

# Numerical investigation of forced convection of nano fluid flow in horizontal U-longitudinal finned tube heat exchanger

S M Qasim<sup>1</sup>, A F A Sahar<sup>1</sup> and A A Firas<sup>2</sup>

<sup>1</sup>Al-Mustansirya University College of Engineering, Baghdad, Iraq

<sup>2</sup>Ministry of Oil Gas Filling Company Wassit, Iraq

E-mail: qasim602006@yahoo.com

**Abstract.** A numerical study has been carried out to investigate the heat transfer by laminar forced convection of nanofluid taking Titania (TiO<sub>2</sub>) and Alumina (Al<sub>2</sub>O<sub>3</sub>) as nanoparticles and the water as based fluid in a three dimensional plain and U-longitudinal finned tube heat exchanger. A Solid WORKS PREMIUM 2012 is used to draw the geometries of plain tube heat exchanger or U-longitudinal copper finned tube heat exchanger. Four U-longitudinal copper fins have 100 cm long, 3.8cm height and 1mm thickness are attached to a straight copper tube of 100 cm length, 2.2 cm inner diameter and 2.39 cm outer diameter. The governing equations which used as continuity, momentum and energy equations under assumptions are utilized to predict the flow field, temperature distribution, and heat transfer of the heat exchanger. The finite volume approach is used to obtain all the computational results using commercial ANSYS Fluent copy package 14.0 with assist of solid works and Gambit software program. The effect of various parameters on the performance of heat exchanger are investigated numerically such as Reynolds' number (ranging from 270 to 1900), volume consternation of nanoparticles (0.2%, 0.4%, 0.6%, 0.8%), type of nanoparticles, and mass flow rate of nanofluid in the hot region of heat exchanger. For 0.8% consternation of nanoparticles, heat transfer has significant enhancement in both nanofluids. It can be found about 7.3 % for TiO<sub>2</sub> and about 7.5 % for Al<sub>2</sub>O<sub>3</sub> compared with the water only as a working fluid.

## 1. Introduction

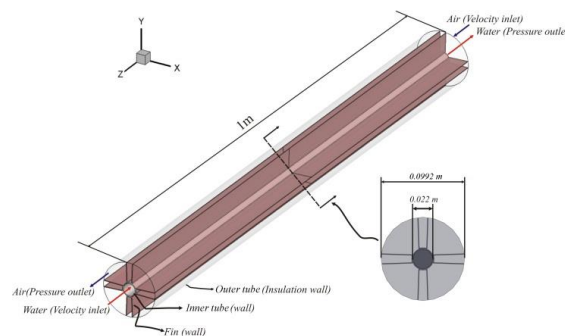
The study of improved heat transfer performance is referred to as heat transfer enhancement, augmentation, or intensification. In general, this means an increase in heat transfer coefficient [1]. Taborek [2] updated sketchy methods for double pipe heat exchangers especially for longitudinal finned tubes. Calculation methods are presented for plain double pipe units, as well as finned tube units. Equations for the mean temperature difference for units with flow in series-parallel are also given. Mir et al. [3] carried out numerical simulation of studying laminar, forced convection heat transfer in the finned annulus for the case of fully developed incompressible flow. The simulation was corresponding to thermal boundary condition of uniform heat input per unit axial length with peripherally uniform temperature at any cross section. The results showed a good comparison with the literature results. Strand berg and Debendra [4] compared the performance of hydraulic finned-tube heating units utilizing nanofluids with the performance of conventional heat transfer fluid of 60% ethylene glycol and 40% water by using mathematical model. Al<sub>2</sub>O<sub>3</sub> and CuO nanoparticles dispersing in 60% EG solution were used. Finned-tube heating performance was enhanced by employing nanofluids. The increase of (11.6%) in finned tube heating output was predicted with 4% of Al<sub>2</sub>O<sub>3</sub> and 60% EG. Furthermore, the increase of (8.7%) was predicted with 4% CuO and 60% EG



