The Effect of Baffles on Heat Transfer

Raheleh Jafari[1][a], Sina Razvarz[2][b], Cristóbal Vargas-Jarillo[2][c] and Alexander Gegov[3][d]
[1]*Centre for Artificial Intelligence Research (CAIR), University of Agder, Grimstad 4879, Norway*
[2]*Departamento de Control Automatico CINVESTAV-IPN, National Polytechnic Institute, Mexico City 07360, Mexico*
[3]*School of Computing, University of Portsmouth, Buckingham Building, Portsmouth PO13HE, U.K.*

Keywords: Baffle, Heat Transfer, Computational Fluid Dynamics.

Abstract: For a long time technicians and engineers have used geometric changes of objects for the purpose of enhancement of heat transfer. The discovery and use of nanofluids and their unique properties lead to a new revolution on the heat transfer. This paper presents the simulation of Ansis software applied to the flow tube with a constant flux, also studies the effect of baffles and the use of nano particles on heat transfer.

1 INTRODUCTION

Throughout the recent years with the aid of fast computers, engineers have become able of operating numerical computations to predict and simulate the experiment and improve the design of models. For so many decades, researching for improving the heat transfer rate of a coolant liquid had been one of the goals of engineering. The modification in properties of fluids that are used for this purpose is one approach that engineers used in previous years. They have been utilized micron and nano-sized particles in order to change and improve this property.

At Argonne National Laboratory, Choi and co-workers (Choi, 1995) showed a considerable increase in thermal conductivity of the liquid by suspending nano-sized particles in a fluid (nanofluids). In another work, Lee et al. (Lee et al., 1999) showed 20% increase in effective thermal conductivity with using suspension of 4.0 %vol, 35 nm CuO particles in ethylene glycol. Das et al. (Das et al., 2003) studied the relation between the temperature and the increment of thermal conductivity in nanofluids experimentally. Pak and Cho (1998) founded that the Nusselt number of the nanofluids increases with increasing the volume fraction of the suspended nanoparticles and Reynolds number.

In (Xuan and Li, 2003) the increment of heat transfer is observed by utilizing water–Cu nanofluids, in the turbulent regime. Furthermore, in (Xuan and Roetzel, 2000) the device of heat transfer increment of the nanofluid is studied. In (Wen and Ding, 2004) the fluid inclusive aluminium nanoparticle is utilized in the tube flow in order to check the laminar heat transfer. They applied 1.6 % nanoparticles by volume in their fluid. The method of particle migration for non–uniform repartition of thermal conductivity and convective heat transfer of nanofluids in $Re<800$ (that is laminar flow) is proposed in (Ding and Wen, 2005; Ding et al. 2006). In (Yang et al., 2005) the authors worked over a horizontal tube heat exchanger and demonstrated that by increasing the Reynolds number the heat transfer coefficient increases, also the fluid temperature and particle volume fraction are in a reverse connection. In (Nguyen et al., 2007) the Al_2O_3–water nanofluid is used for the enhancement of the heat transfer. The experiment results show that by decreasing the size of nanoparticle superior heat transfer coefficients can be produced. In (He et al., 2007) the experimental result for TiO_2 nanofluids in one vertical pipe is presented. Experiments in two different regimes laminar and turbulent are carried out also the experiments are repeated by a different particle size of nanomaterials. Also, it is concluded that the utilization of the nanoparticle concentration

[a] https://orcid.org/0000-0001-7298-2363
[b] https://orcid.org/0000-0003-1549-7307
[c] https://orcid.org/0000-0002-5265-3797
[d] https://orcid.org/0000-0002-6166-296X

