iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** VI **Month of publication:** June 2016

DOI:

www.ijraset.com Volume 4 Issue VI, June 2016
IC Value: 13.98 ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Heat Transfer Enhancement in Circular Wavy Grooved Surface Tube Using Alumina-Water Nanofluid

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Abstract- In this paper the computational analyses of circular wavy grooved surface using alumina nanofluid has been carried out to simulate the fluid flow and heat transfer characteristics for turbulent flow models using ANSYS 15.0. The flow of fluid is assumed to be incompressible, steady and turbulent with constant thermo physical properties. The flow is studied for Reynolds number 3980 to 119425 with constant boundary conditions. The Navier Stokes equations along with the energy equation have been solved by using SIMPLE Technique. The standard k-ϵ turbulence model is used for simulation of fully developed turbulent flow. First, the simulation is done on the simple tube and then the tube is replaced by the circular wavy grooved surfaced tube with same diameter and length and then it is simulated. Then finally the effect of alumina nanofluid is investigated for the same boundary conditions. The result shows 55% to 93% increase in nusselt number and with the use of circular wavy grooved surface and it further enhances with the use of nanofluid. There was also a huge drop of pressure due to use of circular wavy grooved surfaced tube.
Keywords – Heat exchanger, Alumina, Nanofluids, Reynolds number, Nusselt number, specific heat, Navier Stokes.

I. INTRODUCTION

Heat exchangers are commonly used devices that transfer heat from one fluid (gas or liquid) to another without those two fluids mixing. Heat transfer enhancement is the process of enhancing the performance of a heat transfer unit. It is used in heating and air conditioning systems in a household, chemical processing and power production in large plants. There are several methods used to increase the heat transfer rate in compact heat exchangers. The greater part of these techniques have a typical goal, i.e., to separate the boundary layer on the solid surface, introducing secondary flows or to provide disturbance in flow. This research has been going on to get high efficiency, small size, low cost, and light weight of heat transfer unit. The conventional approach for increasing cooling rates is the use of extended surfaces such as fins and microchannels. The other method is to increase the thermal conducitivity of fluid. Choi et al. proposed the use of nanofluids which are having extremely impressive and attractive thermal properties. In other words, the real trick of using nanofluids, characterized as liquids with nanosized molecule suspensions, was initially presented by Choi in 1995 in Argonne National Laboratory. Since Choi made the possibility of nanofluids, various explores have been performed on the thermal performance of nanofluids. Different nanoparticles, for example, silver, CuO, diamond, titanium, nickel oxide, and gold have been used inside within the heat pipe working fluid. Different types of heat exchangers are extensively used in various industries to transfer the heat between cold water and hot stream. The key role of the heat exchanger is to transfer heat at maximum rate. To achieve higher heat transfer rate through a variety of augmentation methods can result in significant energy savings, more compact and less pricey apparatus with higher thermal efficiency.

II. LITERATURE REVIEW

Neha Maheshwari et al. [1], 2015, Computational Analysis of Convective Heat Transfer Enhancement in Double Pipe Helical Coil Heat Exchanger using SiO_2 –Water Nanofluid with Mixture Model. In this a numerical study is carried for the turbulence flow. The result showed the heat transfer enhancement by the nanofluid. Sinan Goktepe et al. [2] numerically and experimentally analysed the Comparison of single and two-phase models for nanofluid convection at the entrance of a uniformly heated tube.the tube is studied under the laminar flow. The result obtained showed that single phase thermal dispersion model suggested by Mokmeli and Saffar-Avval is found to be the most accurate single-phase model. Jaafar Albadr et al. [3], 2014, presents an experimental study on the forced convective heat transfer and flow characteristics of a nanofluid consisting of water and different volume concentrations of Al_2O_3 nanofluid (0.3–2) % flowing in a horizontal shell and tube heat exchanger counter flow under turbulent flow conditions.the result showed that heat transfer increases with the concentration of the particle. Firoz Rangrez & Prof. S.H.Kulkarni, [4], 2014, investigated the CFD Analysis of Air-Cooled Heat Exchanger Using Reduced Diameter Inner Grooved Copper Tube. The result confirms the better performance of grooved tube as compared to the simple tube. R. Mokhtari Moghari et al. [5], 2013, studied the Investigation effect of nanoparticle mean diameter on mixed convection Al2O3-water nanofluid flow in an annulus by two phase mixture model.the result shows that the nusselt number gets enhanced with decreasing of nanoparticle mean diameter. S. Eiamsa-ard & P. Promvonge [6], 2007, studied the Enhancement of Heat Transfer in a Circular Wavy-surfaced Tube with a Helical-tape Insert. The experiment result showed that the heat transfer rate can be substantially improved by using both the wavy-surfaced wall and the helical tape while friction factor also increases due to these methods.

