Numerical analysis of single phase fluid flow and heat transfer in a circular micro channel using nanofluid as a coolant

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***Abstract*— An analysis has been done on micro- channel heat exchanger to predict the hydrodynamic and thermal behaviour. ANSYS workbench has been used for making geometry and meshing of the micro channel heat exchanger. In this study, an investigation of fluid flow and heat transfer is conducted on circular micro channel. CFD model has been solved by commercial software ANSYS/FLUENT. Nanofluid has been used as a coolant fluid to enhance the heat transfer rate because nanofluid has higher thermal conductivity than the base fluid. In this study, nanofluid, a mixture of Al2O3 and water, has been used. The required thermo physical properties of the nanofluid were measured and used in CFD model through user defined function (UDF) in ANSYS/FLUENT software. The CFD result has been compared to the experimental work. And it has been validated that using nanofluid in a circular micro channel heat exchanger enhance the heat transfer. CFD result also predicts the wall temperature, pressure drop in channel and friction factor.**

Keywords— Micro channels, heat exchangers, nanofluids, Fluent, CFD, heat transfer coefficient, pressure drop and friction factor.

I. INTRODUCTION

A heat exchanger is a system designed to transfer heat between two fluids to control the temperature of one of the fluids. Heat exchangers play an important role in the field of energy conservation and conversion. Various application of heat exchangers in today life are condensers and evaporators used in refrigerators and air conditioners, radiators and oil coolers for engines in automobiles and condensers, air coolers and chilling towers in thermal power plants.

Micro channel Heat exchanger

Miniaturization of channel first used by Tuckerman and Pease for the purpose of heat transfer. [1] Their work has motivated many researchers to focus on the topic and micro channel has been recognized as a high performance heat removal tool ever since. The definition for the term―micro channel‖ has been among the topics of debate between researchers. Mehendale used the following classification based on channel dimensions ―D‖ [2].

1µm ⟨ D ⟨ 100µm : Micro channels
100µm ⟨ D ⟨ 1 mm : Mini channels
1 mm ⟨ D ⟨ 6 mm : Compact Passages
6 mm ⟨ D : Conventional Passages

A different classification based on channel dimension has been made by Kandlikar and Grande [3].

1µm ⟨ D ⟨ 10µm : Transitional Micro channels
10µm ⟨ D ⟨ 200 µm : Micro channels
200 µm ⟨ D ⟨ 3 mm : Mini channels
3 mm ⟨ D : Conventional Passages

Obot proposed classification based on the hydraulic diameter [4]. According to him channels of hydraulic diameter under 1mm Dh ⟨ 1mm are as micro- channel. This definition was also adopted by many other researchers. This definition of micro channel has been adopted in this study.

Use of nanofluid

The enhancement of heat transfer in any engineering process is a very important phenomenon. The development of high performance thermal systems for heat transfer enhancement has become popular nowadays. A number of works has been performed to gain an understanding of the heat transfer performance of thermal systems for heat transfer enhancement. Using nanofluid as a coolant is a technique to increase the heat transfer rate. Commonly used heat transfer fluids such as water, ethylene glycol, and engine oil have relatively low thermal conductivities, when compared to the thermal conductivity of solids. High thermal conductivity of solids can be used to increase the thermal conductivity of a fluid by adding small solid particles to that fluid. The term nanofluid was coined by Choi in 1995 at Argonne National Laboratory of USA [5]. After that an abundant amount of experimental as well as numerical studies has been done to explore the advantages of nanofluids as a heat transfer medium over the conventional liquids. Yang measured the convective heat transfer coefficients of several nanofluids under laminar flow in a horizontal tube heat exchanger [6]. Nanoparticles used in nanofluids have been made of various materials, such as oxide ceramics (Al2O3, CuO), metals (Cu, Ag, Au), semiconductors (TiO2, SiC), carbon nanotubes, and composite materials [7]. The most common base liquids are water, ethylene glycol, and oil.

