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A Computational Fluid Dynamics Study and Heat Transfer in A Micro Channel

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ABSTRACT: A theoretical study of single phase microchannel heat exchanger has been carriedout. The computational fluid dynamics (CFD) model equations are solved to predict the hydrodynamic and thermal behaviour of the exchanger. The geometry of the problem and meshing of it have been made in ANSYS Workbench. The models have been solved by ANSYS Fluent 12.0 solver. The utility of nonmaterial as a heat enhancer has been justified by studying a circular microchannel thermal behaviour. Water and its nanofluids with alumina (Al_2O_3) are used as the coolant fluid in the microchannel heat sink. The present CFD calculated heat transfer coefficient values have compared with the analytical values and very close agreement is observed. The result shows that nanofluids help to increase the heat transfer coefficient by 15% and 12% respectively in laminar and turbulent zone. Thus use of nanofluids has been found beneficial both in laminar and turbulent zone. The relation between heat transfer coefficient and thermal conductivity of the fluid i.e. *h* is proved in the present study.

Key Words: microchannels, heat exchangers, nanoparticles, nanofluids, Fluent, CFD, heat transfer coefficient, pressure drop, friction factor.

I. INTRODUCTION

Heat sinks are classified into single-phase or two-phase according to whether boiling of liquid occurs inside the micro channels. Primary parameters that determine the single phase and two-phase operating regimes Over the last decade, micromachining technology has been increasingly used for the development of highly efficient cooling devices called heat sink because of its undeniable advantages such as less coolant demands and small dimensions. One of the most important micromachining technologies is micro channels. Hence, the study of fluid flow and heat transfer in micro channels which are two essential parts of such devices, have attracted more attentions are heat flux through the channel wall and coolant flow rate. For a fixed amount of heat flux (heat load), the coolant may maintain its liquid state throughout micro- channels. With a lower flow rate, the flowing liquid coolant inside the channel may reach its boiling point and thus flow boiling occurs, which results in a two-phase heat sink.

MICROCHANNEL AND ITS USE

Tuckerman and Pease (1981) first made use of miniaturization for the purposes of heat removal, within the scope of a Ph.D. study in 1981. Their publication titled "High Performance Heat Sinking for VLSI" is credited as the first study on microchannel heat transfer. Their pioneering work has motivated many researchers to focus on the topic and microchannel flow has been recognized as a high performance heat removal tool ever since. Before proceeding with microchannel flow and heat transfer, it is appropriate to introduce a definition for the term "microchannel". The scope of the term is among the topics of debate between researchers in the field. Mehendale et al. (2000) used the following classification based on manufacturing techniques required to obtain various ranges of channel dimensions, "*D*", being the smallest channel dimension:

As is evident from the diversity of application areas, the study of flow and heat transfer in microchannels is very important for the technology of today and the near future, as developments are following the trend of miniaturization in all fields. Literature shows that the microchannels and microchannels heat sinks were studied extensively, , this work studies the CFD simulation of micro channel flow and conjugates heat transfer, which couples fluid convection in a rectangular micro channel and heat conduction in the solids.

The present work is undertaken to study the following aspects of

1. Computational Fluid Dynamics modeling and simulation of single phase microchannel heat

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exchanger to understand its hydrodynamic and thermal behaviour.

2. Validation of the CFD models by comparing the present simulated results with thedata available in the open literature.

3. Parameter sensitivity study of micro channel

II. LITERATURE REVIEW

Some experimental and theoretical work on micro channel heat exchanger has been done inthe last decades. Both the industrial and academic people have taken interest in this area. The following is a review of the research that has been completed especially on microchannel heat exchangers. The literature survey is arranged according to similarity to the work done in this thesis. In this literature review emphasis is directed on:

2. Experimental study of fluid flow and heat transfer in micro channels

3. Numerical study of fluid flow and heat transfer in micro channels

4. Nano fluid as heat enhancer

Peng and Peterson (1996) had also investigated experimentally the single-phase forced convective heat transfer micro channel structures with small rectangular channels havinghydraulic diameters of 0.133–0.367 mm and distinct geometric configurations. The results indicate that geometric configuration had a significant effect on single-phase convective heat transfer and flow characteristics. The laminar heat transfer found to be dependent upon theaspect ratio i.e. the ratio of hydraulic diameter to the centre to centre distance of micro channels. The turbuWith the development of micro fabrication technology, microfluidic systems have been increasingly used in different scientific disciplines such as biotechnology, physical and chemical sciences, electronic technologies, sensing technologies etc. Microchannels are one of the essential geometry for microfluidic systems; therefore, the importance of convective transport phenomena in microchannels and microchannel structures has increased dramatically. In recent years, a number of researchers have reported the heat transfer and pressure drop data for laminar and turbulent liquid or gas flow in microchannels. The concept of micro channel heat sink at first proposed by **Tuckermann and Pease (1981)**, they demonstrated that the micro channel heat sinks, consisting of micro rectangular flow passages, have a higher heat transfer coefficient in laminar flow regime than that in turbulent flow through conventionally-sized devices. They said that the heat transfer can be enhanced by reducing the channel height down to micro scale. This pioneering work initiated other studies, some confirmed findings reported by others. Many researchers compared their numerical or analytical studies with Tuckerman and Pease .

Wang and Peng (1995) had investigated experimentally the single-phase forced convective heat transfer characteristics of water/methanol flowing through micro-channels with rectangular cross section of five different combinations, maximum and minimum channel size vlent flow resistance was usually smaller than predicted by classicalrelationships [3].

Fedorov and Viskanta (2000) developed a three dimensional model to investigate the conjugate heat transfer in a micro channel heat sink with the same channel geometry used in the experimental work done by Kawano et al (1998). This investigation indicated that the average channel wall temperature along the flow direction was nearly uniform except in the region close to the channel inlet, where very large temperature gradients were observed. This allowed them to conclude that the thermo–properties are temperature dependent. The modifications of thermo-physical properties in the numerical process are very difficult as temperature and velocity are highly coupled.

Jiang et al. (2001) performed an experimental comparison of microchannel heat exchanger with microchannel and porous media. The effect of the dimensions on heat transfer was analyzed numerically. It was emphasized that the heat transfer performance of the microchannel heat exchanger using porous media is better than using of microchannels, butthe pressure drop of the former is much larger.

Qu and Mudawar (2002) have performed experimental and numerical investigations of pressure drop and heat transfer characteristics of single-phase laminar flow in 231 *m* by 713 *m* channels. Deionized water was employed as the cooling liquid and two heat flux levels, 100 W/cm^2 and 200 W/cm^2, defined relative to the planform area of the heat sink, were tested. Good agreement was found between the measurements and numerical predictions, validating the use of conventional Navier–Stokes equations for micro channels. For the channel bottom wall, much higher heat flux and Nusselt number values are encountered near the channel inlet.

Qu and Mudawar (2004) conducted a three-dimensional fluid flow and heat transfer analysis for a rectangular micro channel heat sink using a numerical method similar to that proposed by both Kawano et al. (1998) , and Fedorov and Viskanta. (2000) This model considered the hydrodynamic and thermal developing flow along the channel and found that the Reynolds number would influence the length of the developing flow region. It was also found that the highest temperature is typically encountered at the heated base surface of the heat sink immediately adjacent to the channel outlet and that the temperature rise along the flow direction in the solid and fluid regions can both be approximated as linear .

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Mishan et al. (2007) has worked on heat transfer and fluid flow characteristic of a rectangular microchannel experimentally, having water as a working fluid. The experimental results of pressure drop and heat transfer confirm that including the entrance effects, the conventional theory is applicable for water flow through microchannels. They have developed new method for measurement of fluid temperature distribution and it gives the fluid temperature distribution inside the channel.

Lee and Mudawar (2007) have done experimental work to explore the micro-channel cooling benefits of water-based nanofluids containing small concentrations of Al2O3. It was observed that the presence of nanoparticles enhances the single-phase heat transfer coefficient, especially for laminar flow. Higher heat transfer coefficients were achieved mostly in the entrance region of micro-channels. However, the enhancement was weaker in the fully developed region. Higher concentrations also produced greater sensitivity to heat flux. A large axial temperature rise was associated with the decreased specific heat for the nanofluid compared to the base fluid. For two-phase cooling, nanoparticles caused catastrophic failure by depositing into large clusters near the channel exit due to localized evaporation once boiling commenced.

