International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 11
November 2017

Numerical Prediction of Thermodynamics and Heat Transfer Characteristics of Nano Fluid.

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ABSTRACT
A numerical simulation is carried out to understand the thermodynamics and heat transfer characteristics of Nano fluid combustion. Three types (0.1%, 0.2% and 0.3%) of volume fraction of nano particles were used in this present investigation. AlO_2 and Cu nano particles were added with the main fuel of kerosene. The Thermodynamics properties of the nano fluid were calculated and found that the thermal conductivity, heat capacity increases in volume of the nano particle in the main fluid. It was also found that heat transfer coefficient and Nusselt's numberincreases with increase in volume fraction of nano-particles.

Keywords
Nusselts number, Heat transfer coefficient, Nano fluid

1. INTRODUCTION

Several new technological advancements are being made in the recent years to enhance the performance of liquid rocket engines, one of which is the addition of nanoparticles to the fuel. Research works done in this area show an increased enhancement in heat transfer and combustion characteristics of the modified fuel. These heat transfer properties make them useful in regenerative cooling in liquid rocket engines.Hsien-Huung Ting and ShuhnShyurng investigated the convective heat transfer of water based Al_2O_3 nanofluidsof various volume fractions (0.2%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5%) for various Reynolds number of the range 7000<Re<2050 flowing through a square cross-section with a constant heat flux under laminar conditions. The effects of nanoparticles concentration and Peclet number on the heat transfer behavior of the nanofluids were studied. The physical properties of the nanofluid were determined.SaeedZeinaliHeris, SeyyedHosseinNoie, ElhamTalaii, JavedSargolzaeianalysed a triangular duct under constant wall temperature was investigated numerically for laminar flow forced convective heat transfer of Al_2O_3/water nanofluid. It was also found that by decreasing the size of nanoparticles, the ratio of surface area to volume of nanoparticles increased.Joseph Edher, GuilhermeAzevedo Oliveira, EnioPedoneBandarra analysed on the thermal and hydrodynamic behaviour of nanofluids made of metallic and metal oxide nanoparticles in water flowing in a horizontal circular tube was done using the commercial software CFX. The density of nanofluid was calculated based on mixture rule. Specific heat,Viscosity and Thermal conductivity were also determined. These properties were determined for alumina and silver nanoparticles and for three different volume concentrations each i.e. 0.5%, 1.0%, 3.0%..

2. METHODOLOGY

2.1. Computational Domain

A circular tube of specific length and internal diameter is designed using ANSYS workbench software and a laminar flow is modelled with the help of FLUENT 15.0. Convective heat transfer coefficient is determined for pure kerosene at various Reynolds number. Properties affecting heat transfer are calculated for various volume concentrations of kerosene-alumina and kerosene-copper nanofluid using analytical models. These

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www.ijetsr.com
ISSN 2394 – 3386
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properties are used to create modified fuels in FLUENT database. Convective heat transfer coefficient and Nusselt number variation for these modified fuels are compared with pure kerosene and the enhancement is studied. A theoretical approach is used to validate the simulation results.

2.2 DETERMINATION OF CONVECTIVE HEAT TRANSFER COEFFICIENT:

Convective heat transfer measurements are carried out for varying boundary conditions. The purpose of using a heat transfer coefficient is to calculate the heat flux between the wall and the fluid. In the case of uniform wall flux an energy balance can be used directly to infer theway in which the bulk average temperature of the fluid changes with distance along the axial direction.

2.3 NUMERICAL APPROACH:

The value of heat transfer coefficient depends on many variables. In a three dimensional case where the flow and temperature fields interact, the fluid flow behaviour would only be obtained by first evaluating the three velocity components u, v, w, the temperature T, the pressure p, the density ρ, the viscosity μ and the thermal conductivity k of the fluid. This would involve the simultaneous solution of 8 equations, viz., 3 equations of motion, laws of conservation of mass and energy, equation of state and empirical relations for viscosity and thermal conductivity.

The local and average heat transfer coefficients are obtained which can be written as

$$h = \frac{q}{(T_s - T_f)}$$

$$\overline{h_L} = \frac{1}{L}\int_0^L h\, d$$

where L is the length of the tube.