II. EXPERIMENTAL WORK

The experimental setup with test module was developed by Qu and Mudawar as shown in Fig.1 [8]. The micro channel is made of oxygen free copper. A flow loop was constructed to supply deionized water to the heat sink at the desired pressure, temperature, and flow rate. The water was pumped from a liquid reservoir and circulated through the flow loop by a gear pump. Coming out from the pump, a portion of the flow, controlled by a by-pass valve, entered the test loop containing the heat sink, while the remaining portion returned to the reservoir though a by-pass loop. The test loop water first passed through a heat exchanger where the water was cooled to the desired inlet temperature. Then water passed through a 15 µm filter to prevent any solid particles from blocking the heat sink micro-channels. After exiting the filter, the water was routed to one of two rota meters for volume flow rate measurement. The water then entered the micro-channel heat sink test module where the electric power supplied to the heat sink was removed by the water. Leaving the test module, the water returned to the reservoir where it mixed with the bypassed flow. The experimental work which was performed by Qu and Mudawar, on the test rig is simulated in the present study [8].

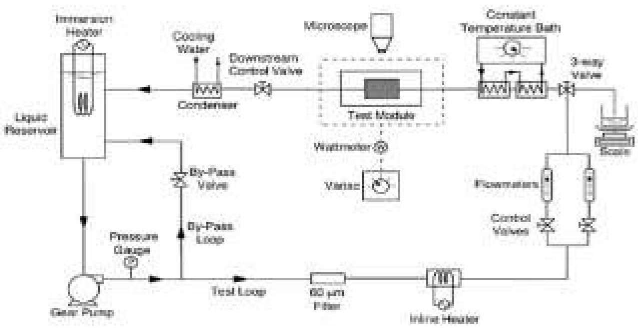

Figure 1: Schematic of flow loop

III. CFD SIMULATION

Ansys workbench has been used for simulating the model and a model equation has been solved by FLUENT 15 solver [9]. No slip boundary condition was assigned for the non-porous wall surfaces, where both velocity components were set to zero at that boundary i.e. $v_x = v_r = 0$. A constant heat flux (100 W/m^2) is applied on the channel wall. Axis symmetry was assigned at centerline. A uniform mass flow inlet and a constant inlet temperature were assigned at the channel inlet. At the exit, pressure was specified as 1 atm.

IV. RESULTS

Comparison of the present computed pressure drops and friction factors for water and its nanofluid at different Re 140-941 with experimental results Lee and Mudawar [10]. It shows that as Reynolds number increases, pressure drop increases and friction factor decreases. Here one thing is noticeable that the pressure drop increases with increasing nano particle concentration at the same Reynolds number. For example at Reynolds number 200, pure water and its nanofluid with alumina (1% and 2% volume concentration) gives pressure drop across micro channel equal to 0.38 bar, 0.46 bar and 0.61 bar respectively

