Design and Analysis of Micro Heat Exchanger

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Abstract

Advancement in electronics technology makes humans life better but also creates new challenges for controlling their performance. Nowadays, devices are getting smaller to provide human portability without compromising on performance. Thermal management of electronics is a major challenge as it strongly affects the performance of electronic devices.

In this work, the nano fluid is a mixture particles and water, and its thermo physical properties are function of temperature and particle concentration. The particles which used are alumina and zirconia. To find optimum bend different bend angles from 20° to 90° are studied while considering pressure drop and Nusselt number. Different cross-section of channel between 25μm to 250μm range is simulated with 320K, 325K and 365K base temperature. Performance parameters including Nusselt number (Nu), pressure drop and base temperature is selected for single-channel configuration.

Present results indicate that nano particle effects enhance the heat transfer performance and also increased pressure drop. To enhance heat transfer different particle concentration studied. TPF (thermal performance factor) is greater than 1 means more heat transfer and less pressure drop. Zircona-water is better performance than alumina-water.

The present study calculated Nusselt number (Nu) and pressure drop for bend and straight channel. Furthermore, dean vortices effect on pressure drop and heat transfer is studied. Due to dean vortices heat transfer increases. Bend channel is better performance than single channel due to vortices.

Table of Contents

List of Figures

List of Tables

1 INTRODUCTION

Heat exchangers are mainly used to transfer heat between one or more fluids. Heat exchangers which have typically dimension below 1mm are called micro heat exchangers. Heating problem reduce durability of electronic devices, it's a crucial problem to be eliminated by solution. It can be used from phones to industrial components. Micro channels have less material, mobility and better performance. Share same principles as conventional heat exchanger. Due to small channels provides intimate contact. It consists of confined spaces and small channels have higher surface area to volume ratio and thermal resistance is reduced.

1.1 Micro-channels

Tucker and Pease [1] used micro—channel for first time in 1981 for removal of heat with title "High Performance Heat Sinking for VLSI" which is considered as pioneer work. Mehendale [2] classified micro- channels in betwee dimension of 1µm to 100µm. Classification adopted by Kandlikar and Grande [3] involves a channel dimension is between 10 µm to 200µm. Obot [4] provided a classification of micro-channel based on hydraulic diameter. Obot says that channel hydraulic diameter less than 1mm which adopted by Bahrami et al [5], Pindugu [6] and Jovanovich [7].

Micro-channel heat sink is used in industries like automobiles, air conditioning, and refrigeration. High thermal conductivity of material of heat sink like silicon and copper. To eliminating heat from straight parallel channel, gas or liquid used coolant flow. Coefficient of heat transfer is proportional to Reynolds number or velocity flow is usually laminar. Advantages of micro heat exchanger includes less coolant required, high surface to volume ratio, compact size, low material cost, contact between fluid and heater is more and better performance than conventional. Equation 1.1 shows convective heat transfer.

$$h = Nu\,(k/\mathrm{d}) \qquad 1.1$$

Heat transfer coefficient and nusselt number increases when hydraulic diameter decrease, results in increase convective heat transfer. Micro-channel suitable for microprocessor, laser diode arrays, high energy laser mirrors and radars.

1.2 Structure of Micro-channel

Micro-channels can be rectangular, square and circular. Channel can be straight bend at 90 degree. Micro-channels have inlet from side or top of the channel. Fluid enters into manifold, which can be different shapes like circular, rectangular, or triangular. Bends in macro-channels like pipe have been used for many years but in micro-channels bends are implemented for harnessing effect of secondary vortices mainly for cell focusing purposes in biomedical field. Dean vortices in micro-channel result in increase in nusselt number. Due to vortices pressure drop also increase. For acceleration of fluid, energy is needed when bend is initiated. Variation in bend angle varies the phenomena at bend.

2 SCOPE OF WORK

Micro-processor heating problem is a serious issue in computation and portable desktops which decreases performance. Air cooled micro-channel have less dissipation than water cooled. Straight micro-channels are extensively studied in literature but limited work is done on modification of geometry to increase convective heat transfer. The present work involves the bend of channel and used nano-fluids to increase performance of micro heat exchanger.

The present work studies the following aspect:

1. Introduction of bend in micro-channel to investigated heat transfer and flow behavior.
2. Validation of model with analytical and experimental data available in literature.
3. Reynolds number effect on heat transfer and pressure drop in bend micro-channel.
4. High base temperature on heat transfer and pressure drop.
5. Cross-section width and height effect on micro-channel performance.
6. Introduction of nano-fluids to investigate performance of micro-channel.
7. Effect of nano-fluids on heat transfer and pressure drop in micro-channel.

