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Investigation on thermal effects of Al_2O_3 Nano particles mixed with water in forced convection micro channel using Computational fluid dynamics

David Paul. D, Vijayan. S. N, Navish Kumar

***Abstract**: Micro channels are of current interest for use in compact heat exchangers, micro reactors where very high heat transfer performance is desired. These electronic equipments are virtually synonyms with modern life applications such as appliances, instruments and computers. The dissipation of heat is necessary for the proper functioning of these instruments Micro channels provide very high heat transfer coefficients because of their small hydraulic diameters. Here, an investigation of fluid flow and heat transfer in micro channels is conducted. The computational fluid dynamics (CFD) model equations will be solved to predict the hydrodynamic and thermal behaviour of Micro channel. This study will be aimed at investigation of the forced convection heat transfer and flow characteristics of water-based Al_2O_3nanofluids inside a horizontal circular tube in the laminar flow regime under the constant wall temperature boundary condition. The analysis will be carried out for concentrations 0.05% , and the diameter of nano particle is 40 nm. The simulation will carried out for inlet velocities range from 1.3 -6.5 m/s. analysis will be validated with experimental results provided in the literature as a part of validation. To carry out this study twodimesnional circular duct of will be taken as micro channel. The geometry of the problem and meshing of it will be made in ANSYS ICEM CFD. The models have to be solved by ANSYS Fluent 14.0 solver. The results will be shown that the use of the Al_2O_3nano particles leads to an enhancement in the heat transfer.*

***Keyword**: Nanofluids, Micro Channel, Heat Transfer, Heat Exchanger, CFD.*

I. INTRODUCTION

In the course of the most recent decade, nano innovation has been slowly utilized for the advancement of exceedingly able cooling gadgets called heat sink on account of its incontestable points of interest, for example, less coolant requests and little extents. A standout amongst the most imperative micromachining advancements is miniaturized scale channels. Henceforth, the reconsider of liquid stream and heat move in miniaturized scale channels which are two fundamental parts of such gadgets, have pulled in more considerations with wide applications in both business and medicinal issues. Heat sinks are arranged into single-stage or two-stage as per whether bubbling of liquid happens inside the miniaturized scale channels.

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Essential parameter that settle the single stage and two-stage working administrations are heat flux through the channel divider and coolant stream rate. For a settled measure of heat flux (heat load), the coolant may save its fluid state all through smaller scale channels. With a second rate stream rate, the streaming fluid coolant inside the channel may achieve its breaking point and along these lines stream bubbling happens, which brings about a two-stage heat sink

II. PROBLEM STATEMENT

In recent years various researches were conducted in the field of heat exchangers using different heat transfer medium. Although the rate of heat transfer is not improved while using conventional coolant. To overcome these issues, Al_2O_3 particles are mixed with conventional coolant to improve the rate of heat transfer.

III. METHODOLOGY

Two dimensional model of micro channel was drawn using ANSYS Workbench. In pre processor stage the model is imported and meshed with ICEMCFD and required boundary conditions were given and exported to Ansys Fluent 14.0 for further post processing. Heat flux, fluid outlet temperature and wall temperature were extracted from the results. The same procedure was carried out for Reynolds number ranging from 360 to 2100 (laminar).

Al_2O_3 Nano particle with 0.05% concentration mixed with water was analysed to calculate Nusselt number ratio (Nu/Nu0), Friction factor ratio (f/f0) and Thermal enhancement factor (TEF) for velocities range from 1.3-6.5 m/s. The results were validated with existing experimental results.

IV. DESIGN OF MICRO CHANNEL

Two dimensional view of micro channel is shown in "Fig. 1,". with dimensions and the meshed view of micro channel is shown in "Fig. 2,".

