This is due to the change in Reynolds number and other flow parameter.

Table 6.12: Variation in Nusselt number of air and air + TiO_2 with Reynolds number

Reynolds number	**Air only (Nu)**	**Air + TiO_2 (Nu)**	**Change in Nu**
600	7.59	8.35	0.76
750	8.16	8.74	0.58
900	8.65	9.05	0.40

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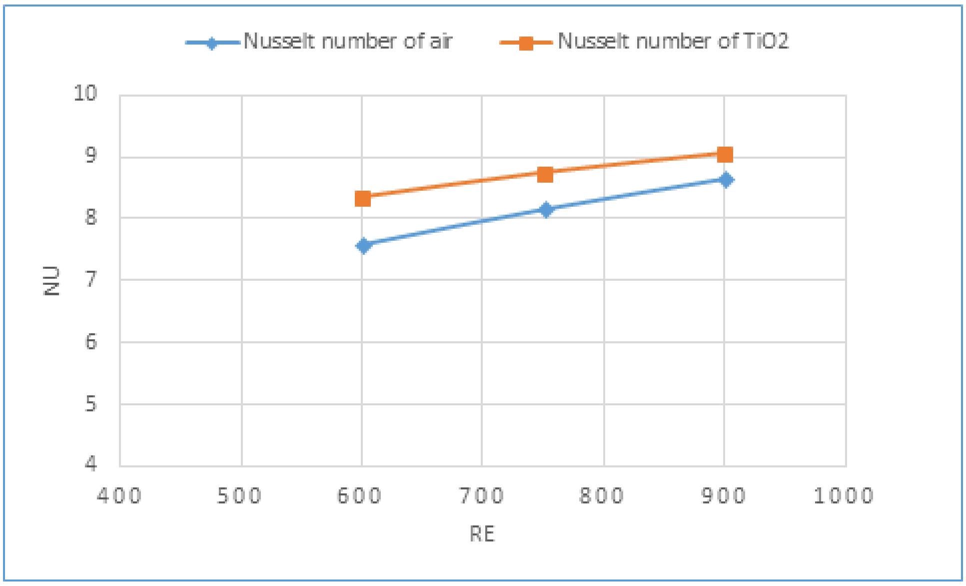

Figure 6.2: Re Vs Nu graph of air and air + TiO_2

The figure 6.2 shows the graph of Re Vs Nu of Air and Air + TiO_2.Figure shows that there is a enhancement in the Nusselt Number of Air + TiO_2 according to the Reynolds Number

6.3 Setup Parameters and Boundary Conditions for Air + MgO

In the Air + MgO Nano aerosol all the properties are calculated by using the Equation number 5.1, 5.2, 5.3, 5.4.By using these Properties all the flow parameter are calculated Which is use into the setup and Boundary conditions

Table 6.13: Detail of setup parameters and Boundary condition for Air + MgO

Solver type (Steady state)	Pressure based
Model (Single phase)	Viscous-Laminar
Material	Air-MgO
Inlet	Velocity inlet (value as per Re number)
Outlet	Pressure outlet = 0 Pa (gauge)
Symmetry	Symmetry
Solution method (for pressure velocity coupling)	SIMPLE scheme
Solution method (for convective & diusive term)	Second order upwind method
Convergence criteria	1e-04, 1e-06 (for energy)

Table 6.14: Effective property of Air + MgO

Density	209.6882 Kg/m3
Specific Heat	49.7521 J/Kg-K
Viscosity	1.93098 e-05 Kg/m-s
Thermal Conductivity	0.026321 W/m-K

Table 6.15: Numerical data for air and air + MgO (Re 600)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	305.95	297	312.98
873	297	306.8	297	313.81
923	297	307.65	297	314.56

In the table 6.15 the comparison of the outlet temperature of Air and Air + MgO is given.It shows that outlet temperature of Air + MgO is more compare to air at the three different temperature of NIchrome wire and at 600 Reynolds number.

Table 6.16: Numerical data for air and air + MgO (Re 750)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	305.95	297	309.01
873	297	306.8	297	310.16
923	297	307.65	297	311.30

In the table 6.16 the comparison of the outlet temperature of Air and Air + MgO is given.It shows that outlet temperature of Air + MgO is more compare to air at the three different temperature of NIchrome wire and at 750 Reynolds number.In table 6.16 the values of outlet Temperature of Air + MgO is small than the values which we get in the Table 6.15.

