International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 12 (2015) pp. 32627-32635

http://www.ripublication.com

Determination of Dual Phase Forced Convective Heat Transfer of Nano Fluids by Means of CFD

Appadurai. M, Baburaj Prasath.A, Chithambara Thanu.M[1], Richard.S[1]

Assistant Professor, Department of Mechanical Engineering,
Dr. Sivanthi Aditanar College of Engineering, Tuticorin, Tamil Nadu, India
appadurai86@gmail.com, ubak007@gmail.com, mcthanu@ymail.com,
iamrichi@yahoo.com

Abstract

Increasing demands for heat removal need the development of more effective thermal management technologies. In applications employing convective heat transfer, one direction of innovation is miniaturization, which affords increased rates of heat transfer.The heat transfer of nano fluids in a double pipe heat exchanger is calculated numerically using a Computational Fluid Dynamics (CFD) approach. Heat transfer performance of an internal fin in a circular tube has been experimentally examined. Wall temperature, bulk fluid temperature, and pressure drop along the axis of the finned tube were measured for different Reynolds number ranging from $2.0x10^4$ to $5.0x10^4$. The present study indicates an increase of the thermal performances of nano fluids compared to water. The nano fluid is composed of aluminium oxide (Al2O3) particles dispersed in water for various concentrations ranging (1, 3 and 5%).

Keywords- Nano fluid, Nusselt Number, Reynolds Number, Heat Transfer, Heat transfer Enhancement, Forced Convection, Finned Tube, Double Pipe Heat Exchanger, Pressure Drop, CFD.

I. INTRODUCTION

Heat exchanger is a device used to transform heat from one source to another source at different temperatures. These are widely used in chemical plants, petroleum refineries, natural gas processing, refrigeration, petro-chemical plants, air conditioning, space heating and power plants. One of the most commonly used heat exchanger is car radiator, in which heat is transferred from water to air [1]. Based on type of contact heat, exchangers are mainly classified as

1. Direct contact type
2. Indirect contact type

Convective heat transfer is very important for many industrial heating or cooling equipments. The heat convection can passively be enhanced by changing flow geometry, boundary conditions or by enhancing fluid thermo physical properties. An innovative way of improving the thermal conductivities of fluids is to suspend small solid particles in the fluid. Maxwell [1] showed the possibility of increasing thermal conductivity of a mixture by more volume fraction of solid particles. These fluids containing colloidal suspended nano particles have been called nano fluids. Several investigations revealed that nano fluid heat transfer coefficient could be increased by more than 20% also in the case of very low nano particles concentrations [2], [3].Akbarnia and Behzadmehr [4] reported a Computational Fluid Dynamics (CFD) model based on single phase model for investigation of laminar convection of water/Al2O3 nano fluid in a horizontal curved tube. In their study, effects of buoyancy force, centrifugal force and nano particle concentration have been discussed. Zeinali [5] proposed a dispersion model to account for the presence of nano particles in nano fluid. They showed that the dispersion and random movement of nano particles inside the fluid change the structure of flow field and led to heat transfer enhancement. In this work we have numerically studied the heat performance of water-based nano fluids, Al2O3 with 10 nm particle-sizes, in a double pipe heat exchanger.

II.MATHEMATICAL MODEL

The CFD approach uses a numerical technique for solving the governing equations for a given flow geometry and boundary conditions. The use of CFD reduces the number of necessary experiments and gives results, which would hardly be accessible by measurements. The detailed flow field for the dual-phase flow in a circular tube with constant wall temperature can be determined by solving the volume-averaged fluid equations, as follows:

Continuity Equation.

$$\nabla(\rho V) = 0.$$

Momentum Equation.

$$\nabla(\rho VV) = \nabla P + \nabla(\tau - \tau t)$$

Energy Equation.

$$\nabla(\rho V C_p T) = \nabla(k \nabla T - C_p \rho \overline{\overline{v t}}).$$

In order to solve above-mentioned equations, the thermo-physical parameters of nano fluids such as: density, viscosity, heat capacity, and thermal conductivity, must be evaluated. These parameters are defined as follows:

A. DENSITY AND HEAT CAPACITY.

The relations determined by Pak and Cho[6]have the form

$$\rho_n = (1 - \varphi_v)\,\rho_0 + \varphi_v\,\rho_m,$$

$$C_n = (1 - \varphi_v)\,C_0 + \varphi_v\,C_m.$$

B. THERMAL CONDUCTIVITY.

The effective thermal conductivity of a mixture can be calculated using the relation of Mohorianu and Agop [7]

$$\frac{k_{nf}}{k_f} = 1 + 0.043\,\frac{k_p \varepsilon_1}{k_f (1 - \varepsilon_1)}$$

where we consider that $r_f / r_p = 0.043$ and $k_{eff} = k_{nf}$.