Jafari, R., Razvarz, S., Vargas-Jarillo, C. and Gegov, A.
The Effect of Baffles on Heat Transfer.
DOI: 10.5220/0007832206070612
In *Proceedings of the 16th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2019)*, pages 607-612
ISBN: 978-989-758-380-3

has an impact on the increment of the convective heat transfer coefficient. In (Heris et al., 2006; 2007) the experimental outcomes of the convective heat transfer of water and Aluminium oxide nanofluids inside a circular tube is demonstrated. It is concluded that by utilizing the nanoparticles the heat transfer coefficient increases. Some researchers have been worked on numerical methods and have been introduced the equation for the convective heat transfer of nanofluids (Roy et al., 2004; Palm et al., 2006). In (Buongiorno, 2006) the laminar and turbulence regime are used for modeling, also the viscosity effect is studied. Furthermore, it is shown that by reduction of viscosity the heat transfer increases. Viscosity, as well as particle volume fraction, have less amount in the viscous sub-layer, but conductivity in that region has more amount. In (Daungthongsuk and Wongwises, 2007; Patel et al., 2005; Bergles, 1985; Nijemeisland and Dixon, 2001; Vyver et al., 2003; Sivashanmugam, 2008) the computational fluid dynamics (CFD) models are introduced, also the heat transfer is increased by utilizing CFD simulation and changes in the parameters of the system such as the geometry of tube and active fluid through the pipe. Also, the model is comprised of experimental models. In order to estimate the average shell-side heat transfer coefficients as well as pressure drop, many investigations is carried out (Tinker, 1951; Bell, 1963; Donohue, 1949; Palen and Taborek, 1969). Recently, artificial neural networks (ANNs) have become universal and many interesting ANN usages are reported in engineering area (Jafari and Yu, 2015; Jafari et al., 2016a; 2016b; 2017a; 2017b, 2018a; 2018b; Razvarz et al., 2017; 2018a; 2018b; 2018c, 2019; Yu et al., 2019). In (Aly, 2015) a neural network controller technique is suggested for control of the pump flow rate.

The present study concentrates on the heat transfer enhancement in the laminar developing region with changing the geometry of pipe via adding the baffles in the pipeline also effect of adding of nanoparticle in the enhancement of heat transfer. The Ansis program is utilized in order to simulate the model and results.

The rest of the paper is structured as follows: Section 2 presents the analysis of data and introduces the properties of nanofluid. Section 3 describes the experimental details and method of simulation the approach of changing the geometry of the model is stated. Section 4 presents the result of the simulation and effect of changing of the model in the Nusselt number as well as the thermal conductivity. Finally, conclusions are given in Section 5.

2 ANALYSIS OF DATA

Analysis of the heat transfer behaviour of the nanofluids is carried out by the evaluation of the local heat transfer coefficient and local Nusselt number which are defined as

$$Nu(x) = \frac{h(x)D}{k}$$
$$h(x) = \frac{q''}{(T_w(x) - T_f(x))} \tag{1}$$

where Nu [dimensionless parameter] is Nusselt number, q'' [$\frac{W}{m^2}$] is the heat flux, D [m] is the diameter of the tube, $h[\frac{W}{m^2.k}]$ and k [$\frac{W}{m.k}$] are thermal connectivity and thermal conductivity of the fluid respectively, also T_w [k] and T_f [k] are the local wall and fluid temperatures (in kelvins) respectively. The utilized thermal conductivity value is at the average bulk temperature. The density and specific heat of the nanofluid is evaluated using the averaged volume fraction ratio, which is generally acceptable and is defined as

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_p \tag{2}$$

where ρ_{nf} is the density of nanofluid, ρ_{bf} is the density of the basic fluid, ρ_p is the density of nanoparticle and φ is Nanomaterial concentration.

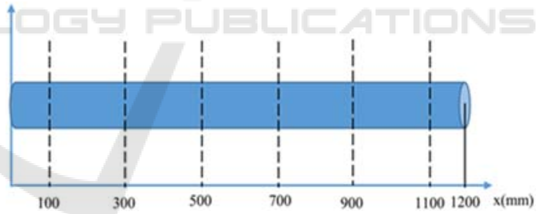


Figure 1: Schematic of the experimental setup.

3 EXPERIMENTAL RESULT

3.1 Experimental Conditions

Experimental conditions that are performed in ideal terms with input and outlet pressure are equal to atmospheric pressure. It is tried to prevent all factors, which effect the system. The length of tube that selected is 1200 mm, the diameter is graded 45mm, the inlet temperature is 295°K and without accepting the thickness of the pipe. The wall temperature of pipe is 310°K. Characteristics of sensors are used to obtain the temperature of specified locations in the interval x of 100, 300, 500, 700, 900 and 1100, see

Figure 1. The Position and distance of the edges are based on nanofluids and they are applied to verify other temperatures and liquids which are effective on baffles. The input speed is based on the input Reynolds number.