Chein and Chuang (2007) have addressed microchannel heat sink (MCHS) performance using nanofluids as coolants. They have carried out a simple theoretical analysis that indicated more energy and lower microchannel wall temperature could be obtained under the assumption that heat transfer could be enhanced by the presence of nanoparticles. The theoretical results were verified by their own experimental results. It was observed that nanofluid-cooled MCHS could absorb more energy than water-cooled MCHS when the flow rate was low. For high flow rates, the heat transfer was dominated by the volume flow rateand nanoparticles did not contribute to the extra heat absorption.

Jung et al (2009) have studied experimentally the heat transfer coefficients and friction factor of Al2O3 with diameter of 170 nm in a rectangular micro channel. Appreciable enhancement of the convective heat transfer coefficient of the nano fluids with the base fluid of water and a mixture of water and ethylene glycol at the volume fraction of 1.8 volume percent was obtained without major friction loss. It has been found that the Nusselt number increases with increasing the Reynolds number in laminar flow regime, which is contradictory to the result from the conventional analysis.

Ergu et al. (2009) had described the pressure drop and local mass transfer in a rectangular microchannel having a width of 3.70 mm, height of 0.107 mm and length of 35 mm. The pressure drop measurements were carried out with distilled water as working fluid at Reynolds numbers in the range of 100–845, while mass transfer measurements with a chemical solution at Reynolds numbers in the range of 18–552 by using the electrochemical limiting diffusion current technique (ELDCT). Experimental friction factors were found slightly higher than those calculated by theoretical correlation. The Sherwood number correlation was also obtained.

Muthtamilselvan et al. (2009) has conducted a numerical study to investigate the transport mechanism of mixed convection in a lid-driven enclosure filled with nanofluids. The two vertical walls of the enclosure were kept insulated while the horizontal walls were at constant temperatures with the top surface moving at a constant speed. The model equations were discretized by finite volume technique with a staggered grid arrangement. The SIMPLE algorithm is used for handling the pressure velocity coupling. Numerical solutions are obtained for a wide range of parameters and copper-water nanofluid was used with Pr = 6.2. The streamlines, isotherm plots and the variation of the average Nusselt number at the hot wall have been presented and discussed. The variation of the average Nusselt number was observed linear with solid volume fraction.

In one of the recent studies by **Al-Nmir et al. (2009)**, an investigation of the hydrodynamic and thermal behavior of the flow in parallel plate micro heat exchanger was performed numerically, by adopting a combination of both the continuum approach and the possibility of slip at the boundaries. In their work, both viscous dissipation and internal heat generation were neglected. Fluent analysis was made based on solving continuum and slip boundary condition equations. Effects of different parameters; such as, Knudsen number (Kn), heat capacity ratio (Cr), effectiveness (ε), and number of transfer units (NTU) were examined. The study showed that both the velocity slip and the temperature jump at the walls increase with increasing Kn. The increase of the slip conditions reduce the frictional resistance of the wall against the flow, and under the same pressure gradient, pumping force leads to that the fluid flows much more in the heat exchanger.

Very recently, **Mathew and Hegab (2009)** theoretically analyzed the thermal performance of parallel flow micro heat exchanger subjected to constant external heat transfer. The model equations predicts temperature distributions as well as effectiveness of the heat exchanger. Moreover, the model can be used when the individual fluids are subjected to either equal or unequal amounts of external heat transfer.

One of the comprehensive studies in counter flow micro channel heat exchanger area was done by Hasan et al. 2009. In this work, numerical simulations were made to study the effect of the size and shape of channels; such as circular, square, rectangular, iso-triangular, and trapezoidal, in counter flow exchanger. The results show that for the same volume of heat exchanger, increasing the number of channels leads to an increase in both effectiveness and

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pressure drop. Also circular channels give the best overall performance (thermal and hydraulic) among various channel shapes.

Kang and Tseng (2007) theoretically modeled thermal and fluidic characteristics of a cross- flow micro heat exchanger assuming that flows in rectangular channels, where fin height and width are 32 µm and 200 µm respectively, are incompressible, steady, and laminar. The simulated results were validated with the experimental data. The effects of change of material from cupper to silicon and dimensions on its performance were investigated. The study shows that under the same effectiveness value, a small rise in the temperatures of working fluids results in an increase of the heat transfer rate, but a decrease in pressure drop occurs.