3 LITERATURE REVIEW

The Idea of micro heat exchanger was developed by Tuckerman and Pease [1] in 1981 first developed the idea of micro heat exchanger that high aspect ratio and confined flow of liquid increased heat dissipation. Compared to micrometer or millimeter solid particle suspensions, nano-fluids almost free from problems of clogging, sedimentation, erosion and abrasion [8]. Qu et al[9] performed experimental and numerical investigation on single-phase laminar flow considering pressure drop and heat transfer as investigation parameters by selecting 231µm by 713µm channel. 100 W/cm2 and 200 W/cm2 heat flux were defined at bottom of the channel. Experimental and numerical results were in good agreement. An important thing of nano-fluids is to increase conductivity of fluid, which attributed to parameters volume fraction [10-17], shape [10- 15], size [13 and 17] and temperature [10, 11, 14], and type of particle material [11-13] and stability [15] of the nano-fluid.

Experimental indicate that nan0-fluids convective heat coefficients are higher than base fluids [10-15]. Meshan et al [18] experimental study heat transfer and flow characteristics and conclude through heat transfer and pressure drop results that conventional theory of flow is applicable to flow in micro-channel and entrance length effect. Williams et al. [19] experiments on zirconia (ZrO_2) and alumina (Al_2O_3) inside tube. They showed pressure-drop and heat transfer of nano-fluids with correlations of a single-phase flow. Ulzie Rea [20] studied viscous pressure loss and laminar convective heat transfer of zirconia–water and alumina-water nano-fluids in micro-channel considering laminar flow. He found that, for given channel geometry, and velocity 6 % volume alumina nano-fluid heat coefficient up to 26% more than water at entrance region, zirconia nano-fluid heat coefficient have lower increase than water. Lee at al [21] experimentally studied effect of water-based nano-fluids with a small concentration of AL_2O_3 on heat transfer performance and observed that for laminar flow nano-particles improves heat transfer coefficient. At the entrance region of micro-channel, more heat transfer coefficient was achieved. However, for a fully developed region case, the enhancement was weak.

Heat transfer characteristics for copper-water based nano-fluids through tube are conducted by Xuan and Li. Results showed that nano-fluids increase heat transfer than water. [22]. Ding and wen [23] studied laminar convective heat and resulted increased at entry region. He et al. [24] studied the titania nano-fluids in turbulent and laminar flow, and resulted increased heat transfer with decreasing size and concentration of particles. The thermo physical properties of nano-particles (viscosity, density, specific heat, and thermal conductivity) are function of particle concentration and temperature [25].

Hansel [26] performed experimental and numerical study on 90o and 45o bench micro- channels for monitoring flow and heat transfer phenomena in single-phase laminar flow case. He developed relation for predicting friction factor after studying experimental and simulation data. A detailed study by Peterson [27] on high density electronic devices concluded that heat sink performs best when device junction and heat sink are properly in contact. Shah [28] developed analytical equation for predicting friction factor of rectangular cross-section micro-channels by utilizing aspect ratio and Poiseuille number relation.

Qu et al [29] numerically investigated heat transfer and flow characteristics in rectangular micro-channels considering 3D fluid with thermally and hydrodynamic developing flow along the channel. It was found that length of developing flow region was influenced by Reynolds number. Furthermore, temperature rise along flow direction in fluid and solids can be approximated linearly. Fedorov et al [30] investigated a 3D model for conjugate heat transfer and concluded that thermo-physical properties are temperature dependent after finding average wall temperature uniformity along the flow in channel wall, however, non-uniform at the inlet. Jiang et al [31] made numerical comparison between micro-heat exchanger and micro heat exchanger with porous media concluding that convective heat transfer performance of micro-heat exchanger was less than micro-heat exchanger with porous media but pressure drop was larger in latter.

Tuckerman [32] performed numerical analysis on efficient cooling system for dissipating 1000 w/cm2 heat while maintaining structure temperature in limit of transistor operation. While considering scaling effects, axial wall conduction is also an important problem which contributes to decreasing thermal efficiency of micro-channel heat exchanger. Experimentation and numerical simulation by scientists proved that by increasing thermal conductivity of micro heat exchanger axial wall conduction is increased which lowers thermal efficiency. Low thermal conductivity materials were concluded efficient for heat exchanger and resisting to axial wall conduction [33, 34].