Table 6.17: Numerical data for air and air + Mg (Re 900)

Nichrome wire	**Air only**		**Air + Nanoparticle (Nano aerosol)**	
T(K)	T in(K)	Tout(K)	Tin(K)	Tout(K)
823	297	305.95	297	307.35
873	297	306.8	297	308.34
923	297	307.65	297	309.32

In the table 6.17 the comparison of the outlet temperature of Air and Air + MgO is given.It shows that outlet temperature of Air + MgO is more compare to air at the three different temperature of NIchrome wire and at 900 Reynolds number.In table 6.17 the values of outlet Temperature of Air + MgO is small than the values which we get in the Table 6.16 This is due to the change in Reynolds number and other flow parameter.

Table 6.18: Variation in Nusselt number of air and air + MgO with Reynolds number

Reynolds number	**Air only (Nu)**	**Air + MgO (Nu)**	**Change in Nu**
600	7.59	8.61	1.02
750	8.16	10.53	2.37
900	8.65	11.24	2.59

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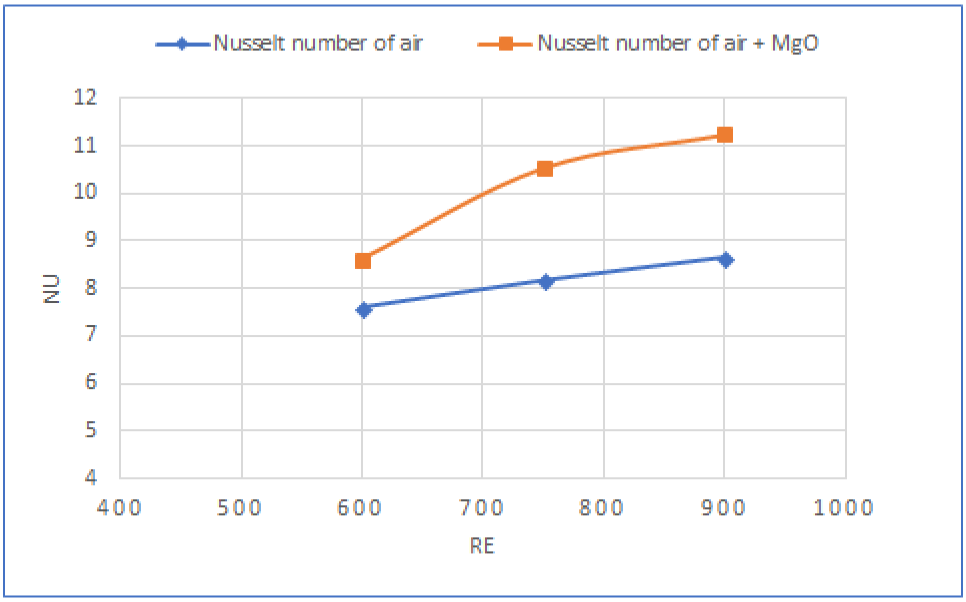

Figure 6.3: Re Vs Nu graph of air and air + MgO

The figure 6.2 shows the graph of Re Vs Nu of Air and Air + MgO.Figure shows that there is a enhancement in the Nusselt Number of Air + MgO according to the Reynolds Number

Table 6.19: Numerical results of Nusselt number of different Nano Aerosols

Reynolds number	**Nusselt number of air**	**Nusselt number of Air +** Al_2O_3	**Nusselt number of Air +** SiO_2	**Nusselt number of Air +** TiO_2	**Nusselt number of Air + MgO**
600	7.59	10.34	8.1	8.35	8.61
750	8.16	11.35	8.86	8.74	10.53
900	8.65	12.22	9.11	9.05	11.24

In the above table the comparison of Nusselt Number of all the Nanoaerosols with respect to Reynolds number is given.The table shows that among all the values the Enhancement in Air + Al_2O_3 is more.This is due to the Effective property of Air + Al_2O_3 and by the other flow parameter.

Chapter 7

Conclusion & Future scope of work

7.1 Conclusion

This project work is investigation of Enhancement in the heat transfer coefficent of air by blendig different nanoparticles Numerically.All the Numerically carried work concludes that:

For Air $+Al_2O_3$

- At 600 reynolds number the Nusselt of Air is 7.59 and for Air + Al_2O_3 it is 10.34, Which shows 36.23% improvement.