comparing of basefluid. Syed et al. [5] performed numerical simulation of finned annulus in the steady and laminar convection in the thermal entry region, fully developed flow at uniform heat flux. Finite difference based marching procedure was used to compute the numerical solution of the energy equation. The numerical results showed the Nusselt's number has complex depending on the geometric variables like ratio of radii, fin height, and number of fins. The validation of the simulation was performed by comparison with open literature. Present work concerns of studying the performance of U-longitudinal finned tube heat exchanger and comparing it with smooth tube. Then, its performance with nanofluids. This is done after adding nanoparticles to basefluid. The effect of this new technology on estimated reduction in surface area of fins will be examined. Numerical simulation by ANSYS FLUENT 14 package is used to simulate the system and then using laminar flow with and without nanofluids.

## 2. Mathematical modelling and numerical simulation

Numerical simulation performs analysis of a system involving fluid flow, heat transfer and associated phenomena based on various disciplines of science. These are includes mathematics, computer engineering and physics to provide meaningful modeling of fluid flow. ANSYS FLUENT 14 package has been conducted for performing numerical simulation across the heat exchanger using three-dimensional model. The solution of conservation continuity, momentum and energy equations is used to analyze the flow field inside the heat exchanger. A comparison of heat transfer for smooth, finned tube with or without nanofluids is carried out. A SOLID WORK PREMIUM 2012 is used to draw the geometries of this work which consist smooth tube heat exchanger and U-longitudinal finned tube heat exchanger with inlet and outlet portions. The outside flow is confined by insulating tube having inlet and outlet portions as shown in figure1. Computational domains in the present study are displayed as inlets and outlets of both hot side (water or nanofluids) in the inner tube, and air side in the annuli. Fins are built on the outside surface of the inner tube and the flow on both sides is counter flow.



**Figure 1.** U-longitudinal finned tube heat exchanger.

The assumptions used for water, nanofluid and air during the present study are steady state, Newtonian fluid, incompressible, three dimensional, laminar flow in the inner side (water or nanofluid) and turbulent flow in the annuli side (air). Both fluids are forced convection heat transfer. Buoyancy effect is assumed to be negligible. Radiation heat transfer is not considered. The governing equations for continuity, momentum, and energy of laminar flow in an inner tube are [6]:

Continuity Equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (1)$$

Momentum Equations

$$\rho \left( u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = - \frac{dP}{dx} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) \quad (2)$$

$$\rho \left( u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) = - \frac{dP}{dy} + \mu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) \quad (3)$$

$$\rho \left( u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) = - \frac{dP}{dz} + \mu \left( \frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) \quad (4)$$

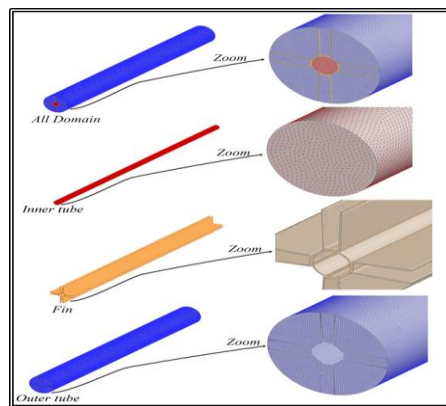
Energy Equation

$$\rho C_p \left( u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} \right) = k \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \quad (4)$$

where, (u, v, w) = velocity component, T = temperature, k = thermal conductivity, Cp = specific heat,  $\mu$  = dynamic viscosity, and  $\rho$  = density.

### 3. Mesh generation

Unstructured mesh is used in the present study to discretize the computational domain into a finite number of control volumes by using the finite-volume scheme. The model was meshed by GAMBIT software [7]. The refinement and generation of mesh system are very crucial to predict the heat transfer in sophisticated geometries. In this study triangular element type is employed for surface mesh and tetrahedron element type is used for three dimensional geometry. This is because it has priority in the sophisticated geometries. Figure 2 shows the mesh of present model. To estimate the performance of the present heat exchanger, some introductory requirements of the physical model are defined adequately as Reynolds number in the inlet was specified for inner and annuli sides during this study. On the other hand the temperature inlet of the inner tube is 60 °C while in annuli is 20°C and specifications of nanofluid particles as in table 1