III. GEOMETRY AND MATHEMATICAL FORMULATION

In case of simple tube, the geometry of tube consists of a tube 840 mm long having 40 mm internal diameter. While in second case, the tube consists of circular wavy surface on the inside of tube. The wavy surface wall is of length 70mm, with converging and diverging sections. The converging sections are of length 30 mm and diverging sections is of length 40 mm. the outer diameter of the tube is 40 mm and while the throat diameter is of 20 mm. Further there are circular grooves on the pipe of diameter 4mm. The difference in diverging and converging angle helps in reducing eddy current losses. The pipe is simulated in ANSYS using constant wall temperature conditions.

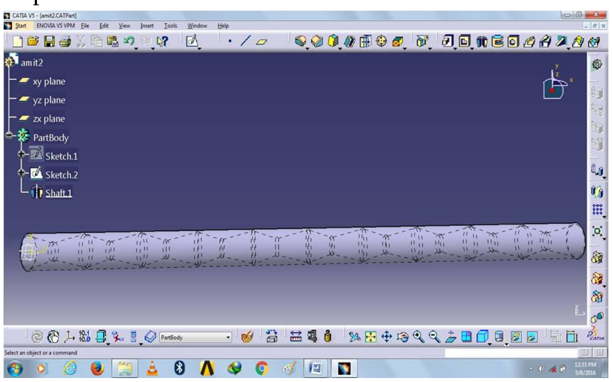

Fig. 1 Design of circular wavy grooved surfaced tube in CATIA

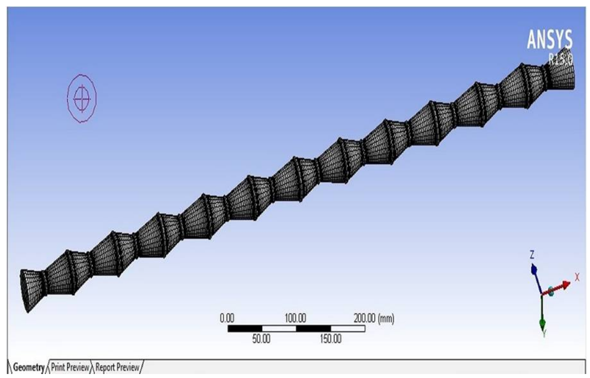

Fig. 2 meshing of circular wavy grooved surface tube in ANSYS

IV. GOVERNING EQUATIONS AND BOUNDARY EQUATIONS

A. *Governing equations*

The basic governing equations are continuity equations, momentum equations (navier stokes equations) and energy equations.

B. *Governing equations for single phase model*

In the single phase model, the mixture of nanoparticles and the fluid phase are considered as a single fluid with effective properties. In order to calculate the thermo physical properties of
nanofluids, there are several correlations in literature, and in this study for density, viscosity, heat capacity and thermal conductivity, the following equations have been used.
Density of nanofluid can be obtained as

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

Where bf and nf represents the base fluid and nanofluid.Φ represents the concentration of the naoparticle in the nanofluid.
The viscosity of the fluid can be calculated as