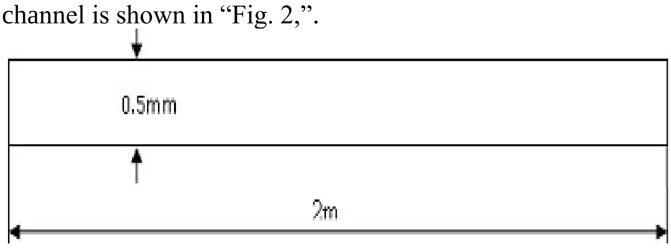

Fig. 1, Two dimensional view of micro channel

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Fig. 2, Meshed view of Micro channel

V. ASSUMPTIONS AND BOUNDARY CONDITIONS

The necessary assumptions were taken for completing the process. Flow of nano fluid with water is considered as steady state and laminar and the same time properties of fluid are taken at bulk mean temperature with pressure based solver. Convergence criteria has been assumed as $1e^{-6}$ and inlet duct wall is considered as adiabatic. The following boundary conditions were given

a) At Inlet uniform velocity has been used
b) Outlet has been considered as pressure outlet
c) Wall Temperature of Micro channel is 293.15
d) Uniform inlet Temperature of fluid is 373.15 K

VI. FLUID PROPERTIES

The Al2O3 Nano particles of 0.05% by volume is mixed with distilled water. The properties of Distilled water mixed with Al2O3 Nano particles are evaluated at various temperatures such as 200C, 400C and 600C respectively. For carrying out the analysis and estimating the Nusselt number, thermal properties have been evaluated at bulk mean temperature. The properties of Nano particles mixed with distilled water is shown in "Table. 1,".

Table 1; Properties of Nano Particles Mixed With Distilled Water

Density of Distilled water (ρ (kg/m^3))	Specific Heat (Cp(J/kg.K))	Density For 0.05 % Concentration of Al_2O_3	Specific Heat for 0.05 % Concentration of Al_2O_3	Temperature (°C)
998.3	4182	999.75	4175.56	20
992.3	4179	993.75	4172.53	40
983.1	4186	984.56	4179.45	60

VII. GOVERNING EQUATIONS

Continuity equation,

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \quad \text{.......... (1)}$$

Momentum equation,

$$\frac{\partial}{\partial x_i}(\rho u_i u_k) = -\frac{\partial P}{\partial x_k} + \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial u_k}{\partial x_i}\right)\right] \quad \text{.......... (2)}$$

Energy equation,

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial T}{\partial x_j}\right) \quad \text{..........(3)}$$

In the present study, the parameters considered are, Reynold's number (Re), Nusselt number (Nu), friction factor (f) and thermal enhancement factor (TEF). They are expressed as follows,

Reynold's number,

$$Re = \frac{\rho U_c D_h}{\mu} \quad \text{........... (4)}$$

Friction factor,

$$f = \frac{(2\Delta p)}{\rho U_c^2}\left(\frac{D_h}{L}\right) \quad \text{......... (5)}$$

Nusselt number,

$$Nu = \frac{hD_h}{k} \quad \text{.......... (6)}$$

Thermal enhancement factor,

$$TEF = \frac{Nu/Nu}{(f/f)^{1/3}} \quad \text{............ (7)}$$

Where, U_c is the mean velocity within the minimum flow cross section in the flow channel, μ is the viscosity, k is the thermal conductivity, D_h is the hydraulic diameter, Δ_p is the pressure drop in the computation domain. The equations from used for analyse the problems in CFD. The equations from to calculate Reynold's number, Friction factor, Nusselt number, Thermal enhancement factor.