4 METHODOLOGY

4.1 Simulation Methodology

4.1.1 Geometry

4.1.1.1 Single channel

To solve heat transfer problem numerical solution adopted. Fluid through channel have convective heat transfer and through copper conduction heat transfer. Geometry is designed in Solid Works with fix length can be seen in Figure 4.1. To investigate change in pressure drop and Nusselt number a bend is introduced in straight channel. Width and height combination with fix length and angle as shown in Table 1 is employed. Angle is selected at different angle from 10° to 90° while keeping width, height, and length of channel same.

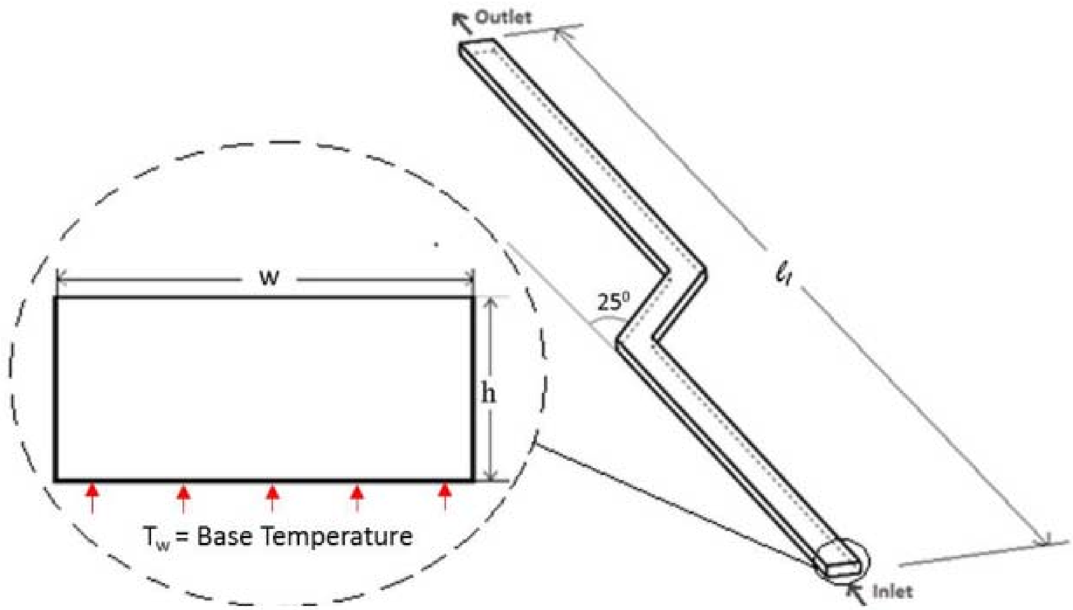


Fig. 1: Single channel geometric parameters.

Symbol	Dimension (mm)
l_1	18
l_3	2
w	0.2
h	0.2

Table 4.1: Single-channel model corresponding parameters.

4.1.2 Meshing

Meshing is done in ANSYS 18.1 build-in mesh generator module. Structured mesh is developed for single channel model consisting of hexahedron as shown in Figure 4.2. Mesh quality parameters are studied for single channel. Mesh orthogonality, aspect ratio and skewness are the quality parameters for single channel as shown in table 4.2.