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

Specific heat of nanofluid can be calculated as

Volume 4 Issue VI, June 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

$$C_{pnf} = \frac{(1-\varphi)(\rho C_p)_p}{(1-\varphi)\rho_{bf} + \varphi\rho_p}$$

Where subscript p represents the nanoparticle.
The thermal conductivity of the nanofluid can be calculated as

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{pe} + 2k_{bf} + 2(k_{pe} - k_{bf})(1+\beta)^3\varphi}{k_{pe} + 2k_{bf} - (k_{pe} - k_{bf})(1+\beta)^3\varphi}$$

Where k_{pe}

$$k_{pe} = \frac{[2(1-\gamma)+(1+\beta)^3(1+2\gamma)]}{[-(1-\gamma)+(1+\beta)^3(1+2\gamma)]}k_p$$

And β is the ratio of thickness to the radius to the radius of particle.
$\beta = t/r_p$

C. Standard k-ε model for turbulence flow

The standard k-ε model has been chosen as the turbulence model. The turbulence kinetic energy, k, and its rate of dissipation, ε, are defined as follow:
For turbulent kinetic energy k,

To obtain the equation for turbulent kinetic energy k, complicated algebra and rearrangements are made to the time-averaged continuity equation and the time-averaged Navier-Stokes equations for momentum.

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij}E_{ij} - \rho\epsilon$$

For dissipation ϵ

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_i}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}2\mu_t E_{ij}E_{ij} - C_{2\epsilon}\rho\frac{\epsilon^2}{k}$$

In this Rate of change of k or ϵ + Transport of k or ϵ by convection = Transport of k or ϵ by diffusion + Rate of production of k or ϵ Rate of destruction of k or ϵ.

D. Boundary Conditions

The boundary conditions used in this study is of constant temperature wall conditions. The tube is continuously heated or is connected to a high heat source having constant temperature throughout the simulation. The temperature of the wall is maintained constant at 450 K. the fluid flow from inlet of the pipe with velocity 0.1, 0.2, 0.5, 1, 2 and 3 m/s velocity. The flow conditions are assumed to be as turbulent conditions and k-epsilon model is used for simulation of the tube.
The nanofluid having alumina as nanoparticle is used in this study. The nanoparticle is of diameter 20,mm and the concentration of alumina in water is 2%.

Table 1 Thermo-Physical Properties of Al_2O_3-Water Nanofluids

	Al_2O_3	Water	Nanofluid
Density(Kg/m^3)	3970	998.2	1057.636
Thermal conductivity(W/mK)	35	0.6	0.66348
Specific heat(J/KgK)	880	4182	3934.11
Viscosity(Ns/m^2)		0.001003	0.001055

E. Meshing

The partial differential equations that govern fluid flow and heat transfer are not usually amenable to analytical solutions, except for very simple cases. Therefore, in order to analyze fluid flows, flow domains are split into smaller subdomains (made up of geometric primitives like hexahedra and tetrahedra in 3D and quadrilaterals and triangles in 2D). The governing equations are then discretized and solved inside each of these subdomains. The simple tube consists of 7638 elements and 9180 nodes while the circular wavy tube with grooves inside contains 40448 nodes and 33443 elements.

IV. RESULTS AND DISCUSSIONS

A. Effects of Wavy Surface and Grooves in Tube

It is observed that tube fitted with the wavy surface wall give higher heat exchange rate than the plain tube. Because of wavy surface tube there happens better mixing of fluid wall and core region and causes the reverse flow and pressure gradient in radial direction. The boundary layer along the tube wall would be redeveloped along the wavy wall bringing about more heat transfer through the liquid.

B. Effect of Al_2O_3 Nanofluid

The nanofluid used in thesis is Al_2O_3 nanoparticles in water. The effect of nanofluid used in the tube results in increase in thermal conductivity of fluid. This causes fluid to transfer heat more efficiently with the walls. When nanofluid is added to the base fluid the viscosity and density of fluid also increases resulting in more frictional losses thus causes high pressure drop means extra pump work. But due to greater increase of heat transfer due to nanofluid is a better option to increase the heat transfer rate.