VII. RESULTS AND DISCUSSIONS

A. For Reynolds Number 360

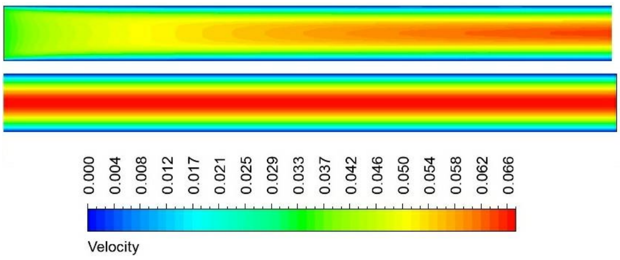

Fig. 3, Velocity contours in entry and exit part of channel

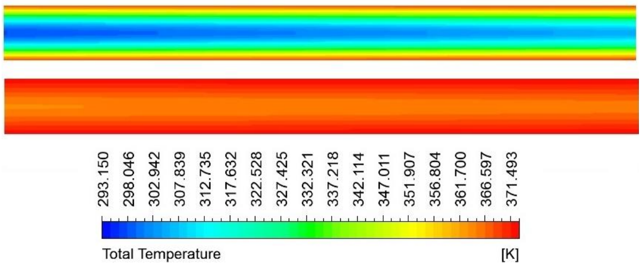

Fig. 4, Total Temperature contours in entry and exit part of channel

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At the inlet, uniform velocity has been defined which is shown in "Fig. 3," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.066 m/s and least velocity is 0 m/s at wall."Fig. 4," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

B. For Reynolds Number 400

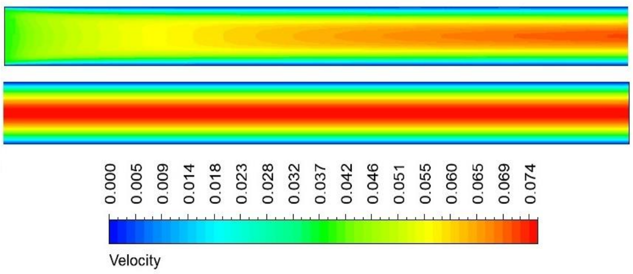

Fig. 5, Velocity contours in entry and exit part of channel

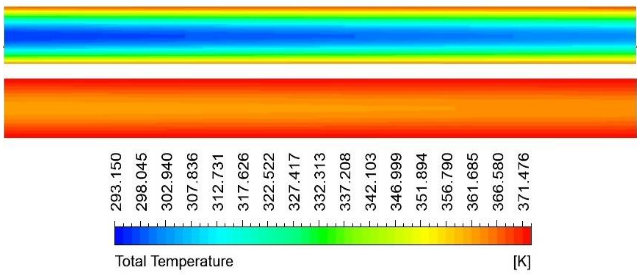

Fig. 6, Total Temperature contours in entry and exit part of channel

At the entry, uniform velocity has been defined as shown in "Fig. 5," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.074 m/s and least velocity is 0 m/s at wall.

"Fig. 6," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

C. For Reynolds Number 500

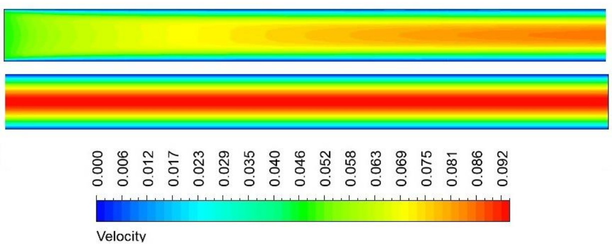

Fig. 7, Velocity contours in entry and exit part of channel

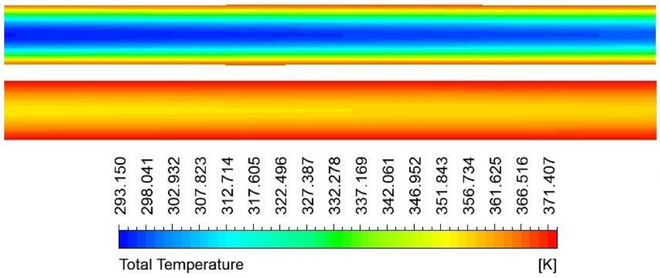

Fig. 8, Total Temperature contours in entry and exit part of channel

At the inlet, uniform velocity has been defined as shown in "Fig. 7," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.092 m/s and least velocity is 0 m/s at wall. "Fig. 8," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