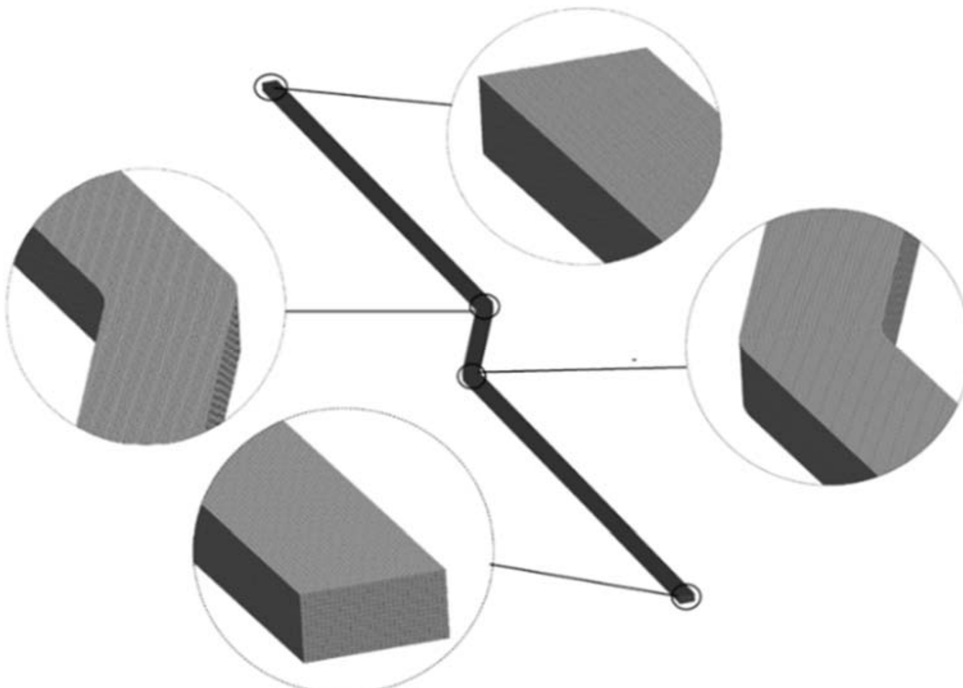


Figure 4.2: Single channel mesh

Parameter	Average value
Mesh Orthogonality	0.9862
Skewness	0.0985
Aspect Ratio	1.1628

Table 4.2: single channel mesh parameters

4.1.3 Physical Model

Viscous laminar model is used with SIMPLE scheme for solving pressure-velocity coupling using second order upwind discretization. Governing equations is set to 10-5. converging criteria.

4.1.4 Simulation Matrix

An optimum bend will have to be selected. A test matric for bend selection is developed as shown in Table 4.3.

Table 4.3: Bend Selection Simulation Matrix.

Sr. no	Height (µm)	Width (µm)	Temperature (K)	Angle (°C)
1	25	250	320	20
2	25	250	320	30
3	25	250	320	50
4	25	250	320	60
5	25	250	320	70
6	25	250	320	90

Different input parameters are studied on flow performance and heat transfer characteristic of micro-channel shown in Table 4.4.

Table 4.4: Single Channel Simulation Matrix.

Group	Height Range (µm)	Width Range (µm)	Temperature (K)
1	25-250	25-250	320
2	25-250	25-250	325
3	25-250	25-250	365

Design point technique involves selection of optimum design point for a model by plotting Nusselt number (Nu) and friction factor graph with respect to Reynolds number (Re). Design point matrix case shown in Table 4.5.

Table 4.5: Design Point Test Matrix

Sr. no	Height (μm)	Width (μm)	Temperature (K)	Cases
1	25	25	320,325,365	3
2	100	25	320,325,365	3
3	200	25	320,325,365	3
4	250	25	320,325,365	3
5	25	100	320,325,365	3
6	100	100	320,325,365	3
7	200	100	320,325,365	3
8	250	100	320,325,365	3
9	25	200	320,325,365	3
10	100	200	320,325,365	3
11	200	200	320,325,365	3
12	250	200	320,325,365	3
13	25	250	320,325,365	3
14	100	250	320,325,365	3
15	200	250	320,325,365	3
16	250	250	320,325,365	3

4.1.5 Material Properties

Fluid properties are available in NIST database. Material database from NIST is utilized for temperature dependent properties of de-ionized water. De-ionized water is used a working fluid with temperature varying properties like specific heat (Cp), viscosity (μ) and thermal conductivity (k). Copper with constant properties is selected for solid part because of high thermal conductivity. Following properties are defined in ANSYS Fluent.

Table 4.6: Fluid and Solid Properties

Symbol	De-ionized water	Copper
μ (Pa.s)	$0.0194 - 1.065\times10^{-4}\,T + 1.489\times10^{-7}\,T^2$	--
k (W/m.k)	$-0.829 + 0.0079T - 1.04\times10^{-5}\,T^2$	387.6
Cp (J/kg.k)	$5348 - 7.42T + 1.17\times10^{-2}\,T^2$	381
$\boldsymbol{\rho}$ (kg/m3)	998.2	8978

4.1.6 Methodology

ANSYS Fluent 8.1 is used for numerical computation of micro- heat exchanger models. Copper using as micro heat exchanger material and de-Ionized water as working fluid. Convergence criteria is set to 0.0001 for accurate results.

Assumptions

- 3D incompressible fluid with steady state formulation.
- Temperature dependent fluid (nano-fluid)) properties and constant solid (Copper) properties are used.
- Flow is assumed to be developed.
- Viscous dissipation and radiation is neglected.