The heat transfer coefficient is often calculated from the Nusselt number Nu= $\frac{hD}{k}$where D is the diameter of the tube. The solutions for the heat transfer coefficient up to the entry length are available. In practise it is normally the mean value of the Nusselt number over the length x=0 to x=L. The mean value defined as

$$\overline{N}_D = \frac{1}{L}\int_{x=0}^{L}(N_D)_x d$$

can be computed if the local value of Nusselt number is known as a function of x.

3 ANALYTICAL MODELS FOR DETERMINING THE PHYSICAL PROPERTIES OF NANOFLUIDS:

3. 1 DENSITY (ρ):

Density or volumetric density which is the mass per unit volume of a substance is calculated based on the physical properties of the mixture rule for nanofluids.

$$\rho_n = \left(\frac{m}{v}\right)_n = \frac{m_f + m_p}{v_f + v_p} \quad (5.1)$$

$$\rho_n = \frac{\rho_f v_f + \rho_p v_p}{v_f + v_p} \quad (5.2)$$

Where the subscripts denote f-fluid, p-particle and nf- nanofluid

Taking the volume concentration as φ = $\frac{v_p}{v_p + v_f}$

Equation (5.2) becomes $\rho_n = (1 - \varphi_p)\rho_f + \varphi_p \rho_p$ (5.3)

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The above equation is also called Newton's mixture equation. This equation has been experimentally validated by several researchers to measure density of Al_2O_3- water nanofluids at room temperature and the results were in good agreement.

If density is considered for temperature dependent case then the following equation can be used for determining density of basefluid for various temperatures [1]

$$\rho_b = 999.79 + (.068 * t) - (.0107 * t^2) + (0.00082 * t^{2.5}) - (2.303 * 10^{-5} * t^3) \quad (3.14)$$

wheret is the temperature in ºC. This dependence of temperature is non-linear.

Density determines the volume required for storage. Fuels with larger density are preferred because the volume can be reduced and additional amount of fuel can be carried. Addition of nanoparticles to liquid fuels tends to increase the density

3. 2 THERMAL CONDUCTIVITY (k):

Several theoretical models are available for calculating thermal conductivity of nanofluids but there are no theoretical results in the literatures to accurately predict the thermal conductivity of nanofluids because its value varies with size of the particles.

$$k_e = \frac{k_p + (n-1)k_f + (n-1)\varphi_p(k_p - k_f)}{k_p + (n-1)k_f - \varphi_p(k_p - k_f)} k_f \quad (5.4)$$

n in equation (5.4) denotes the shape factor given by n=3ψ where ψ is the particle sphericity defined by the ratio of the surface area of the particle. This model is reduced to Maxwell's model when sphericity is equal to 1. Important parameters such as temperature and particle size are not considered in this model which is a major drawback.

3. 3 SPECIFIC HEAT CAPACITY (C_p):

Specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius. It is measured in J/gºC or J/kgK

By assuming thermal equilibrium between the nanoparticles and the base fluid phase the specific heat of nanofluid can be determined and can be expressed as follows.

Thus
$$c_e = \frac{(1-\varphi_p)\rho_f c_f + \varphi_p \rho_p c_p}{\rho_e} \quad (5.5)$$

A simpler expression for specific heat can be given by,

$$c_e = (1 - \varphi_p)c_f + \varphi_p c_p \quad (5.6)$$

Literature studies show that specific heats calculated based on the above models decrease with increase in volume fractions.

3. 4 VISCOSITY (μ):

Viscosity refers to the fluid's resistance to flow. It denotes the internal friction of a moving fluid. Low viscous fluids flow easily and do not require much pumping power. Viscosity gives a direct assessment of processibility and is important for designing

$$\mu_b = 0.00169 - (4.25 * 10^{-5} * t) + (4.92 * 10^{-7} t^2) - (2.09 * 10^{-9} t^2) \quad (5.7)$$

where t is in ºC

3. 5 GOVERNING EQUATIONS :

For a single phase flow of nanofluid the following governing equations are used for mathematical formulation.

Conservation of mass

$$\text{div}\,(\rho\vec{V}) = 0$$

Conservation of Momentum

$$div\,(\rho\vec{V}\vec{V}) = -grad\,\mathbf{P} + \nabla.(\nabla\vec{V})$$

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Conservation of energy:

$$div\ (\rho\vec{V}C_pT) = div\ (k\ grad\ \mathbf{T})$$

Compression is considered to be negligible in the energy equation.