3.2 The Experiment Software

This test is performed with *Ansis* software. *SimpleC* algorithm is used for solving the energy equation, momentum equation, and mass equation defined in the heat transfer model.

3.3 Determination of Mesh Building

The measurement is prepared with trial and error method. Three different number of meshes are used systematically and constantly, 46000, 96000, and 165000 with increasing 1.2 step, see Figure 2. Comparison results between meshes are demonstrated in Figure 3. It can be seen that the number of 96000 mesh is more suitable and optimal. In this figure, the meshes with the number of 96000 and 165000 are more close to experimental data.

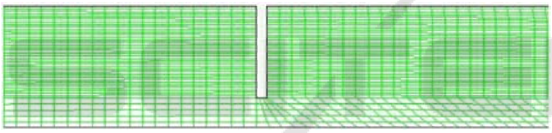


Figure 2: Type and valve of baffling and meshing.

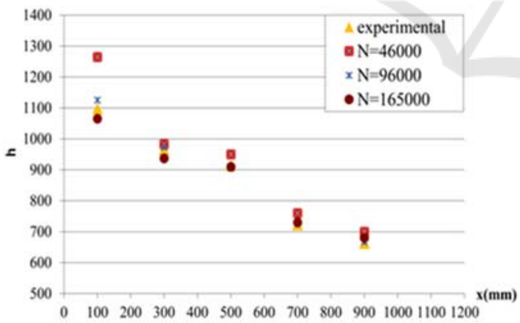


Figure 3: Effect of meshing in Re=1588 and repeating 500.

3.4 Baffle on the Surface

In order to increase the heat transfer, we want to evaluate geometric changes of fluid activity. Normally, there is a simple and regular fluid flow in the pipe (see Figure 4). The path of the fluid is smooth and regular. Fluid flow is steady and laminar in the pipe. The heat transfer and temperature are expanded along the radius of the pipe regularly (see Figure 5).

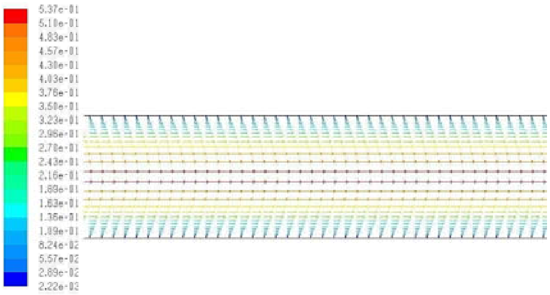


Figure 4: Variation of velocity in pipe.

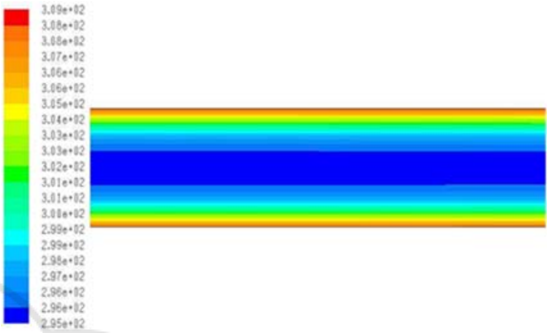
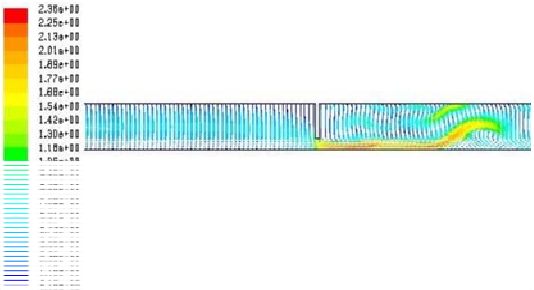


Figure 5: Variation of temperature in steady and laminar condition.