D. For Reynolds Number 700

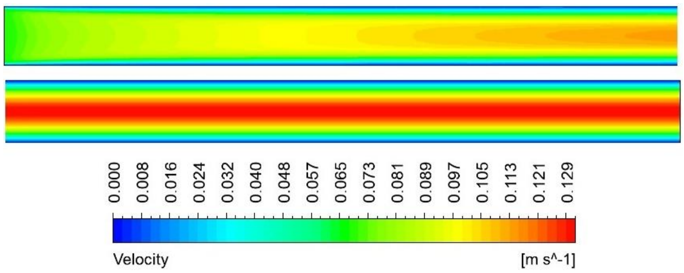

Fig. 9, Velocity contours in entry and exit part of channel

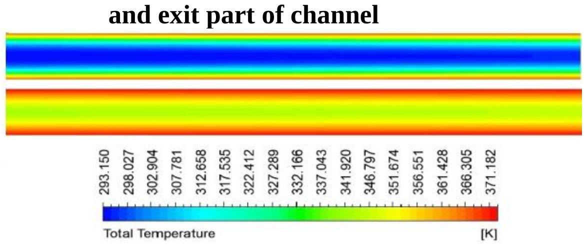

Fig. 10, Total Temperature contours in entry and exit part of channel

At the entry, uniform velocity has been defined as shown in "Fig. 9," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.129 m/s and least velocity is 0 m/s at wall. "Fig. 10," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

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E. For Reynolds Number 1000

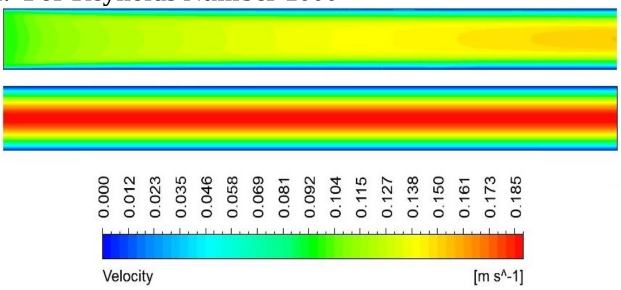

Fig. 11, Velocity contours in entry and exit part of channel

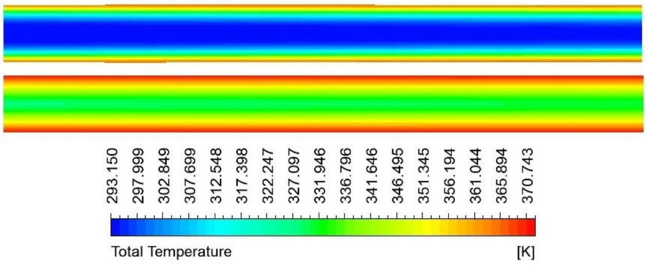

Fig. 12, Total Temperature contours in entry and exit part of channel

At the entry, uniform velocity has been defined as shown in "Fig. 11," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.185 m/s and least velocity is 0 m/s at wall. "Fig. 12," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

F. For Reynolds Number 1200

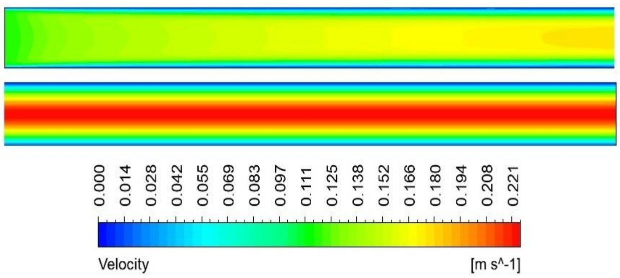

Fig. 13, Velocity contours in entry and exit part of channel

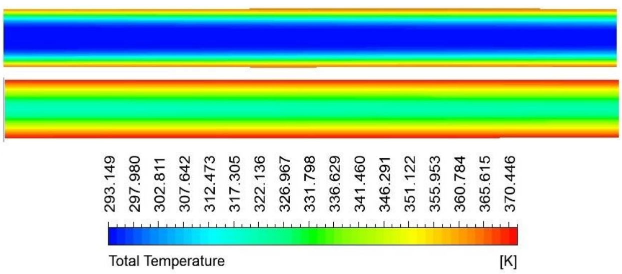

Fig. 14, Total Temperature contours in entry and exit part of channel

At the entry, uniform velocity has been defined as shown in "Fig. 13," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.221m/s and least velocity is 0 m/s at wall. "Fig. 14," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