**Figure 2.** Mesh of present model.

**Table 1.** Specifications of nanoparticles [9].

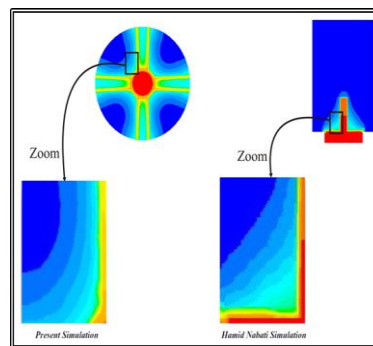
Type	D [nm]	$\rho$ [ $\frac{\text{kg}}{\text{m}^3}$ ]	$k$ [ $\frac{\text{W}}{\text{m} \cdot ^\circ\text{C}}$ ]	$C_p$ [ $\frac{\text{J}}{\text{kg} \cdot ^\circ\text{C}}$ ]
TiO <sub>2</sub>	10-25	4230	8.9	686.2
Al <sub>2</sub> O <sub>3</sub>	< 80	3970	40	765

The outlet domain is specified as pressure outlet for both sides. No slip boundary condition is specified in the wall of the inner tube. These conditions are used to bound fluid and solid region. It is worth mentioning that convenient numerical control and modeling techniques are very important to step up convergence and stability during the calculation. By adopting control-volume technique, FLUENT shifts the governing equations to algebraic equations that can be solved numerically. The

control volume technique involves of integrating the governing equations inside each control volume, yielding discrete equations [8]. Simplifying of geometry which is avoided during this study to get the best degree of accuracy which may be influenced by reducing the resolution as long as the computer ability is capable to achieve the simulation accurately. For this study, an average of 11 million cells is used and it is the maximum number of iterations performed to get the solver terminates. 4000 iterations are needed in this study.

#### 4. Model validation

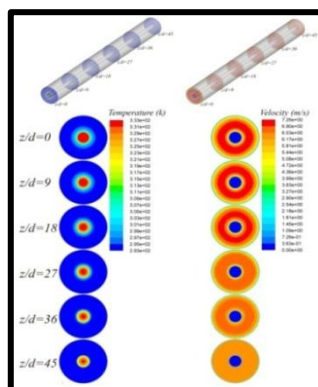
In order to validate present numerical simulation, a comparison has been carried out with previous numerical results achieved by Hamid Nabati [10]. He had performed a numerical study for predicting the heat transfer in heat exchanger with pin fins by ANSYS FLUENT. Figure 3 shows the temperature contour for both simulations. Good agreement between the present results and reference results [10] which indicates acceptable validation of present simulation.



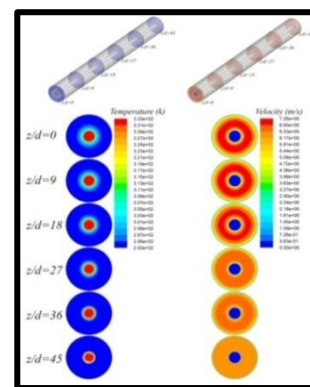
**Figure 3.** Validation of numerical simulation.

#### 5. Results and discussions

Figures 4 and 5 show both temperature and velocity contours of smooth tube heat exchanger at various water Reynold's numbers and different axial distances.



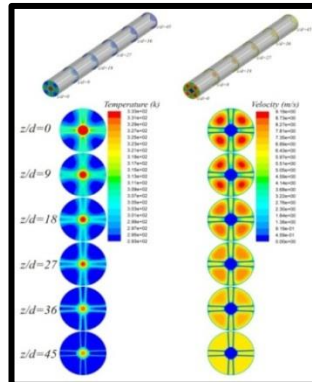
**Figure 4.** Temperature and velocity contours at  $Re_h=590$ ,  $\dot{m}_c=0.05\text{kg/sec}$  for smooth tube.