In this work, a numerical investigation using single phase models was performed on both pure base water and Al_2O_3/water nanofluid flowing inside a simple circular tube. The aim of the study is to inspect the effect of circular wavy surfaced tube on heat transfer and other thermo physical properties. In The present project work the computational fluid dynamics simulations is carried out on different Reynolds number on a simple pipe and then tube having circular wavy surface having grooves inside in order to investigate the heat transfer capability in both the pipes. In this paper for simulation of nanofluid the single phase model is used to simulate the nanofluid. The results shows that the average nusselt number increases with the adjustment of Reynolds number. The nanofluid has a higher thermal conductivity, which leads to the improvement of heat transfer rates. The different values at different Reynolds number have been calculated by ANSYS software. The values are validated using Dittus Boelter and were found to be in good agreement. The values are used to draw graphs to visualise the effect of different thermal physical with Reynolds number to see the effect of different tube designs.

The figure 3 represents the value of pressure drop in the fluid flow with respect to the Reynolds number. The values are predicted by the ANSYS software for 6 reynolds number values. Then graph is plotted for different configurations of the tube studied.the pressure values are to be taken in pascals(Pa). Figure 4 represnts the outlet temperature of the fluid at tube outlet. The values are predicted by the ANSYS software and are summed up. Then they are used to plot the graph which clearly shows the comparisons between different configurations of the tube studied. The temperature values are taken in Kelvin (K).