3. 6 BOUNDARY CONDITIONS:

The boundary conditions are as shown in the figure. Constant velocity inlet which is calculated from the Reynolds number and pressure outlet boundary conditions are applied. For heat transfer analysis a constant wall heat flux of 4000W/m^2 is considered.

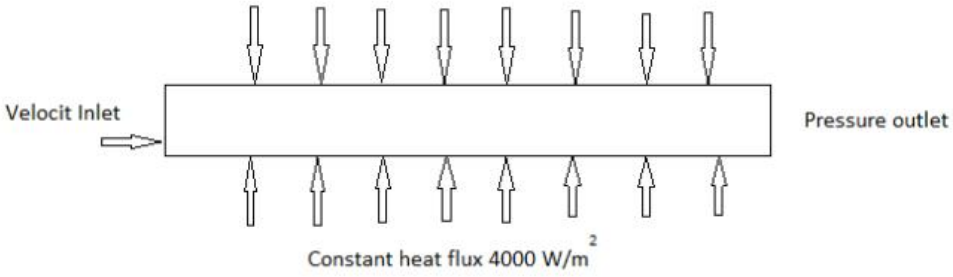

Figure 5.1: Boundary conditions

3. 7 MESH GENERATION:

TheICEM CFD meshing software from ANSYS workbench is used for mesh generation. Mapped face meshing is used for the inlet and outlet faces to obtain uniformity. A fine mesh with following size is generated.Cells: 319421, Nodes: 719573, Faces: 123605

4. RESULTS AND DISCUSSIONS

4.1 Thermal properties of Nano fluid

It is seen from table 6.1 and 6.2 that the thermal conductivity of nanofluids is increasing with the addition of nanoparticles and is dependent on the volume concentration. A similar rise is seen in the case of density due to the higher mass per unit volume of the nanoparticles. Since the viscosity is calculated based on Einstein's model which takes into consideration only the volume concentration and not the material property the values are found to be the same in both the cases of alumina and copper. Due to higher thermal conductivity and density of copper compared to alumina the effective values of copper nanofluid is higher than alumina nanofluid. A decreasing trend is seen for specific heat of nanofluid with the addition of particles contrary to the other three properties and is lesser for copper nanofluid compared to alumina nanofluid.

Table 6.1: Properties of Kerosene-Alumina nanofluid

Properties	**Pure kerosene**	**Kerosene Alumina φ=0.5%**	**Kerosene Alumina φ=1.0%**	**Kerosene Alumina φ=3.0%**
k(W/m K)	0.149	0.1512	0.1534	0.1626
ρ(kg/m^3)	780.0	795.6	811.2	873.6
C$_p$(J/kg K)	2090.0	2083.95	2077.9	2053.7
μ(kg/ms)	0.0024	0.00243	0.00246	0.00259

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ISSN 2394 – 3386
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Table 6.2: Properties of Kerosene-Copper nanofluid

Properties	Pure kerosene	Kerosene Copper φ=0.5%	Kerosene Copper φ=1.0%	Kerosene Copper φ=3.0%
k(W/m K)	0.149	0.1512	0.1535	0.1628
ρ(kg/m^3)	780.0	820.9	861.8	1025.4
C_p(J/kg K)	2090.0	2081.475	2072.95	2038.85
μ(kg/ms)	0.0024	0.00243	0.00246	0.00259

Table 6.3: Properties of materials used

Material	Density (kg/m^3)	Specific heat (J/kg-K)	Thermal conductivity (W/mK)
Alumina	3900	880	40
Copper	8960	385	401

Table 6.4: Velocity calculation for inlet boundary condition

Reynolds number	Pure kerosene	Kerosene Alumina φ=0.5%	Kerosene Alumina φ=1.0%	Kerosene Alumina φ=3.0%
250	0.769	0.763	0.758	0.741
500	1.538	1.527	1.516	1.482
1000	3.077	3.054	3.032	2.964
2000	6.154	6.108	6.065	5.929

Reynolds number	Pure kerosene	Kerosene Copper φ=0.5%	Kerosene Copper φ=1.0%	Kerosene Copper φ=3.0%
250	0.769	0.74	0.713	0.63
500	1.538	1.48	1.427	1.26
1000	3.077	2.96	2.85	2.52
2000	6.154	5.92	5.70	5.04

The variation of static temperature across the wall of the tube is shown in figures (7.1) and (7.2) for both cases of Alumina and Copper. The wall temperature is found to increase across the length due to the heat transfer. Similar trend is seen with the addition of nanoparticles but the temperature is lesser than the pure kerosene. Further decrease in wall temperature is seen with the increase in concentration of the nanoparticles.