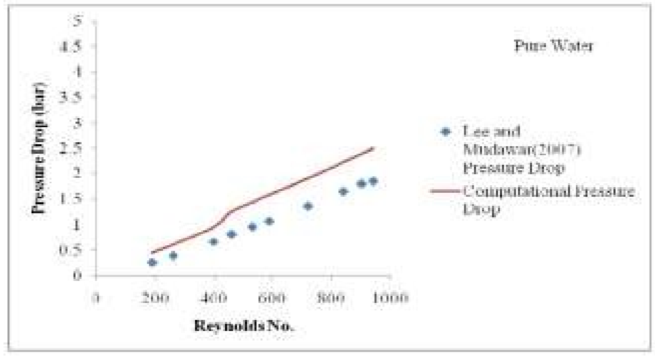

Figure 2: Variation of computational and experimental pressure drop

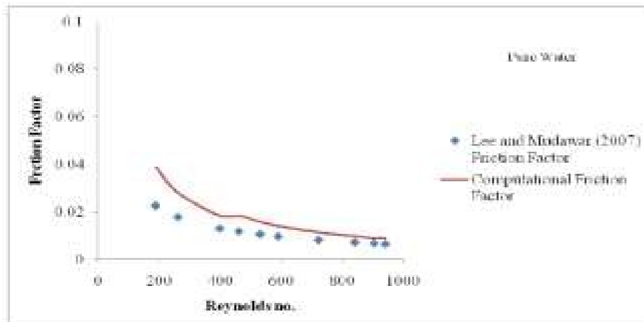

Figure 3: Variation of computational and experimental friction factor

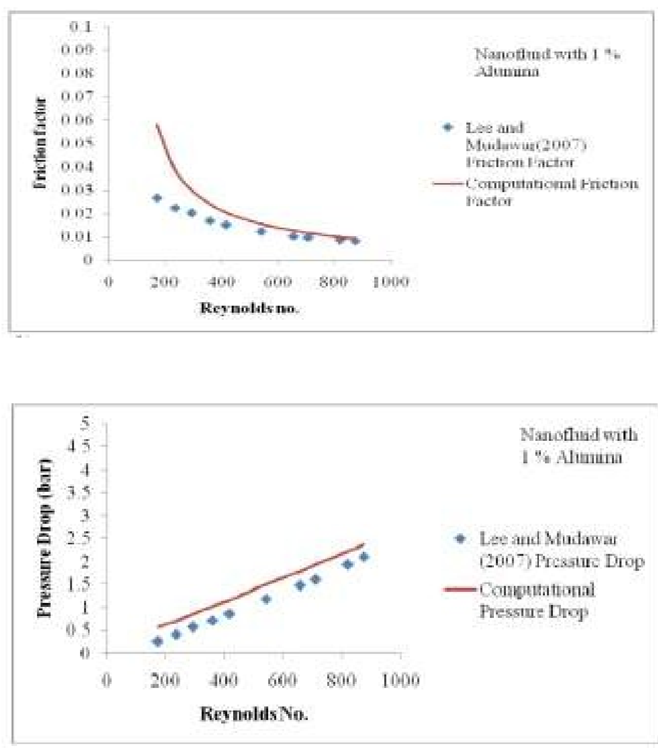

Figure 4: Variation of computational and experimental pressure drop and friction factor for 1% alumina

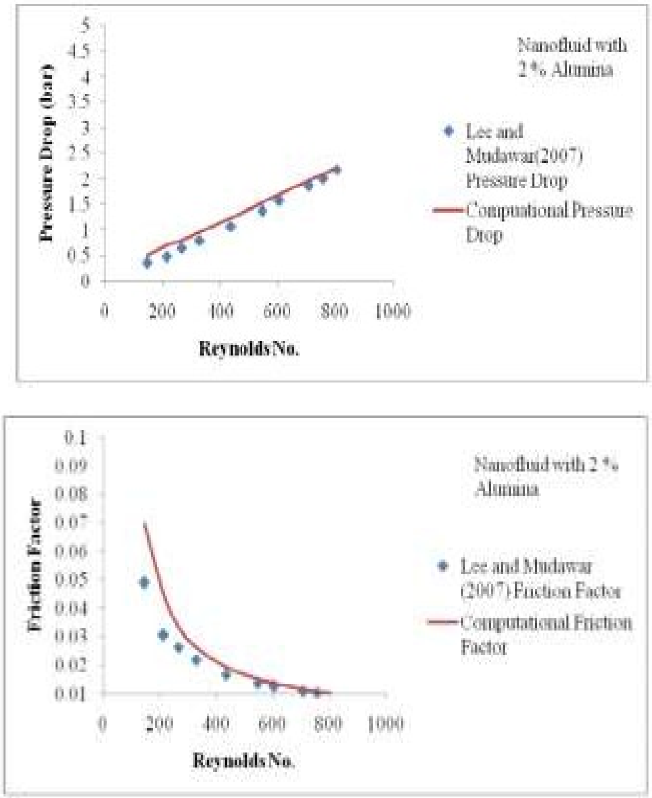

Figure 5: Variation of computational and experimental pressure drop and friction factor for 2% alumina

The computed values of wall temperature in the flow direction using water and its nanofluids are compared with the experimental data Qu and Mudawar and analysis done by Lee and Mudwar [8, 10]. The comparison shows that CFD results can predict well the experimental data**.**