III. RESULTS AND DISCUSSIONS

The variation of velocity of water and its nanofluid (1% alumina and 2% alumina) with axial position (x) at Re=140. Velocity is at centerline as indicted. It is observed almost at the entrance velocity of all types of fluids got fully developed. The entrance length of all the fluids also found to be same.

Comparison of the present computed pressure drops and friction factors for water and its nano fluid at diffrenent Re 140-941 with experimental results (Lee and Mudawar, 2007) are depicted in Table 5.2, 5.3 and 5.4 respectively. These show that as Reynolds number increases pressure drop increases and friction factor decreases. Here one thing is noticeable that the pressure drop increases with increasing nanoparticle 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.

Table 1 Comparison of computation pressure drop and friction factor of water withexperimental values (Lee and Qudawar, 2007)

Reynolds No	Experimental		Computational	
	Pressure Drop	Friction Factor	Pressure Drop	Friction Factor
189.524	0.259653	0.022414	0.4496	0.038811
260.276	0.389479	0.017827	0.6135	0.028081
397.529	0.66536	0.013055	0.9491	0.018622
459.665	0.811415	0.011907	1.2572	0.018449
530.531	0.957469	0.010548	1.4409	0.015873
588.074	1.071	0.009603	1.588	0.014238
721.075	1.363	0.008128	1.9136	0.011412
840.98	1.655	0.007256	2.2304	0.009778
903.115	1.801	0.006847	2.3971	0.009113
941	1.85	0.006478	2.4962	0.008741

Table 2 Comparison of computation pressure drop and friction factor of 1% Aluminawith experimental values (Lee and Mudawar, 2007)

Reynolds No.	Experimental		Computational	
	Pressure Drop (bar)	Friction Factor	Pressure Drop	Friction Factor
172.062	0.259653	0.026503	0.5681	0.057986
234.198	0.405707	0.022352	0.7041	0.038791
292.081	0.56799	0.020119	0.8505	0.030125
358.581	0.714045	0.016781	1.0219	0.024016
416.351	0.8601	0.014993	1.1641	0.020293
540.849	1.185	0.012241	1.4955	0.015449
656.388	1.477	0.010359	1.7888	0.012546
709.68	1.607	0.009642	1.9234	0.01154
821.081	1.931	0.008655	2.2218	0.009959
874.599	2.093	0.008268	2.3731	0.009375

Table 3 Comparison of computation pressure drop and friction factor of 2% Aluminawith experimental values (Lee and Qudawar, 2007)

Reynolds No.	Experimental		Computational	
	Pressure Drop (bar)	Friction Factor	Pressure Drop	Friction Factor
146.551	0.357022	0.048986	0.5067	0.069522
212.824	0.470621	0.030618	0.6922	0.045034
266.342	0.632903	0.026291	0.8041	0.033403
328.591	0.795186	0.021702	0.9651	0.02634
435.287	1.071	0.016657	1.2454	0.019369
546.575	1.379	0.013602	1.5382	0.015173
604.685	1.574	0.012685	1.6989	0.013692

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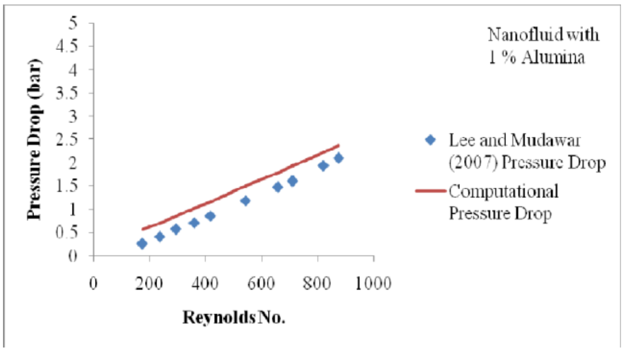
707.128	1.866	0.010997	1.9793	0.011665
756.168	2.012	0.010369	2.0973	0.010809
805.434	2.191	0.009953	2.2391	0.010171