The figures (7.3) and (7.4) show a decreasing trend of heat transfer coefficient along the length of the tube the reason for which is given by Seider Tate relation. It shows that as the length of the tube increases Nu decreases with $L^{-\frac{1}{3}}$and hence h decreases with distance. A very small increase in convective heat transfer coefficient is noticed with the addition of nanoparticles for both alumina and copper for Re=250Similar to the

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previous comparison plot simulations are run for different concentrations of nanofluids at Reynolds number of 1000. This is shown in figures (7.5) and (7.6). The convective heat transfer coefficient trend across the tube is similar to the previous case but there is an increase in the values. Also the enhancement with addition of nanoparticles is much higher when compared to the previous case.

The plots show the increase of convective heat transfer coefficient for different Reynolds number for both alumina and copper nanofluids of kerosene. Very small enhancement is seen for lower Reynolds number but the percentage enhancement increases with increase in Re.

Nusselt number for all concentrations of nanofluid seems to increase with increasing Reynolds number. For the model and fluid medium considered in this problem, there is no much difference in the increasing trend of Nusselt number with Reynolds number for change in volume concentration and particles (alumina or copper). This is because thermal conductivity of the nanofluids also increases with addition of nanoparticles.

4.2 COMPARISON OF THEORETICAL AND SIMULATION RESULTS:

The theoretical results are found to go well with the simulation results for lower Reynolds number. As the Reynolds number increases the difference increases because the Seider Tate correlation is valid only for thermal entrance region. Heat transfer in laminar flow is maximum in the thermal entrance region. As the Reynolds number increases the length of this region decreases thereby increasing the deviation in theoretical and simulation results.

VARIATION OF STATIC TEMPERATURE ACROSS THE TUBE FOR Re=500

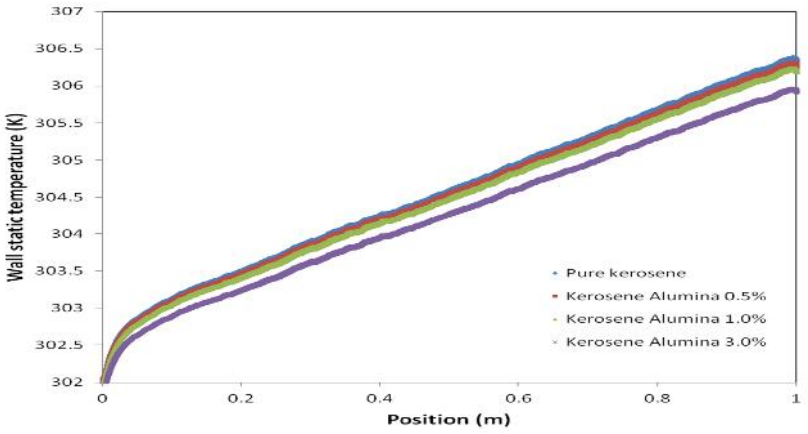

Figure 7.1: Wall static temperature across the tube for Re=500 (Alumina)

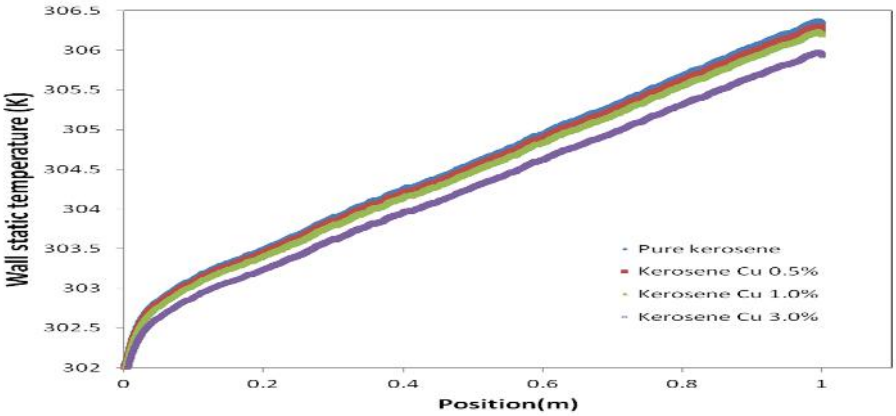

Figure 7.2: Wall static temperature across the tube for Re=500 (Copper)