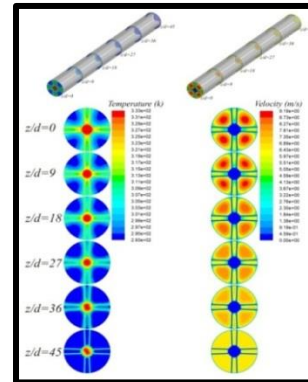
**Figure 5.** Temperature and velocity contours at  $Re_h=1900$ ,  $\dot{m}_c=0.05\text{ kg/sec}$  for smooth tube.

It can be noted that the maximum air and water temperatures appears at  $Z/d = 0$  while the minimum temperatures appears at  $Z/d = 45$ . It can be seen also when observing  $Z/d = 18$ , that changing water Reynold's number will not have a significant effect on air side. It seems that the air in annuli has the main reason for this behavior. This is because air thermal conductivity is small velocity contours in these figures show that air inlet velocity distribution at  $Z/d = 45$  are uniform. It will also tend to decrease inside heat exchanger near the walls of inner and outer tubes as shown at  $Z/d$  from 36 to 0.

Figures 6 and 7 reveal the temperature and velocity contours of U-longitudinal finned tube heat exchanger for water Reynold's numbers and air mass flow rates at various axial distances ratio.



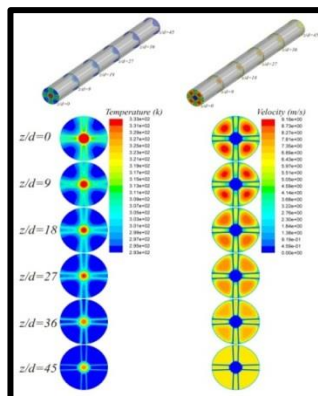
**Figure 6.** Temperature and velocity contours at  $Re_h=590$ ,  $\dot{m}_c = 0.05$  kg/sec for finned tube.



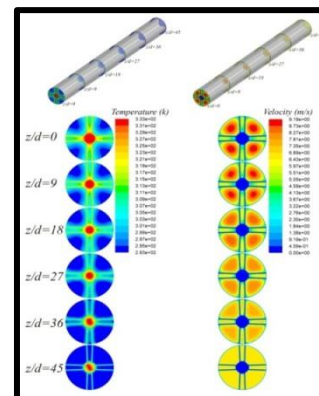
**Figure 7.** Temperature and velocity contours at  $Re_h=1900$ ,  $\dot{m}_c = 0.05$  kg/sec for finned tube.

Results showed a significant heat transfer augmentation in heat exchanger at  $Z/d$  from 0 to 45 for air and water sides. The effect of adopting fins on heat transfer enhancement is apparent in both sides. Heat transfer enhancement behavior at  $Z/d = 27$  and  $\dot{m}_c = 0.05$  kg/sec is clear when increasing water Reynolds's number. Velocity contours in these figures reveal that air velocity is uniform at  $Z/d = 45$ . However, it increases at the center between every two pairs of fins and U channels at  $Z/d$  from 36 to 0.

The effect of wall on decreasing the velocity in air and water sides is apparent in these figures. Also from these figures it can be seen that the distance between the two fins U is important because it clearly give an indication that the velocity between them has been changed and that would effect on the heat transfer in this region. Figures 8 and 9 represent the temperature and velocity contours of U-longitudinal finned tube heat exchanger with nanofluids.



**Figure 8.** Temperature and velocity contours at  $Re_h=590$ ,  $\dot{m}_c = 0.05$  kg/sec for finned tube with alumina-nanofluid.

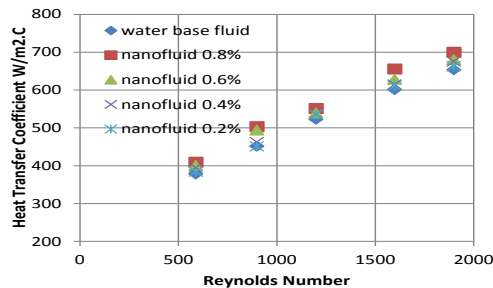


**Figure 9.** Temperature and velocity contours at  $Re_h=1900$ ,  $\dot{m}_c = 0.05$  kg/sec for finned tube with titania-nanofluid.