- At 750 reynolds number the Nusselt of Air is 8.16 and for Air + Al_2O_3 it is 11.35, Which shows 39.09% improvement.

- At 900 reynolds number the Nusselt of Air is 8.65 and for Air + Al_2O_3 it is 12.22, Which shows 41.27% improvement.

For Air + SiO_2

- At 600 reynolds number the Nusselt of Air is 7.59 and for Air + SiO_2 it is 8.1, Which shows 6.71% improvement.

- At 750 reynolds number the Nusselt of Air is 8.16 and for Air + SiO_2 it is 8.86, Which shows 8.58% improvement.

- At 900 reynolds number the Nusselt of Air is 8.65 and for Air + SiO_2 it is 9.11, Which shows 5.31% improvement.

For Air + TiO2

- At 600 reynolds number the Nusselt of Air is 7.59 and for Air + TiO_2it is 8.35, Which shows 10.01% improvement.

- At 750 reynolds number the Nusselt of Air is 8.16 and for Air + TiO_2 it is 8.74, Which shows 7.10% improvement.

- At 900 reynolds number the Nusselt of Air is 8.65 and for Air + TiO_2 it is 9.05, Which shows 4.62% improvement.

For Air + MgO

- At 600 reynolds number the Nusselt of Air is 7.59 and for Air + MgO it is 8.61, Which shows 13.44% improvement.

- At 750 reynolds number the Nusselt of Air is 8.16 and for Air + MgO it is 10.53, Which shows 29.04% improvement.

- At 900 reynolds number the Nusselt of Air is 8.65 and for Air + MgO it is 11.24, Which shows 34.61% improvement.

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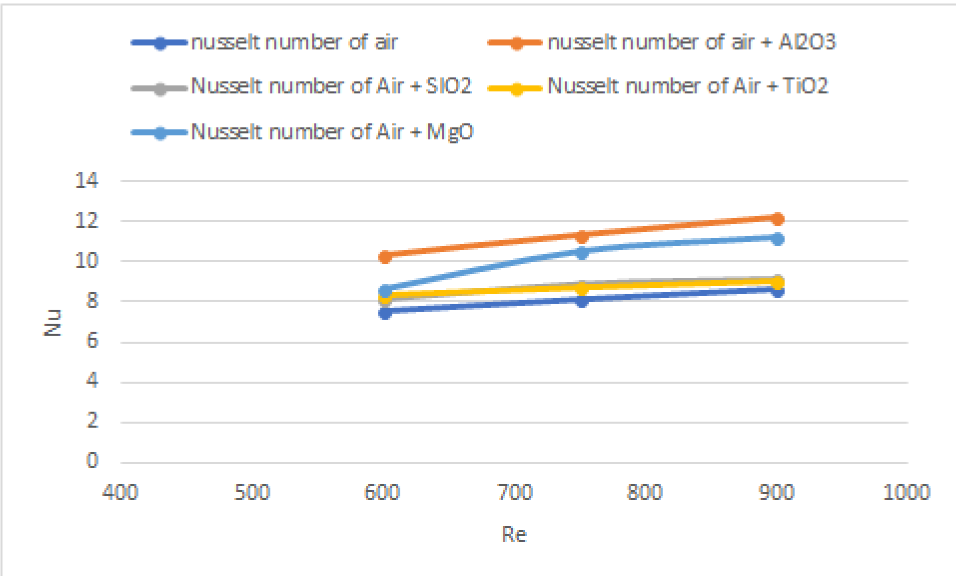

Figure 7.1: Re Vs Nu graph

This graph compares Nusselt number against Reynolds number for air and different Nano aerosols. It shows that Air + Al_2O_3 gives the best results among all the combinations.

7.2 Future Scope of work

- All these works are Numerically which can be further implemented to experimental works.
- In this project work is carried on circular geometry,which could be study for other non circular geometry for help in various practical application

Bibliography

[1] Sarit K. Das et al., Nanofluids science and technology, Willey.

[2] J.C. Maxwell, A Treatise on Electricity and Magnetism, second ed, Clarendon Press, Oxford, UK, 1881.

[3] [3]. Choi SUS. Enhancing thermal conductivity of fluids with nanoparticles, in Development and Applications of Non-Newtonian Flows. ASME FED 231/ MD 1995;66:99103.