C. VISCOSITY.

The viscosity of the nanofluid can be estimated with the existing relations for the two phase mixture.Drew and Passman introduced Einstein’s formula for evaluating the effective viscosity.

$$\mu_n = \mu_0 (1 - 2.5\varphi_v).$$

Fluid is containing a dilute suspension of small rigid spherical particles. This formula is restricted for low volumetric concentration of particle, under 0.05%.

Brinkman proposed to extend Einstein’s formula by

$$\mu_n = \mu_0 (1 - \varphi_v)^{2.5}.$$

Other relations of effective viscosity of two phase mixture exist in the literature. Each relation has its own limitation and application. Some complex reaction has been observed by NguyenComTang [8]. Unfortunately results reveal that Brinkman’s formula underestimates the few experimental data present in literature. Finally we choose the polynomial approximation based on experimental data [8], for water – γ_{Al2O3} nanofluid.

$$\mu_n = \mu_0 (306\varphi_v^2 - 0.19\varphi_v + 1)\mu_0$$

These equations were used to perform the calculation of temperature distribution and transmission fields in the geometry studied.

D. BOUNDARY CONDTIONS.

By inner tube will circulate a nano fluid as primary agent, and by the outer tube will circulate pure water as secondary agent. The nano fluid used is composed of aluminium oxide Al_2O_3 particles dispersed in pure water in different concentrations (1%, 3% and 5%).The continuity, momentum and energy equations are non-linear partial differential equations, subjected to the following boundary conditions: at the tubes inlet, "velocity inlet" boundary condition was used. The magnitude of the inlet velocity varies for the inner tube between 0.12 m/s and 0.64 m/s, remaining constant at the value of 0.21 m/s for the outer tube. Temperatures used are 400k for the primary agent and for the secondary agent is 300k. Heat loss to the outside was considered null, imposing the heat flux to be null at the outer wall of heat exchanger. The interior wall temperature is considered equal to the average temperature value of interior fluid. Using this values for velocity, the flow is turbulent and we choose a corresponding model (k – ε) for solve the equations.

III. GOMETRY MODEL

This model is developed according to TEMA design is created using ANSYS WORKBENCH software as shown in fig.1 as per the design and geometry parameters.