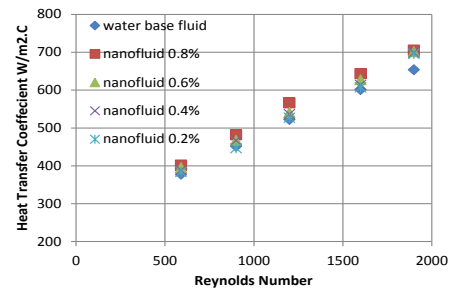
It can be noted that the heat transfer enhancement in air side appears clearly at  $Z/d$  from 0 to 18. But with regards to water side at  $Z/d$  from 27 to 45. Thermo physical properties of nanofluid have the main reason of this enhancement. This augmentation in heat transfer behavior can be increased by the increase in thermal conductivity of basefluid. From figures it can be seen that for  $Al_2O_3$  nanofluid there is an enhancement but not clearly with respect of  $TiO_2$  but compared with water it can be seen significant enhancement.



Figures 10 and 11 show the variation between Reynolds number and heat transfer coefficient for both of nanofluids ( $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$ ). One of the important advantages of a numerical study is to obtain local heat transfer coefficient values at any point in the test. This observation can lead to improve heat exchanger performance. It can be seen that for  $\text{Al}_2\text{O}_3$  the increasing in heat transfer about 7.5% and for  $\text{TiO}_2$  about 7.3% compared with the water only as a working fluid.



**Figure 10.** Shows the variation of Reynolds number with heat transfer coefficient for different  $\text{TiO}_2$  volume concentration in basefluid.



**Figure 11.** Shows the variation of Reynolds number with heat transfer coefficient for different  $\text{Al}_2\text{O}_3$  volume concentration in basefluid.

## 6. Conclusions

Results of numerical simulation showed that adding fins would enhance heat dissipation through heat exchanger. It is noted that heat transfer behavior increases within present model as air mass flow rates and water Reynold's numbers increases. Heat transfer enhancement by adding nanoparticles to basefluid has been found during numerical simulation. Numerical simulation by FLUENT package is successful for predicting both heat transfer and fluid flow in the present heat exchanger. It has been found that enhancement in heat transfer is about 7.5% for  $\text{Al}_2\text{O}_3$  and for  $\text{TiO}_2$  about 7.3% compared with the water only as a working fluid.

## References

- [1] Bergles A E 1999 *The Imperative to Enhance Heat Transfer* (Department of Mech. Eng., Aeronautical Engineering and Mechanics Rensselaer Polytechnic Institute) pp 13–29
- [2] Taborek J 1997 Double-Pipe and Multitube Heat Exchangers with Plain and Longitudinal Finned Tubes *Heat Transfer Eng.* **18** (2) pp 34–45
- [3] Mir N A, Syed K S and Mazhar I 2004 Numerical Solution of Fluid Flow and Heat Transfer in the Finned Double Pipe *Journal of Research (Science)* **15**(3) pp 253–262
- [4] Strandberg R and Debandra K D 2010 Finned Tube Performance Evaluation with Nanofluids and Conventional Heat Transfer Fluids *International Journal of Thermal Sciences* **49**
- [5] Syed K S, Mazhar I and Mir N A 2007 Convective Heat Transfer in the Thermal Region of Finned Double-pipe *Heat Mass Transfer* **43** pp 449–457
- [6] Davidson L 2009 *An Introduction to Turbulence Models* (Department of Thermo and Fluid Dynamics, Chalmers University of Technology, Sweden)
- [7] Ansys Fluent User's 2011 Guide Ansys Inc. *South pointe 275 Technology Drive Canonsburg*
- [8] Rebay S 1993 Efficient Unstructured Mesh Generation By Means of Delainay Triangulation and Bowyer–Watson Algorithm *Journal of Computational Physics* **106** pp 125–138
- [9] Abd ali Abbas F 2014 Augmentation of Heat Transfer by Using Nanotechnology *M.Sc. thesis* (University of Al – Mustansiriya, College of Engineering, Mech. Eng. Dep.)
- [10] Nabati H 2008 Optimal Pin Fin Heat Exchanger Surface (Mälardalen University Press) Licentiate Thesis **88**