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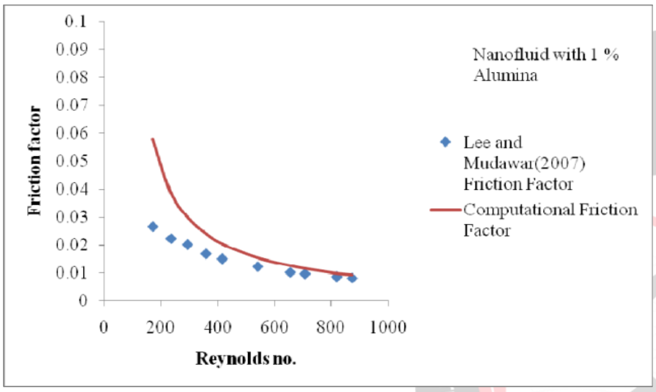
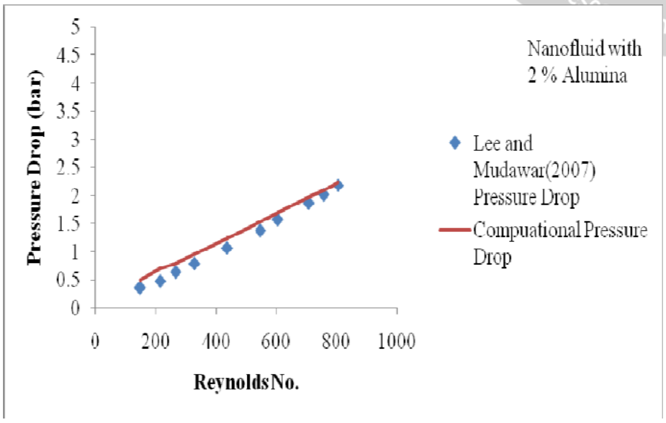


(b)

Fig: Variation of computational and experimental pressure drop and friction factorof 1% Alumina with Re. (a) Pressure drop (b) Friction factor



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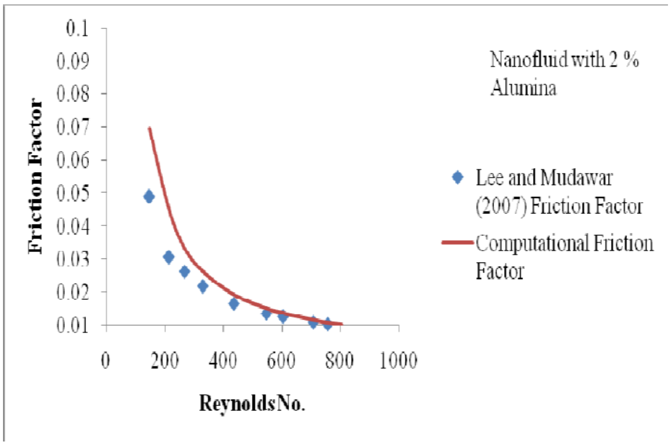
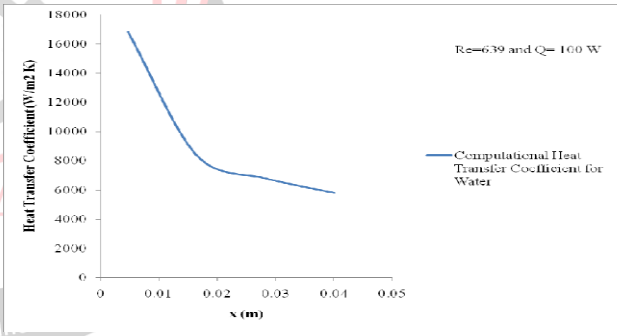


Figure 5.8: Variation of computational and experimental pressure drop and friction factor of 2% Alumina with Re. (a) Pressure drop (b) Friction factor

Variation of heat transfer coefficient on the bottom wall along micro channel at different power inputs for water and its nanofluids (1% and 2% alumina) are shown in Figs respectively. A decreasing trend of the heat coefficient values in the flow direction are observed in all the cases. Higher values of heat transfer coefficient are obtained at entry region of micro channel where as lower values are obtained at the exit region for all fluid properties. transfer coefficient of pure water and its nanofluids and the observation matches with Lee and Mudawar, 2007 observations.