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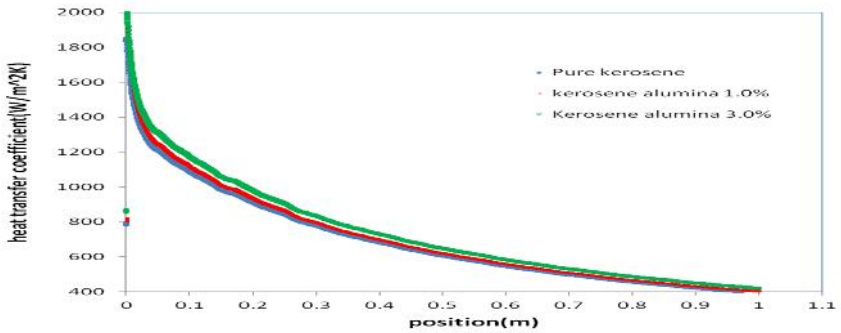

Figure 7.3: Convective heat transfer Re=250,Alumina

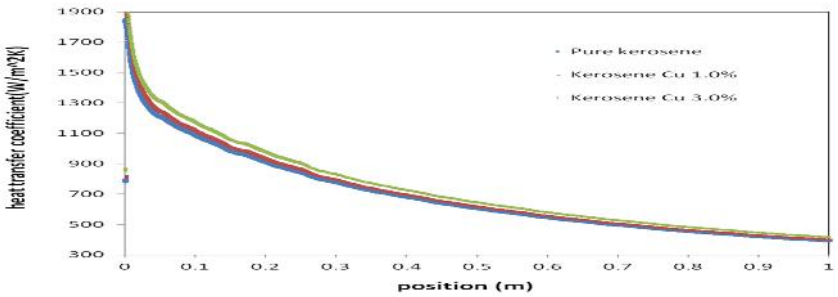

Figure 7.4: Convective heat transfer coefficient across the length of the pipe for Re=250,Cu

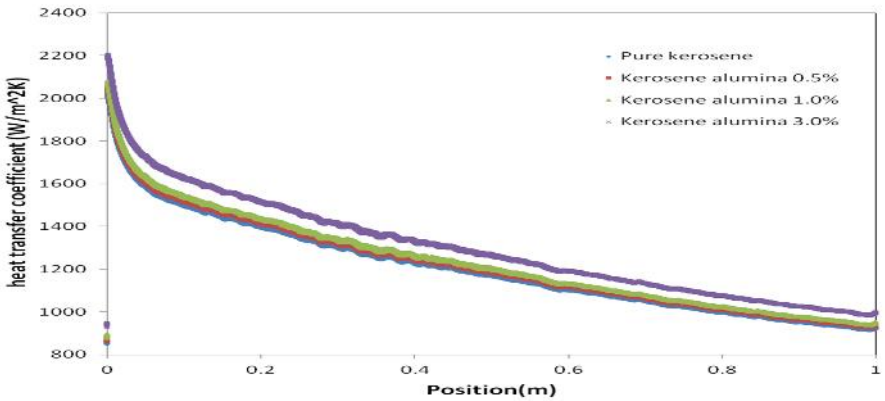

Figure 7.5: Convective heat transfer coefficient at Re=1000(Alumina)

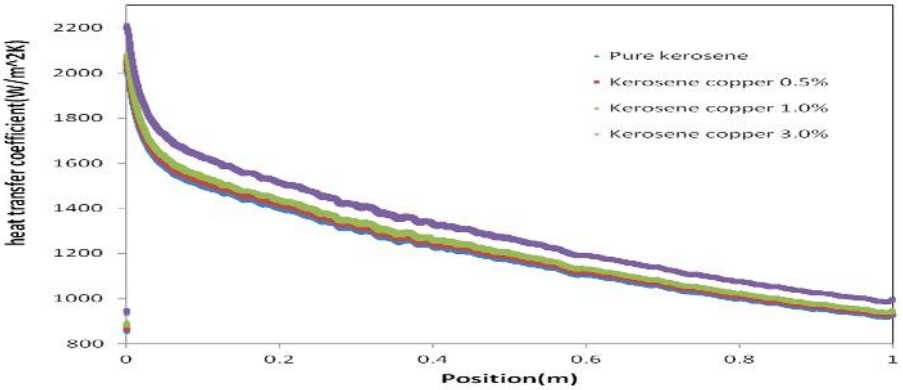

Figure 7.6: Convective heat transfer coefficient across the length of the pipe for Re=1000