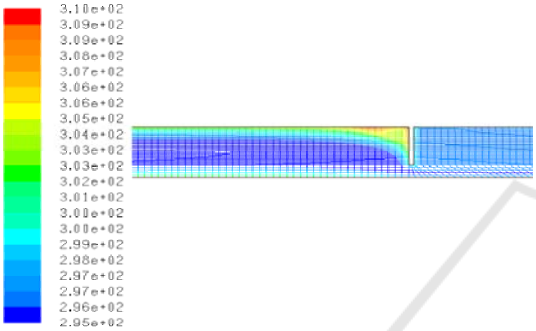
We use the baffle in the pipe and path of the flow in order to make changes in the direction of flow and its geometric shape. The size of baffles is determined via the scale, size, and length of 15% pipe's diameter, and the distance of 200mm from each other in the spiral and zigzag form. The first and last baffles are neglected due to the immediate effect on the flow. The rest of the baffles are in the positions of 400, 600, 800, and 1000 mm. Here we want to measure the influence of baffles on the amount of heat transfer coefficient variation. The base working fluid is pure water in this experiment and Al_2O_3 nanoparticles are the most common nanoparticles used with 45 nm in size. Al_2O_3 particles true density is 3880 kg/m3, which can be converted to weight fraction and volume fraction. The nanoparticles and pure water are mixed by utilizing an ultrasonic homogenizer with the concentration of 0 and 3% by weight.

3.5 Change Resulting from Baffle Creation in the System

By changing the geometric shape of the pipe and creating baffles, the fluid motion inside the pipe varies, and the fluid flow transforms into the turbulence by crashing with the baffles and causes an increment in the heat transfer. As can be seen in Figure 6, variation around the baffles creates turbulence in the fluid. The created turbulence is transformed into the laminar flow after having a small distance from baffles.



a) Velocity vector



b) Variation of temperature

Figure 6: Effect of baffles in the fluid flow a) Velocity vector b)Variation of temperature.

4 RESULTS

After analysing the data for different numbers of Reynolds, the optimal coefficient rate of heat transfer is obtained from different values. By adding the baffles and nanofluids into the pipe we see a considerable increase in the rate of heat transfer coefficient, see Figure 7. As the chart shows in Figure 7, baffles creation improves significantly the level of heat flux, which is mostly due to turbulence flows, the nature and mode of baffles, also creation of vortex and return estate in the back of baffles.

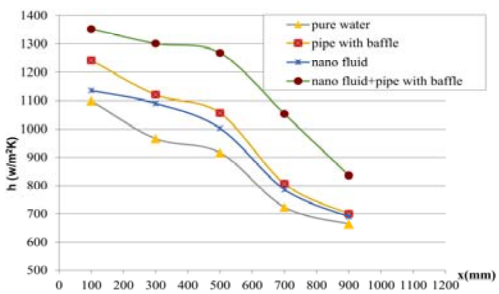


Figure 7: Rate of heat transfer coefficient in tube in Re=1588.

5 CONCLUSION

Implementation of the baffle and the geometric deformation of the pipe cause a dramatic increase in heat transfer. As the experimental results show, the creation of baffle increases the rate of heat transfer as much as 10-20 percent. The use of nanofluids also enhances the heat transfer. The heat transfer efficiency can be improved by combining nanoparticle and baffle.

REFERENCES

Aly, A. A., 2015. An Artificial Neural Network Flow Control of Variable Displacement Piston Pump with Pressure Compensation. *International journal of control, automation and systems*, 1-7.

Bell. K.J., 1963. *Final report of the cooperative research program on shell and tube heat exchangers (6th edn.)*, Bulletin, University of Delaware Engineering Experimental Station.

Bergles, A. E., 1985. *Techniques to augment heat transfer, Handbook of Heat Transfer Application*, McGraw-Hill, New York.

Bergles, A. E., 1988. Some perspectives on enhanced heat transfer, second-generation heat transfer technology, *ASME Journal of Heat Transfer*, 110, 1082-1096.

Buongiorno, J., 2006, Convective transport in nanofluids, *Journal of Heat Transfer*, 128, 240-248.

Choi, S. U. S., 1995. Enhancing thermal conductivity of fluids with nanoparticles, in: *Developments and Applications of Non-Newtonian Flows*, vol. 231, ASME, New York, 99–105.

Das, S. K., Putra, N., Thiesen, P., Roetzel, W., 2003. Temperature dependence of thermal conductivity enhancement for nanofluids, *ASME J. Heat Transfer*, 125, 567–574.