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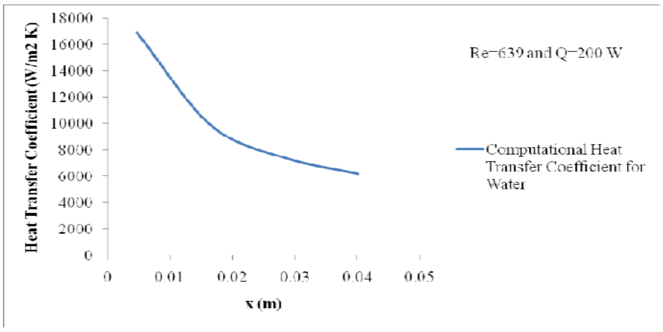

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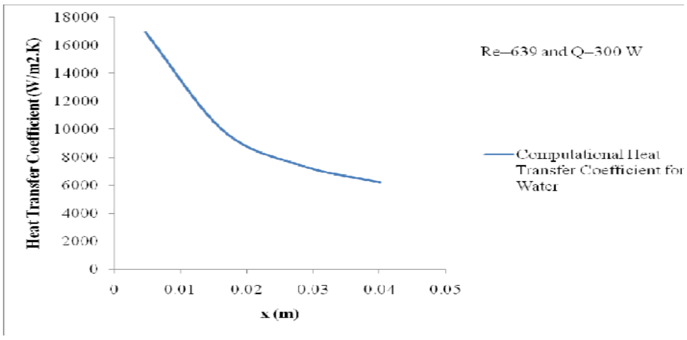

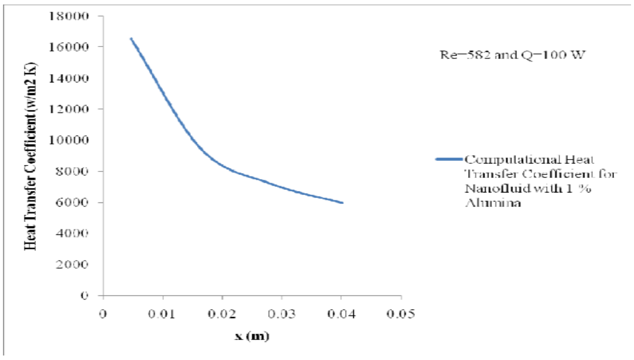

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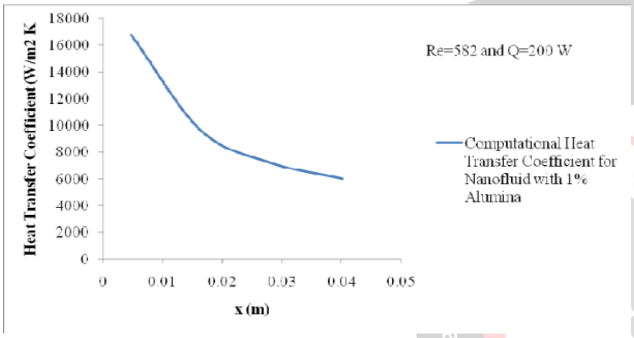

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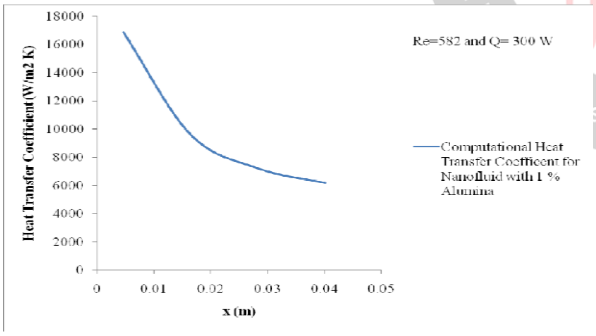
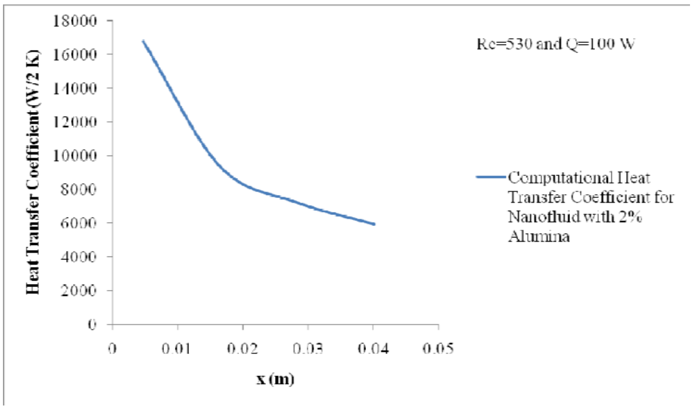


Fig: Variation of Heat Transfer Coefficient forNanofluid with 1% Alumina alongmicro channel at different Power inputs (a) 100 W (b) 200 W (c) 300 W.