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ISSN 2394 – 3386
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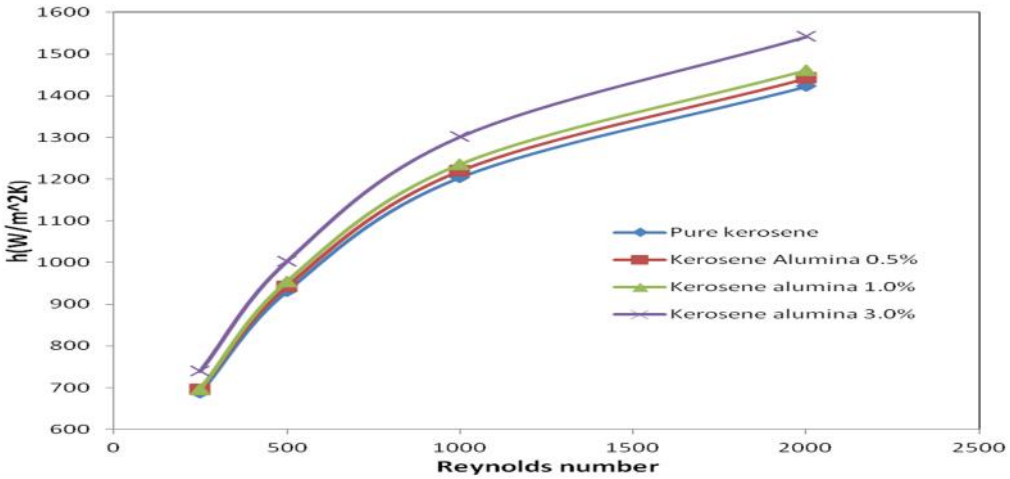

Figure 7.7: Convective heat transfer coefficient for different Reynolds number (Alumina)

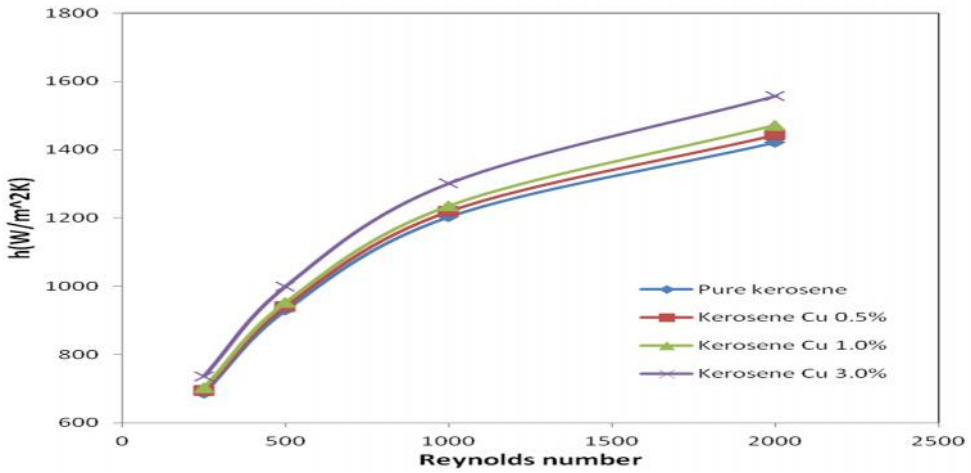

Figure 7.8: Convective heat transfer coefficient for different Reynolds number (Copper)