Daungthongsuk, W., Wongwises, S., 2007. A critical review of convective heat transfer of nanofluids, *Renewable and Sustainable Energy Reviews*, 11, 797–817.

Ding, Y., Alias, H., Wen, D., Williams, A. R., 2006. Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids), *Int. J. Heat Mass Transfer*, 49, 240–250.

Ding, Y., Wen, D., 2005. Particle migration in a flow of nanoparticle suspensions, *Powder Technol*. 149, 84–92.

Donohue, D. A., 1949. Heat transfer and pressure drop in heat exchangers, *Industrial and Engineering Chemistry*, 41, 53-60.

Jafari, R. Yu, W., 2015. Uncertainty Nonlinear Systems Control with Fuzzy Equations, *IEEE International Conference on Systems, Man, and Cybernetics,* 2885-2890.

Jafari, R., Razvarz, S., 2017a. Solution of Fuzzy Differential Equations using Fuzzy Sumudu Transforms. In: *IEEE International Conference on*

Innovations in Intelligent Systems and Applications (INISTA), 84 – 89.

Jafari, R., Razvarz, S., 2018a. Solution of Fuzzy Differential Equations Using Fuzzy Sumudu Transforms. In: *Mathematical and Computational Applications,* 23, 5, 1-15.

Jafari, R., Razvarz, S., Gegov, A. Paul, S., 2018b. Fuzzy modeling for uncertain nonlinear systems using fuzzy equations and Z-numbers. *Advances in Computational Intelligence Systems: Contributions Presented at the 18th UK Workshop on Computational Intelligence,* September 5-7, 2018, Nottingham, UK. Advances in *Intelligent Systems and Computing*, Springer, 840, 66-107.

Jafari, R., Yu, W., 2017b. Uncertain nonlinear system control with fuzzy differential equations and Z-numbers. In: *18th IEEE International Conference on Industrial Technology (ICIT)*, Canada, 2017. 890 -895. DOI: 10.1109/ICIT.2017.7915477.

Jafari, R., Yu, W. Li, X., 2016a. Solving Fuzzy Differential Equation with Bernstein Neural Networks. In: *IEEE International Conference on Systems, Man, and Cybernetics (SMC16)*, Budapest, Hungary, 1245-1250.

Jafari, R., Yu, W. Li, X., 2016b. Solving Fuzzy Differential Equation with Bernstein Neural Networks. In: *IEEE International Conference on Systems, Man, and Cybernetics (SMC16),* Budapest, Hungary, 1245-1250.

He, Y., Jin, Y., Chen, H., Ding, Y., Cang, D., Lu, H., 2007. Heat transfer and flow behaviour of aqueous suspensions of TiO2 nanoparticles (nanofluids) flowing upward through a vertical pipe, *Int. J. Heat Mass Transfer,* 50, 2272–2281.

Heris, S. Z., Esfahany, M. N., Etemad, S. G., 2007. Experimental investigation of convective heat transfer of Al2O3/water nanofluid in circular tube, *Int. J. Heat Mass Transfer,* 28, 203–210.

Heris, S. Z., Etemad, S .G., Esfahany, M. N., 2006. Experimental investigation of oxide nanofluids laminar flow convective heat transfer*, Int. Commun. Heat Mass Transfer,* 33, 529–535.

Hilde, V., Jaco, D., Josua, P., 2003. Meyer, Validation of CFD model of a three dimensional tube-in-tube Heat Exchanger paper presented, in: *Third International conference on CFD in Mineral and process Industries* CSIRO, Melbourne Australia.

Lee, S., Choi, S. U. S., Li, S., Eastman, J. A., 1999. Measuring thermal conductivity of fluids containing oxide nanoparticles, *J. Heat Transfer,* 121, 280– 289.

Nguyen, C. T., Roy, G., Gauthier, C., Galanis, N., 2007. Heat transfer enhancement using Al2O3–water nanofluid for an electronic liquid cooling system, *Appl. Therm. Eng,* 27, 1501–1506.

Nijemeisland, A., Dixon, G., 2001. Comparison of CFD simulations to experiment for convective heat transfer in a gas solid fixed bed, *Chemical Engineering Journal,* 82, 231-246.

Pak, B., Cho, Y. I., 1998. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particle, *Exp. Heat Transfer,* 11, 151–170.