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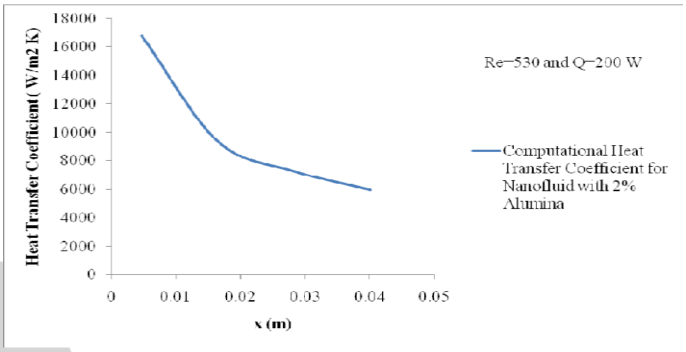

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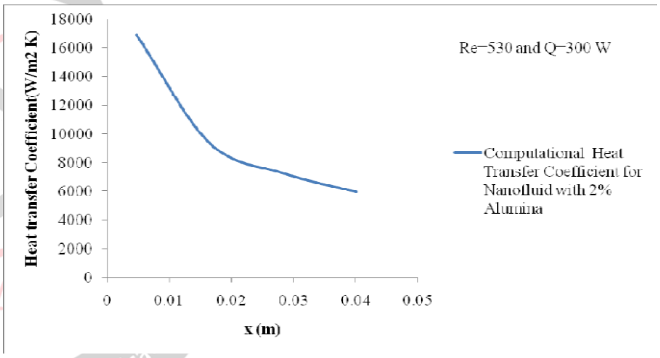

(c)

Fig: Variation of Heat Transfer Coefficient forNanofluid with 2 % Aluminaalong micro channel at different Power inputs (a) 100 W (b) 200 W (c) 300 W

The variation of wall temperature at different power inputs along micro channel are shown in Figs using water and its nano fluids as the coolant. The temperatureis appeared to increase on the wall in the flow direction in all the cases. The rise in temperature from inlet to the outlet of the channel is found directly proportionate to heat input to the channel.

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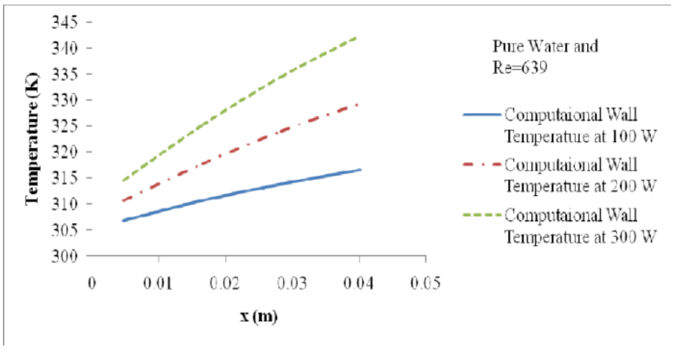

Fig : Variation of wall temperature at different power inputs along micro channelfor Water

IV. CONCLUSIONS

In this work the hydrodynamics and thermal behaviour of circular microchannel and a rectangular microchannel present in a test rig were studied. Pure water and its nanofluids (Al_2O_3) were used as the coolant in the channel. A steady state computational fluid dynamics (CFD) models was simulated by ANSYS Fluent 12.0 here. The effect of Reynolds number and Peclet number on the flow behaviour of the microchannels was found in both cases

Based on the analysis of the circular microchannel behaviour the following conclusions can be drawn

Computed temperatures and heat transfer coefficients were found in closeagreement 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.