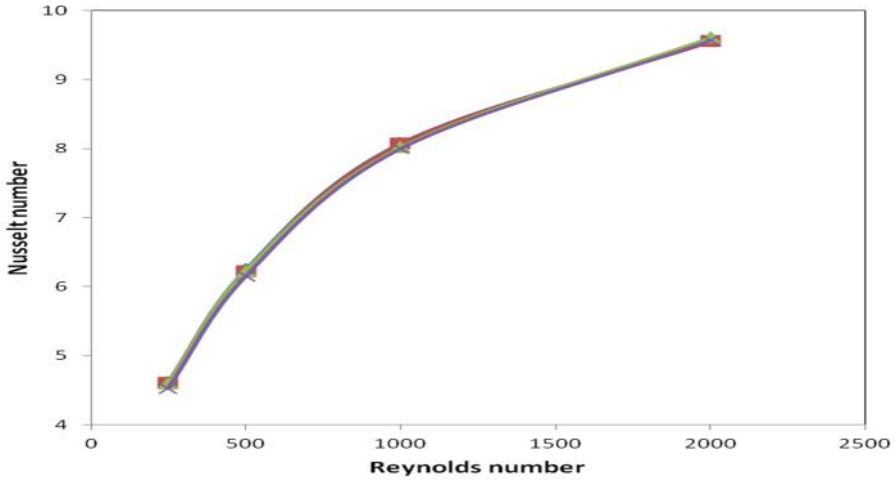

Figure 7.9: Variation of Nusselt number with Reynolds number for both alumina and copper at different volume concentrations

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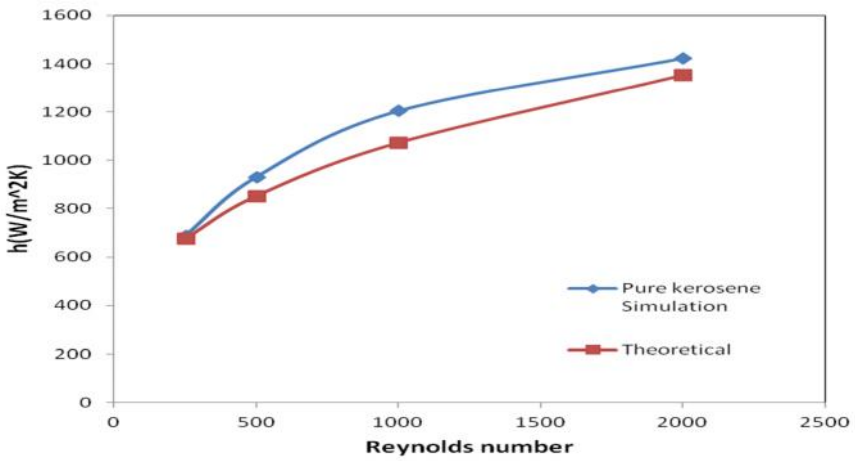

Figure 7.10: Comparison of theoretical and numerical Reynolds number for pure kerosene at different Reynolds number

COMPARISON OF THEORETICAL AND SIMULATION CONVECTIVE HEAT TRANSFER COEFFICIENT:

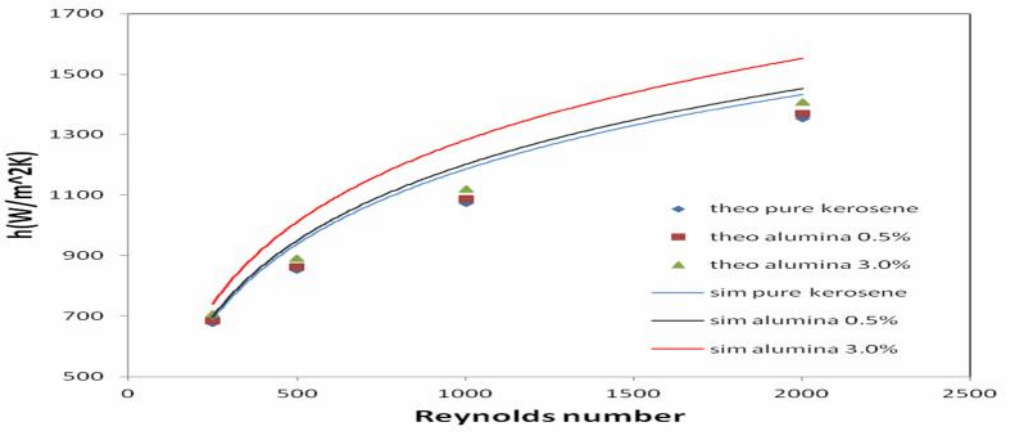

Figure 7.11: Comparison of theoretical and simulation h for different Re (Alumina)