Palen, J. W. Taborek, J., 1969. Solution of shell side flow pressure drop and heat transfer by stream analysis method (6th edn.), *Chemical Engineering Progress Symposium Series,* 92, 53-63.

Palm, S. J., Roy, G., Nguyen, C.T., 2006. Heat transfer enhancement with the use of nanofluids in radial flow cooling systems considering temperature-dependent properties, *Appl. Therm. Eng,* 26, 2209–2218.

Patel, H. E., Das, S. K., Sundararajan, T., Sreekumaran, N. A., George, B., 2005 A micro-convection model for thermal conductivity of nanofluids, *Pramana. J Phys*, 65, 5, 863–869.

Razvarz, S., Jafari, R., Yu, W., 2018a. Numerical solution of fuzzy differential equations with Z-numbers using fuzzy Sumudu Transforms, Advances in Science, *Technology and Engineering Systems Journal,* 3, 66-75.

Razvarz, S., Jafari, R., Granmo, O-C., Gegov, A., 2018b. Solution of dual fuzzy equations using a new iterative method, In Proceedings of the 10th Asian Conference on Intelligent Information and Database Systems, *Lecture Notes in Artificial Intelligence*. Springer. doi: 10.1007/978-3-319-75420-8-23, 245-255.

Razvarz, S., Jafari, R., Yu, W., Golmankhaneh, A. K., 2017. PSO and NN Modeling for Photocatalytic Removal of Pollution in Wastewater. In: The 14th International Conference on Electrical Engineering, *Computing Science and Automatic Control (CCE)*, DOI: 10.1109/ICEEE.2017.8108825.

Razvarz, S., Jafari, R., 2018c. Experimental Study of Al2O3 Nanofluids on the Thermal Efficiency of Curved Heat Pipe at Different Tilt Angle, *Journal of Nanomaterials*, 2018, 1-7. https://doi.org/10.1155/2018/1591247.

Razvarz, S., Vargas-Jarillo, C., Jafari, R., Gegov, A.,2019, Flow Control of Fluid in Pipelines Using PID Controller, *IEEE Access*, 7, 25673-25680, Doi: 10.1109/ACCESS.2019.2897992

Roy, G., Nguyen, C. T., Lajoie, P., 2004. Numerical investigation of laminar flow and heat transfer in a radial flow cooling system with the use of nanofluids, *Superlattices and Microstructures*. 35, 3-6, 497–511.

Sivashanmugam, P., Prabakaran, S., Rao, Ankamma, D., 2008. Modeling of Heat Augmentation in a circular tube fitted with twisted tape inserts in a laminar flow using CFD. Presented in the *International conference on Resource Utilization and Intelligent system conducted in Kongu Engineering College*.

TinkerShell, T., 1951. side characteristics of shell and tube heat exchanger, *Parts I, II, III General Discussion on Heat Transfer The Institution of Mechanical Engineers,* 89-116

Vyver, H. V., Dirker. J., Meyer. J., 2003. Validation of CFD model of a three dimensional tube-in-tube Heat Exchanger paper presented, in: *Third International conference on CFD in Mineral and process Industries CSIRO,* Melbourne Australia, 10-12 December 2003.

Wen, D., Ding, Y., 2004. Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions, *Int. J. Heat Mass Transfer,* 47, 5181–5188.

Yu, W., Jafari, R., 2019, Fuzzy Modeling and Control with Fuzzy Equations and Z-Number. In: *IEEE Press Series on Systems Science and Engineering*, Wiley-IEEE Press, ISBN-13: 978-1119491552

Xuan, Y., Li, Q. 2003. Investigation on convective heat transfer and flow features of nanofluids, *J. Heat Transfer,* 125, 1, 151–155.

Xuan, Y., Roetzel, W., 2000. Conceptions for heat transfer correlation of nano-fluids, *Int. J. Heat Mass Transfer*, 43, 3701–3707.

Yang, Y. Z., Zhang, G., Grulke, E. A., Anderson, W.B., Wu, G., 2005. Heat transfer properties of nanoparticle-in-fluid dispersions (nanofluids) in laminar flow, *Int. J. Heat Mass Transfer*, 48, 1107–1116.