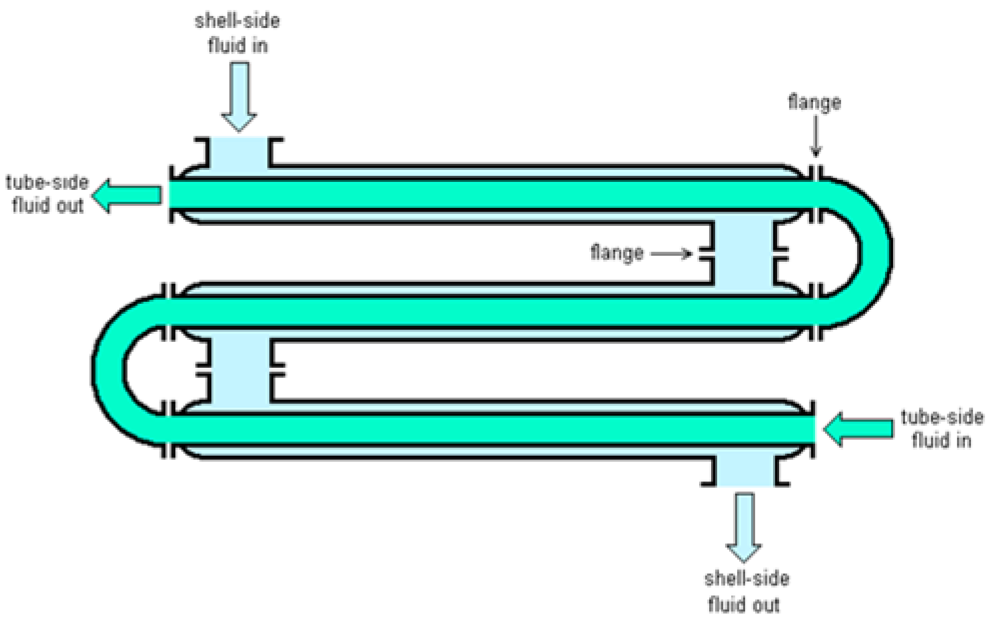


Fig.1 Front view of double pipe heat exchanger.

A. MESH GENERATION

The 3-D geometry is imported to workbench CFD for meshing in order to capture the both velocity and thermal boundary layers. The entire model is meshed using tetrahedral mesh which involves less computational and accurate work. The entire design is divided into two domains, namely solid domain and fluid domain. Fluid domain involves water and gas which is used as working fluids for this study. After defining all the elements, the mesh is generated using the scale factor as 4 and maximum element size is 1as shown Figure-3. Once the mesh is obtained for required quality and free of errors it is found to have minimum, then the mesh is exported to FLUENT for simulation.

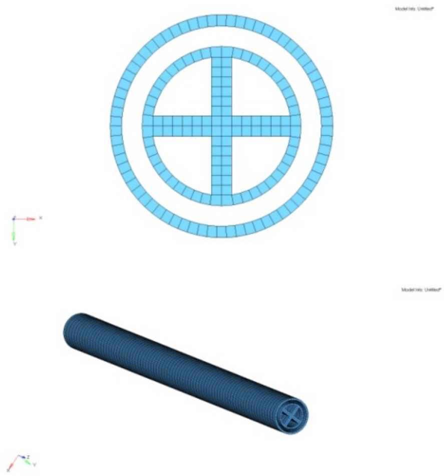


Fig.3 3D view of double pipe heat exchanger with tetrahedral mesh

B.GOVERNING EQUATIONS.

According to the conditions of the problem, the flow through of double pipe heat exchanger is simulated by selecting the suitable governing equations as shown below. Turbulence is taken care by shear stress transportation (SST).

$$\textit{Conservation of mass: } \nabla(\rho\vec{V}) = 0$$

$$\textit{x-momentum: } \nabla(\rho u\vec{V}) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}$$

$$\textit{y-momentum: } \nabla(\rho u\vec{V}) = -\frac{\partial p}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + \rho g$$

$$\textit{z-momentum: } \nabla(\rho u\vec{V}) = -\frac{\partial p}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z}$$

$$\textit{Energy: } \nabla(\rho e\vec{V}) = -p\nabla\vec{V} + \nabla(k\nabla T) + q + \phi$$

C. SIMULATION.

CFD Simulation is carried out mainly in the following three steps

1. Pre-processing,
2. Solving,
3. Post-processing.

In pre-processing, the various solid and fluid domains are defined. The flow is turbulent in this problem. Hence shear stress transportation (SST) k-w model is chosen. The boundary conditions of the problem are

i. The working fluids of the tube side and shell side are nano fluid and water.
ii. The temperature of water is set to 300 K
iii. The temperature of nano fluid inlet is set to 400 K
iv. All wall surfaces are set to be no slip condition.
v. The outlet of cold water is assigned to be pressure outlet
vi. The boundary condition of cell surface is assigned with zero heat flux.
vii. Inlet velocity of water is set to be 0.12 m/s
viii. Inlet velocity of hot nano fluid is set to be 0.64 m/s

III. RESULTS AND DISCUSSION

For mixing between the base fluid and the three types of nano fluids were performed numerical simulations to determine correlations between flows regime, characterized by Reynolds number, and convective coefficient values. The convective coefficient value, α, is calculated using Nusselt number for nano fluids, relation established following experimental determinations by X u a n and L i [9].