1. The change of temperature from inlet to outlet was found increasing withdecreasing Reynolds number.
2. Temperature distribution was found independent of radial position even at very low value of Peclet number.
3. Pressure drop increases with increase in Reynolds number.
4. The entrance length for fully developed flow depends on Nanoparticleconcentrations.
5. Wall temperature has negligible variation for higher Reynolds due to greatervalue of Peclet no in circular micro channel.
6. Based on the analysis rectangular microchannel study, the following conclusions can be made
7. The computational temperature variations, pressure drop and friction factor values can predict the experimental data.
8. As the concentration of nanoparticle increases heat transfer coefficient also increases Greater heat transfer coefficient is obtained at rectangular micro channel entrance. Heat transfer coefficient deceases from entry to exit region in rectangular micro channel whereas it is constant in circular micro channel due to fully developed conditions
9. Wall temperature increases from entry to exit region of rectangular micro channel.
10. Pressure and temperature contours represent successfully the hydrodynamic and thermal behaviour of the system

REFERENCES

[1] Allen, P. W. 2007. Experimental and Numerical Investigation of Fluid Flow and Heat Transfer in Microchannels. Msc Thesis, Mechanical Engineering Department, Louisiana State University.

[2] Al-Nimr, M.A., Maqableh, M., Khadrawi, A.F. and. Ammourah, S.A. 2009. Fully developed thermal behaviors for parallel flow microchannel heat exchanger, International Communications in Heat and Mass Transfer. 36, 385-390.

[3] ANSYS Fluent 12.0 Theory Guide, April, (2009).

[4] Bachok, N., Ishak, A. and Pop, I. 2011. Flow and heat transfer over a rotating porous disk in a nanofluid. Physica B. 406, 1767 – 1772.

[5] Bayraktar, T. and Pidugu, S.B. 2006. Characterization of Liquid Flows in Microfluidic Systems. International Journal of Heat and Mass Transfer. 49, 815-824.

[6] Bahrami, M and Jovanovich, M. M. 2006. Pressure Drop of Fully Developed Laminar Flow in Microchannels of Arbitrary Cross-Section. Journal of Fluids Engineering. 128, 1036-1044.

[7] Bahrami, M., Jovanovich, M. M. and Culham, J.R. 2006. Pressure Drop of Fully Developed, Laminar Flow in Rough Microtubes, Journal of Fluids Engineering, 128, 632-637.

[8] Bianco, V., Chiacchio, F., Manca, O. and Nardini, S. 2009. Numerical investigation of nanofluids forced convection in circular tubes. Applied Thermal Engineering, 29 (17-18), 3632–3642.

[9] Chein, R. and Chuang, J. 2007. Experimental microchannel heat sink performance studies using nanofluids. International Journal of Thermal Sciences. 46, 57-66.

[10] Choi, S.U.S., 1995. Enhancing thermal conductivity of fluids with nanoparticles. In: Proceedings of the 1995 ASME International Mechanical Engineering Congress and Exposition, San Francisco, CA, USA. 66, 99-105.

[11] Das, S.K., Putra, N., Roetzel, W., 2003a. Pool boiling characteristics of nano-fluids. International Journal of Heat and Mass Transfer 46, 851–862.

[12] Das, S.K., Putra, N., Roetzel, W., 2003b. Pool boiling of nano-fluids on horizontal narrow tubes. International Journal of Multiphase Flow 29, 1237–1247.

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

[14] Ding, Y., Chen, H., He, Y., Lapkin, Y., Yeganeh, M., Šiller, L. Butenko, Y. V. 2007. Forced convective heat transfer of nanofluids. Advanced Powder Technol., 18(6), 813– 824.

[15] Eastman, J.A., Choi, S.U.S., Li, S., Thompson, L.J., Lee, S., 1996. Enhanced thermal conductivity through the development of nanofluids. In: 1996 Fall meeting of the Materials Research Society (MRS), Boston, USA.

[16] Eastman, J.A., Choi, S.U.S., Li, S., Yu, W., Thompson, L.J., 2001. Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. Applied Physics Letters 78, 718–720.

[17] Ergu, O. B., Sara, O.N., Yapıcı, S. and Arzutug, S. 2009. Pressure drop and point mass transfer in a rectangular microchannel. International Communications in Heat and Mass Transfer. 36. 618 – 623.

 DOI : 10.35291/2454-9150.2022.0233