G. For Reynolds Number 1500

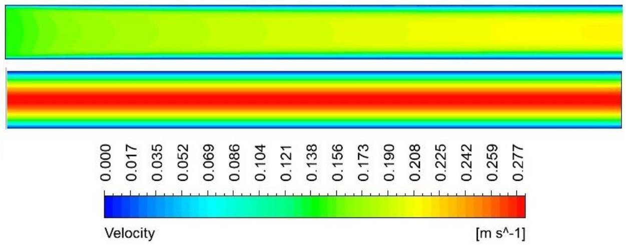

Fig. 15, Velocity contours in entry and exit part of channel

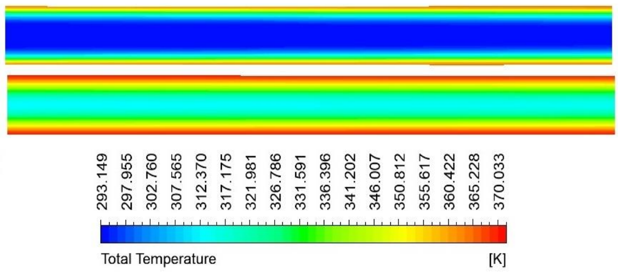

Fig. 16, Total Temperature contours in entry and exit part of channel

At the entry, uniform velocity has been defined as shown in "Fig. 15," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.277m/s and least velocity is 0 m/s at wall. "Fig. 16," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

H. For Reynolds Number 1800

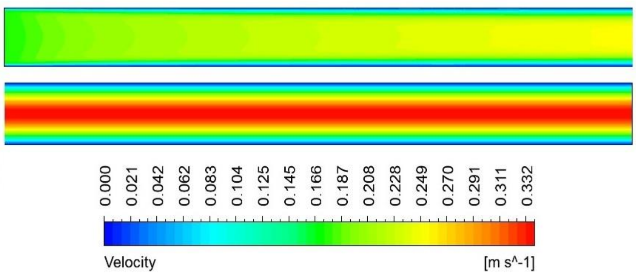

Fig. 17, Velocity contours in entry and exit part of channel

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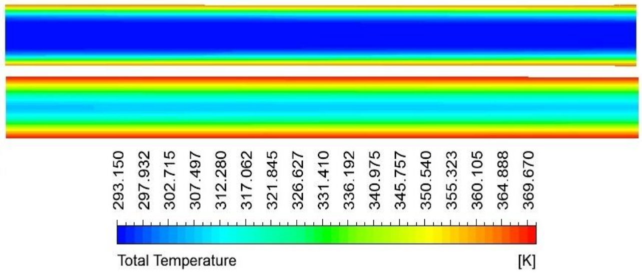

Fig. 18, Total Temperature contours in entry and exit part of channel

At the entry, uniform velocity has been defined as shown in "Fig. 17," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.332 m/s and least velocity is 0 m/s at wall. "Fig. 18," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