$$Nu_{nf} = 0.0023\, Re_{nf}^{0.8}\, Pr_{nf}^{.0.4}$$

The Reynolds number is defined by

$$Re_{nf} = {}^{u\,m\,D}_{\nu}/nf$$

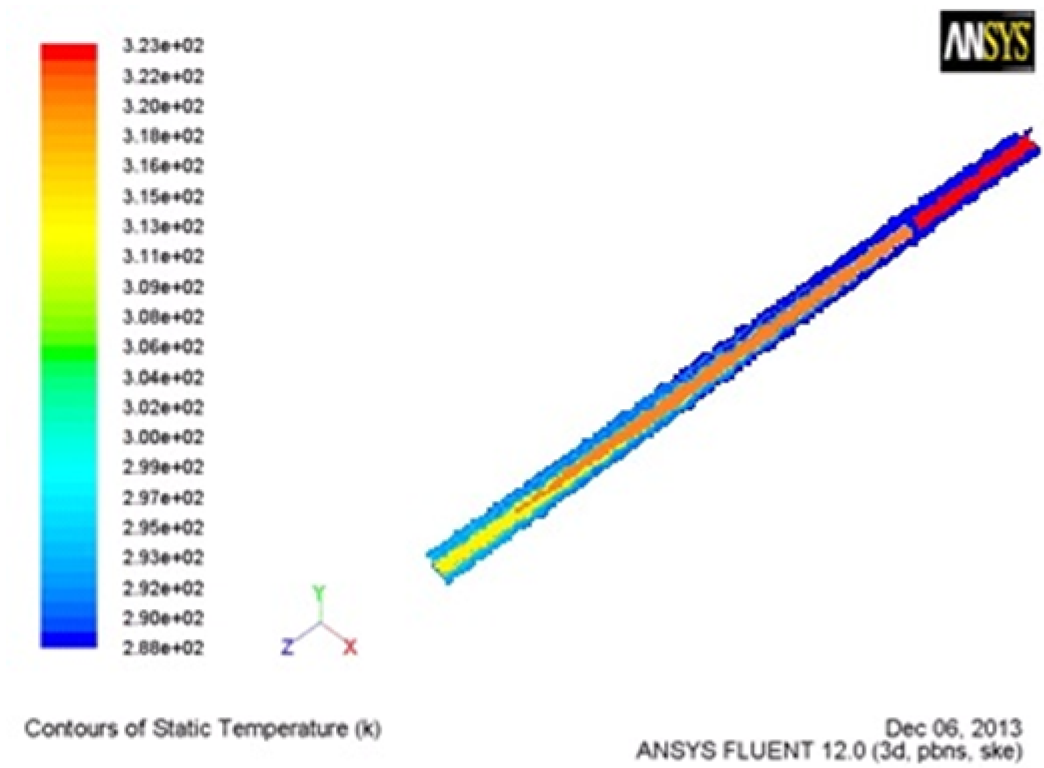
Prandtl number is

$$Pr_{nf} = {}^{vnf}/{}^{\alpha}nf$$

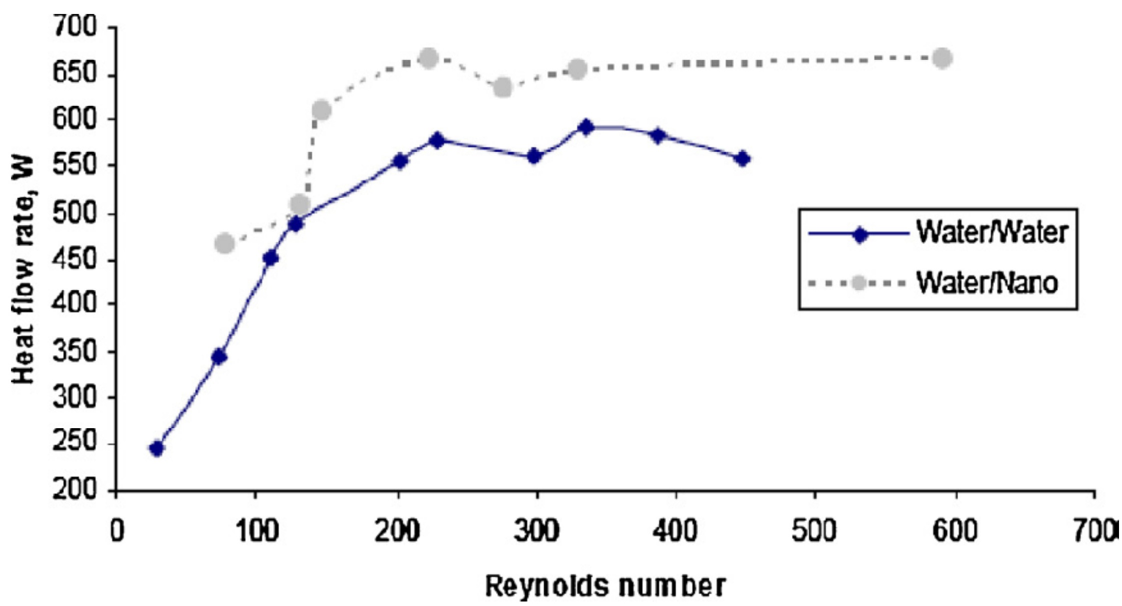
And consequently

$$\alpha = Nu^{\lambda d/nf}$$

The temperature and velocity profiles can be viewed post processing. In Fig. 2 is illustrated one example of the temperature profile visualization in a case study, depending on the boundary conditions imposed.



The analysis of the variation of convective heat transfer coefficient in comparison with flow region, temperature and nano fluids Concentrations.



We can notice a significant increase of convective heat transfer with heat flow rate coefficient of nano fluid at the concentration of 5% compared with water at 300°C.

IV. CONCLUSION

The obtained results clearly show that the addition of particles in a base fluid produces a great increase in the heat transfer. Intensification of heat transfer increases proportionally with increasing of volume concentration of these nano particles.

In the present model, the values of convective heat transfer coefficient and Nusselt number depend of flow regime and temperature values. When temperature is higher, the values of this coefficient increase.

V. NOMENCLATURE

C – Heat capacity, [J/kg.K];
u – Velocity, [m/s];
α – convective coefficient, [W/m2.K];
ρ – Density, [kg/m3];
φv – volumetric concentration, [%];
μ – Dynamic viscosity, [kg/ms];
ν – Kinematic viscosity, [m2/s];
D – Diameter, [m];