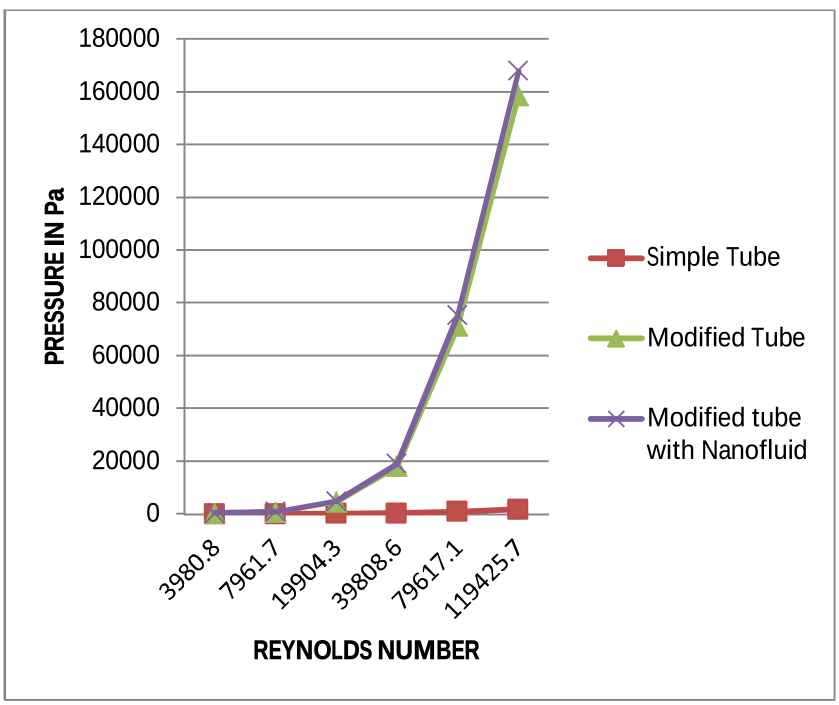

Fig. 3 The graph of pressure drop with respect to Reynolds number

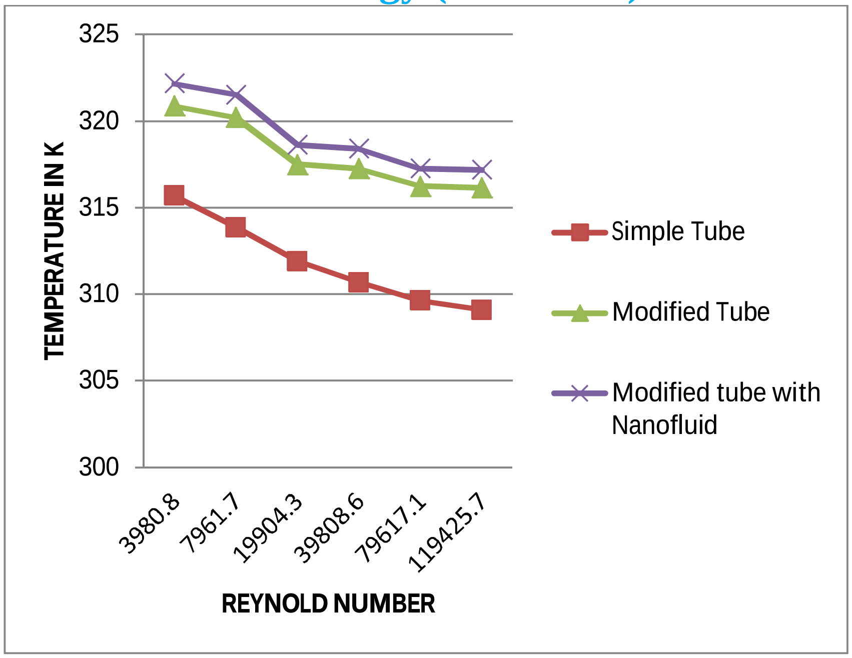

Fig. 4 The graph of outlet temperature with respect to the Reynolds number is

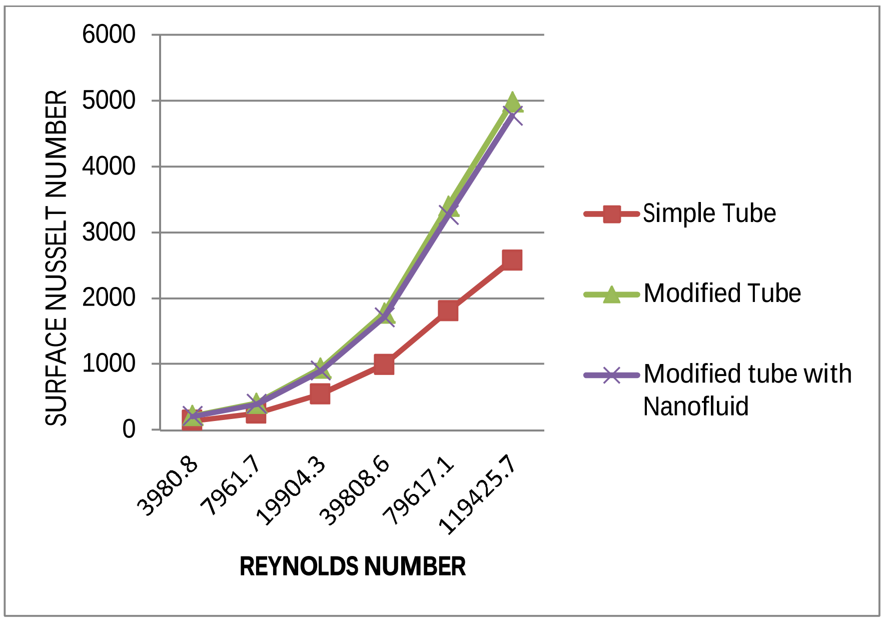

Fig. 5 The graph of nusselt number with respect to the Reynolds number is

Figure 5 represents the graph surface nusselt number values with the Reynolds number. The Nusselt number (Nu) is the ratio of convective to conductive heat transfer across (normal to) within fluid the boundary. The values are predicted at 6 different value of Reynolds number in turbulent flow. the nusselt number is very important criteria for heat transfer. The greater the nusselt number the greater will be heat transfer. The graph is plotted for 3 tube configurations. Modified tube signifies the tube with circular wavy surface and grooved surface inside. The figure 6 represents the graph of skin friction factor with respect to the Reynolds n umber. Skin friction is a dimensionless drag coefficient expressing the proportionality between the frictional force per unit areaand the square of speed. The more will be the friction coefficient the more will be the friction losses. The skin friction factor generally decreases as the velocity of flow increases. The value of skin friction factor have been calculated by the ANSYS software and then a graph is plotted. The graph gives clear visualisation of the difference between tube designs.