I. For Reynolds Number 2100

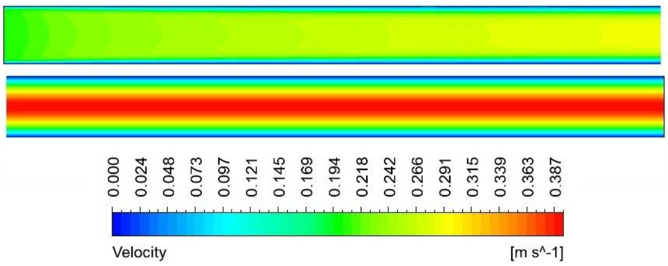

Fig. 19, Velocity contours in entry and exit part of channel

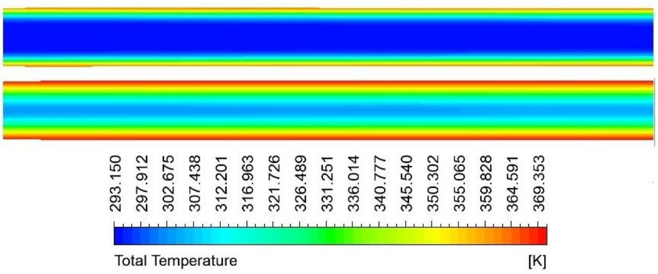

Fig. 20, Total Temperature contours in entry and exit part of channel

At the entry, uniform velocity has been defined as shown in "Fig. 19," the inlet region to make the flow fully developed before entering in to the channel. Thereafter, velocity profile is remains same as shown in the outlet region. In the inlet region, velocity flow is increasing continuously at central core due to formation of boundary layer. Maximum Velocity is 0.387 m/s and least velocity is 0 m/s at wall. "Fig. 20," interprets the variations of total heat all along the micro channel. As wall temperature of 373.15 k is applied on micro channel wall, total temperature of the central core is increasing continuously from inlet to outlet micro channel. Same thing can be observed in the inlet and outlet region of micro channel.

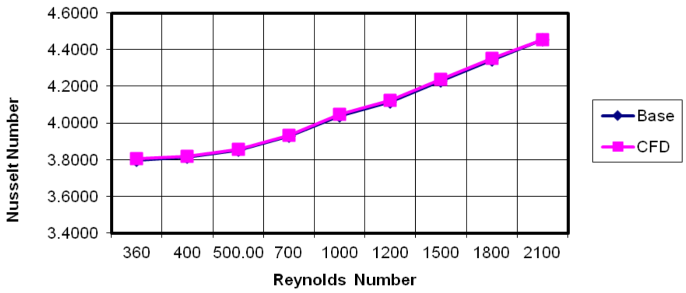

Fig. 21, Comparison and Validation of Nusselt number with base line

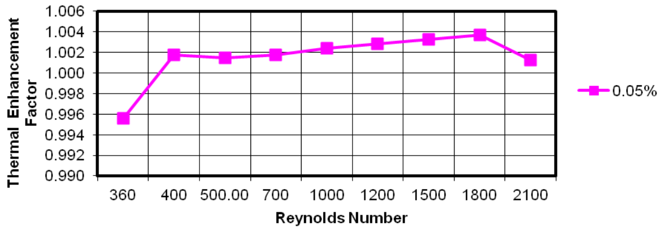

Fig. 22, Variation of TEF with for Reynolds Number

Numerical analysis has been carried out for 0.05% of aluminium oxide particles mixed with pure water. The above "Fig. 21," interprets that slightly increases in Nusselt number compared with base line at each for Reynolds number and with increase in for Reynolds number causes to increase in Nusselt number as for Reynolds number directly proportional to Nusselt Number. First one is due to addition of Al2O3 Nano particles caused for increase in thermal properties like thermal conductivity and Dynamic viscosity.

The "Fig. 22," interprets that TEF increases with for Reynolds number and it is more than one except at for Reynolds number 360. TEF more than one means better heat transfer taking place with minimal pressure drop due to addition of 0.05% Al_2O_3 particles. Thermal Enhancement factor (TEF) = $(Nu/Nu0)/(f/f0)^{(1/3)}$

VIII. CONCLUSION

Nusselt number increases with increases in concentration for any particular Reynolds number. This is due to change in thermal properties of fluid as by adding Nano particles, it changes the properties of fluid medium. The thermal enhancement factor increases with concentration aluminium oxide Nano particles. Thermal enhancement factor (TEF) is parameter which decides heat transfer performance of configuration when heat transfer augmentation is carried out either active or passive augmentation. As it is ratio of Nusselt number ratio and cube root of friction factor ratio, Nusselt number ratio is more compared to cube root of friction factor ratio with increases in concentration of aluminium oxide Nano particles at each Reynolds number.

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