k – Thermal conductivity, [W/m.K];
Nu – Nusselt number;
Pe – Pectelt number;
Pr – Prandtl number;
Re – Reynolds number index;
m – Medium;
nf – nano fluids;
0 – base fluid.

REFERENCES

[1] Maxwell J.C., A Treatise on Electricity and Magnetism. Oxford Univ. Press, Cambridge, 1881.

[2] Li Q., Xuan Y., Heat Transfer Enhancement of Nanofluids, Internat. J. of Heat a. Fluid Flow,**21,** 58-64 (2000).

[3] Kang H.U., Kim S.H., Oh J.M., Estimation of Thermal Conductivity of Nanofluid Using Experimental Effective Particle Volume. Exp. Heat Transfer, **19,** 181-191 (2006).

[4] Akbarnia A., Behzadmehr A., Numerical Study of Laminar Mixed Convection of a Nanofluid in Horizontal Curved Tube. Appl. Thermal Sci., **27,** 1327-1337 (2007).

[5] Zeinali Heris S., Etemad S.Gh., Nasr Esfahany M., Experimental Investigation of Oxide Nanofluid Laminar Flow Convective Heat Transfer, in Circular Tube, Internat. Commun. in Heat a. Mass Transfer, **33,** 529-533 (2006).

[6] Pak B.C., Cho Y.I., Hydrodynamic and Heat Transfer Study of Dispersed Fluids with Submicron Metallic Oxide Particles. Exp. Heat Transfer, **11**, 2, 151-170 (1998).

[7] Mohorianu S.H, Agop M., A Theoretical Approach of the Heat Transfer in Nanofluids. JOAM, **8**, 5, 1741-1743 (2006).

[8] Nguyen Com Tang, Roy G., Lajoie P.R., Refroidissement des microprocesseurs à haute performance en utilisant des nanofluides. Congrès Français de Thermique, SFT 2005, Reims, 30 mai-2 juin 2005.

[9] Yimin Xuan, Qiang Li, Heat Transfer Enhancement of Nanofluids. Heat and Fluid Flow, **1**, 5, 58-64 (2000).