[4] Xiang-Qi Wang, Arun S. Mujumdar. Heat transfer characteristics of nanofluids: a review. International Journal of Thermal Sciences 46 (2007) 119.

[5] Masuda, H., A. Ebata, K. Teramae, and N. Hishinuma. Alteration of thermal conductivity and viscosity of liquid by dispersing ultrafie particles (dispersions of gAl2O3, SiO2, and TiO2 ultrafie particles). Jpn. J. Thrmophys. Prop. 7, no.4, 1993: 227233.

[6] Mosavi et al. An Overview of Numerical Investigation of Nanouids for Enhancement of Heat Transfer in Circular Tubes, International Journal on Emerging Technologies 7(1): 42-46(2016)

[7] S. Lee, S.U.S. Choi, S. Li, J.A. Eastman, Measuring thermal conductivity of fluids containing oxide nanoparticles, Journal of Heat Transfer 121 (1999) 280289.

[8] Davarnejad et al., CFD simulation of the effect of particle size on the nanofluids convective heat transfer in the developed region in a circular tube, SpringerPlus 2013, 2:192

[9] X. Wang, X. Xu, S.U.S. Choi, Thermal conductivity of nanoparticlefluid mixture, Journal of Thermophysics and Heat Transfer 13 (4) (1999) 474 480.

[10] J.A. Eastman, S.U.S. Choi, S. Li, W. Yu, L.J. Thompson, Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles, Applied Physics Letters 78 (6) (2001) 718720.

[11] Saha and paul, Numerical analysis of the heat transfer behaviour of water based Al2O3 and TiO2 nanofluids in a circular pipe under the turbulent flow condition, International Communications in Heat and Mass Transfer 56 (2014) 96108.

[12] Y. Xuan, Q. Li, Heat transfer enhancement of nanofluids, International Journal of Heat and Fluid Transfer 21 (2000) 5864.

[13] salman et al, Numerical Study of Three Different Approaches to Simulate Nanofluids Flow and Heat Transfer in a Microtube, Heat Transfer-Asian Research, 45 (1), 2016.

[14] Bock Choon Pak Young I. Cho (1998): Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Experimental Heat Transfer:A Journal of Thermal Energy Generation, Transport, Storage, and Conversion, 11:2,151-170.

[15] Y. Ding, H. Alias, D. Wen, R.A. Williams, Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids), International Journal of Heat and Mass Transfer 49 (12) (2005) 240250.

[16] Abdolbaqi et al. Heat transfer augmentation in the straight channel by using nanofluids, Case Studies in Thermal Engineering 3 (2014) 5967.

[17] Trivedi et al., Convective heat transfer enhancement with nanoaerosols, International Journal of Heat and Mass Transfer 102 (2016) 11801189.

[18] Kyo et al., Flow and convective heat transfer characteristics of water-based Al2O3 nanofluids in fully developed laminar flow regime, International Journal of Heat and Mass Transfer 52 (2009) 193199.

[19] C.H. Chon, K.D. Kihm, S.P. Lee, S.U.S. Choi, Empirical correlation finding the role of temperature and particle size for nanofluid (AlO) thermal conductivity enhancement, Appl. Phys. Lett. 87 (2005) 153107.

[20] Thesis by Rushabh Patel, Nirma University Ahmedabad.

[21] W. Yu, S.U.S. Choi, The role of interfacial layers in the enhanced thermal of nanofluids: a renovated Maxwell model, Journal of Nanoparticle Research 5 (12) (2003) 167171.

[22] S.E.B. Maiga, C.T. Nguyen, N. Galanis, G. Roy, Heat transfer behaviours of nanofluids in a uniformly heated tube, Superlattices and Microstructures 35 (2004) 543557.

[23] B. Pak, I. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Exp. Heat Transfer 11 (1998) 151170.

[24] C.H. Chon, K.D. Kihm, S.P. Lee, S.U.S. Choi, Empirical correlation finding the role of temperature and particle size for nanofluid (AlO) thermal conductivity enhancement, Appl. Phys. Lett. 87 (2005) 153107.

[25] D. Kim et al., Convective heat transfer characteristics of nanofluids under laminar and turbulent flow conditions, Curr. Appl Phys. 9 (2) (2009) e119e123.