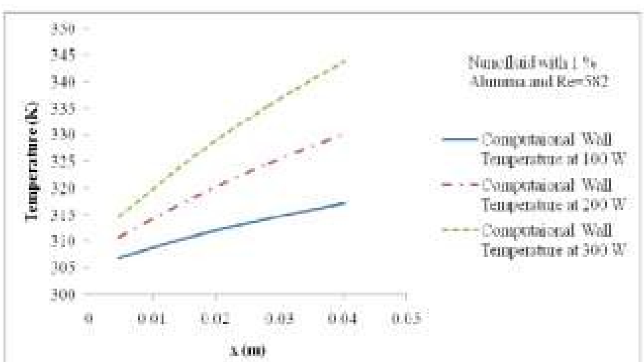

Figure 6: Variation of wall temperature for Nanofluid with 1 % Alumina

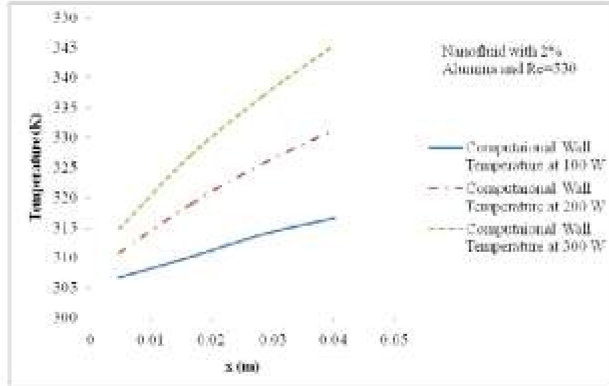

Figure 7: Variation of wall temperature for Nanofluid with 2% alumina

V. CONCLUSIONS

In this work the hydrodynamics and thermal behavior of circular micro channel present in a test rig were studied. A nanofluid (pure water + Al_2O_3) was used as the coolant in the channel. A steady state computational fluid dynamics (CFD) models was simulated by ANSYS Fluent 15.0 here. The effect of Reynolds number and Peclet number on the flow behavior of the micro channel was found. Based on the analysis of the circular micro channel behavior the following conclusions can be drawn.

- Computed temperatures and heat transfer coefficients were found in close agreement with the analytical values.
- The use of nanofluids as the heat transport medium in the channel were found useful both in laminar and in turbulent flow conditions.
- The change of temperature from inlet to outlet was found increasing with decreasing Reynolds number.
- Temperature distribution was found independent of radial position even at very low value of Peclet number.
- Pressure drop increases with increase in Reynolds number.
- The entrance length for fully developed flow depends on Nanoparticle concentrations.
- Wall temperature has negligible variation for higher Reynolds due to greater value of Peclet no in circular micro channel.

REFRENCES

[1]. Tuckerman, D.B. and Pease, R.F. 1981. High- performance heat sinking for VLSI. IEEE Electronic Devices Letters. EDL-2, 5, 126-129.

[2]. Mehendale, S. S., Jacobi, A.M. and Shah, R. K. 2000. Fluid Flow and Heat Transfer at Micro- and Meso-scales

[3]. with Application to Heat Exchanger Design. Applied Mechanics Reviews, 53, 175-193.

[4]. Khandlikar, S. G. and Grande, W.J. 2003. Evolution of Microchannel Flow Passages Thermo hydraulic Performance and Fabrication Technology. Heat Transfer Engineering. 24, 3-17.

[5]. Obot, N.T. 2003. Toward a Better Understanding of Friction and Heat/Mass Transfer in Microchannels – A Literature Review. Microscale Thermophysical Engineering. 6, 155-173. 2003.

[6]. Choi, S.U.S., 1995. Enhancing thermal conductivity of fluids with nanoparticles. In:Proceedings of the 1995 ASME International Mechanical Engineering Congress and

[7]. Exposition, San Francisco, CA, USA. 66, 99-105.

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

[9]. Heat transfer and fluid flow characteristics in microchannels heat exchanger using nanofluids: A review H.A. Mohammeda,, G.Bhaskarana, N.H.Shuaiba, R.Saidurb.

[10]. Qu, W. and Mudawar, I. 2002. Experimental and numerical study of pressure drop and heat transfer in a single-phase micro-channel heat sink. International Journal of Heat and Mass Transfer.ANSYS Fluent 14.0 Theory Guide, April, (2014).

[11]. Lee, J. and Mudawar, I. 2007. Assessment of the effectiveness of nanofluids for singlephase and two-phase heat