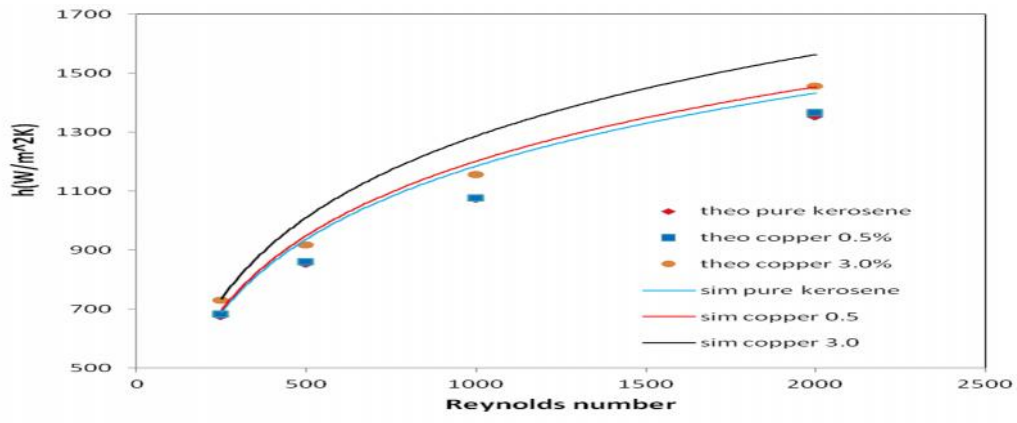

Figure 7.12: Comparison of theoretical and simulation h for different Re (Copper)

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5 PERCENTAGE INCREASE OF HEAT TRANSFER COEFFICIENT:

NANOFLUID	ENHANCEMENT of h (%) for Re			
Re	250	500	1000	2000
Kerosene-Cu 0.5%	1.11	1.20	1.32	1.52
Kerosene-Cu 1.0%	2.23	2.42	2.62	3.53
Kerosene-Cu 3.0%	6.91	7.38	8.10	9.52
Kerosene-Alumina 0.5%	1.18	1.24	1.31	1.37
Kerosene-Alumina 1.0%	2.28	2.46	2.60	2.70
Kerosene-Alumina 3.0%	7.29	7.61	8.04	8.35

Table 8.1: Percentage increase of heat transfer coefficient

The table shows the increase in heat transfer coefficient with increase in Reynolds number and volume concentration. It is seen that for lower Reynolds number kerosene-alumina nanofluid has higher convective heat transfer coefficient than Kerosene-Copper nanofluid. But with higher Reynolds number Kerosene-copper nanofluid is found to be more efficient in terms of convective heat transfer. An enhancement of 9.52% in convective heat transfer coefficient is noticed for kerosene-Copper nanofluid at 3.0% volume concentration and at Reynolds number of 2000. For the same concentration and Reynolds number an enhancement of 8.35% only is seen in the case of Kerosene-alumina nanofluid.

CONCLUSION:

A laminar flow through a circular tube is modelled using FLUENT solver. Properties of nanofluids are determined using the analytical models available in the literature and fed into the fluent material database. Computations are performed for pure kerosene and kerosene nanofluids with added particles of alumina and copper at varying volume concentrations (φ=0.5%, 1.0%, 3.0%). The results are plotted and an increment in heat transfer coefficient with increasing particle volume concentration is observed across the length of the tube. As expected the convective heat transfer coefficient follows a decreasing trend across the length of the pipe. A comparison between the heat transfer coefficient of base fluid and nanofluid at different Reynolds number is made. Increase in Reynolds number increased the heat transfercoefficient across the pipe. Also the difference in heat transfer coefficient between base fluid and nanofluid was more for higher Reynolds number and volume fraction of the particles added.

Nusselt number being directly proportional to the convective heat transfer coefficient was found to increase with Reynolds number. Not much variation was noticed with increase in volume fraction of nanoparticles because the thermal conductivity of the nanofluids also increased with increase in volume fraction of the particles. The simulation results of convective heat transfer coefficient were compared with theoretical correlations and were found to be in good agreement with each other for lower Reynolds number. The deviation in results increased with increase in Reynolds number which was due to the decrease in length of thermal entrance region with increasing Re.

Thus it is concluded that the nanofluids of kerosene can serve to be better coolant for regenerative cooling by increasing the convective heat transfer characteristics. Also due to the addition of metal particles there are possibilities for the combustion chamber temperature to rise resulting in increased specific impulse.

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