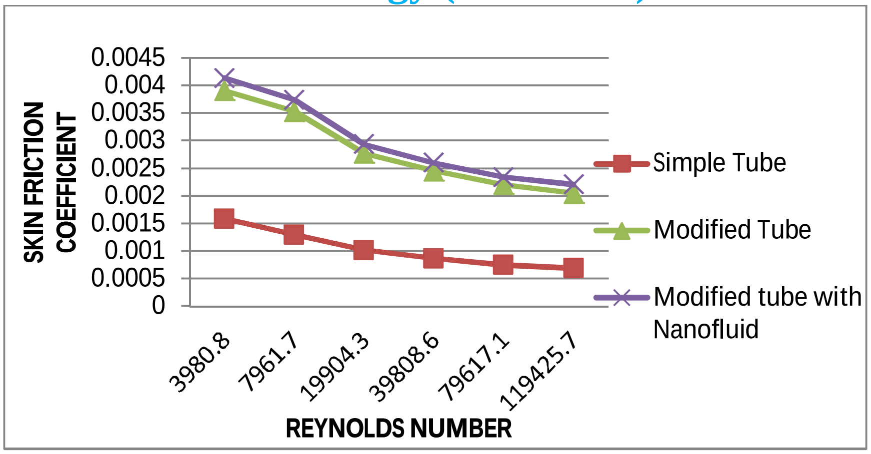

Fig. 6 The graph of skin friction coefficient with respect to the reynolds number

V. CONCLUSION

In this study, the heat transfer coefficient in the developed region of tube flow containing Al_2O_3 water nanofluid during the constant boundary wall temperature is simulated using CFD. With regards to the computational simulation in the present study the following conclusions can be drawn

A. The graph of pressure drop versus mass flow rate predicts that the pressure drop is low at low Reynolds number and increases with the increase of Reynolds number. Further due to introduction of circular wavy surface the pressure drop increases by huge amount (45 to 91 times). This is due to the increases mixing and irregular flow of fluids flowing in the tube.

B. The addition of alumina nanofluid changes the properties of water. The thermal conducitivity of water increases with addition of water. Moreover the viscosity and density of water changes with addition of nanofluid.

C. The nusselt number increases by 55% to 93% for Reynolds number 3980 to 119425. The graph of nusselt number also indicates that the nusselt number increases with the Reynolds number.

D. The outlet temperature increase of the circular wavy surface with grooves inside tube increases by 32.92% to 77.36% for Reynolds number 3980 to 119425. Further with addition of nanoparticle in the water the outlet temperature increases by 41% to 88.72%.

E. The pump work required to flow the fluid in the tube depends on the pressure drop in the tube. Now due to circular wavy surface with grooves inside the ptressure drop increases by a huge amount. With the addition of nanofluid, the viscosity and density of water changes which causes more drop of pressure.

F. The other parameters such as total surface heat flux, total surface heat transfer also increases which clearly indicates the increase in the heat transfer.

VI. ACKNOWLEDGEMENT

I would like to express my sincere regards, appreciation and thanks to my ME Thesis Supervisor, *Dr. Sushant Samir*, Associate Professor, Mechanical Engineering Department, PEC University of Technology, Chandigarh for both constant guide and giving me an chance to perform my dissertation into a complete form. He always provided me the generous guidance and constant encouragement when any difficulties arise by giving valuable time, advice and cooperation. It has been a great pleasure and honor to work with him. I am also thankful to my teachers and other staff members of department, who has been very helpful during my course work. I am also thankful to my family and fellow students of master of engineering, for their wholehearted support, encouragement and cooperation, which helped me, lot during my thesis work to overcome uncertainties and difficulties.

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