4.1.7 Nano-fluid properties

To increase heat transfer nano-fluids are used. Nano-fluids are the mixture of water and particles. Equations are developed for nano-fluids.

	Deionized-water
μ(Pa s)	$0.0194 - 1.065 \times 10^{-4}T + 1.489 \times 10^{-7}T^2$
k(W/m K)	$-0.829 + 0.0079T - 1.04 \times 10^{-5}T^2$
c_p(J/kg K)	$5348 - 7.42T + 1.17 \times 10^{-2}T^2$
ρ(kg/m^3)	998.2

These are the fluid properties. μ is viscosity, k is thermal conductivity, Cp is specific heat of fluid.

Alumina–water nanofluid

$$k(\phi, T) = k_f(T)(1 + 4.5503\phi)$$

$$\mu(\phi, T) = \mu_f(T)\exp[4.91\phi/(0.2092 - \phi)]$$

Zirconia–water nanofluid

$$k(\phi, T) = k_f(T)(1 + 2.4505\phi - 29.867\phi^2)$$

$$\mu(\phi, T) = \mu_f(T)(1 + 46.801\phi + 550.82\phi^2)$$

These are nano-fluid properties with temperature dependent. K is thermal conductivity; μ is viscosity of nano-fluid. Both are temperature dependent. Φ is concentration of particles in water. Value of fluid thermal conductivity and viscosity put in nano-fluid equation to find thermal conductivity and viscosity of nano-fluid. In this work alumina-water and zirconia-water nano-fluids are used. These equations can be used from 20°C to 70°C temperature. In present work base temperature used 325K at base wall.

$$\rho = \phi\rho_p + (1-\phi)\rho_f$$

C (Alumina) = 880 J/kg K

C (Zirconia) = 418 J/kg K

ρ_p (Alumina) = 3920 kg/m^3

ρ_p (Zirconia) = 5600kg/m^3

$$c = \frac{\phi\rho_p c_p + (1-\phi)\rho_f c_f}{\rho}$$

These equations are given to find density and specific heat of nano-fluid. Values of density and specific heat of fluid and particles put in equations to find nano-fluid density and specific heat.

4.1.8 Boundary Condition

Velocity and temperature boundary condition is defined at inlet. Velocity is depending upon Reynolds number from 100 to 900 and fluid temperature is fixed at 298.15. Pressure boundary condition is defined at outlet. Base temperature is 325K. Side and top of channel is considered as adiabatic.

- Inlet
- Velocity (According to Reynolds Number)
- Outlet
- Pressure
- Schemes
- SIMPLE (Pressure-Velocity Coupling)
- Second Order (Pressure)
- Second Order Upwind (Momentum)
- Second Order Upwind (Energy)

4.1.9 Parametric Relations

Pressure drop, Nusselt number (Nu) and Friction factor are output parameters. Pressure drop can be obtained directly. Friction factor and Nusselt number are obtained by relations from literature.

$$Re=\rho_f D_H V_{in}/\mu_f \quad 4.1$$

Reynolds number (Re) which depends upon dynamic viscosity (μf), liquids density (ρf), hydraulic diameter (DH), and inlet velocity (vin) of channel.

Where

$$D_H = 2wh/(w+h) \quad 4.2$$

Nusselt number (Nu) can be calculated by

$$Nu = (D_H/k_f)\ln((T_{wall} - T_i)/(T_{wall} - T_o))(\dot{m}C_p/A_{ht}) \quad 4.3$$

Where, Cp is specific heat of fluid, kf is thermal conductivity of fluid. Both calculated at mean temperature. Twall is base wall temperature, Ti is fluid inlet temperature, $\dot{m}$ is mass flow rate of fluid, To fluid outlet temperature and Aht is area of base at which temperature is applied. Mean temperature can be calculated by equation. Nusselt number can be calculated from ansys fluent post processing using outlet temperature Tout.

$$T_m = (T_i + T_o)/2 \quad 4.4$$

The friction factor and pumping power can be calculated by relations

$$f = (DH/L)(2\Delta P/\rho_f v^2_{in}) \quad 4.5$$

Friction factor for TPF (thermal performance factor) calculation is found using pressure drop value from ansys fluent post processing

$$Ppower = \Delta P\dot{V} \quad 4.6$$

Where, ΔP is pressure difference and V is volume flow rate of fluid calculated by subtracting pressure of outlet going fluid from inlet coming fluid or in this case can be directly find out through fluent or analytical equation.

4.1.10 Grid Independence

To predict a stage where variation in results stabilizes grid independence is done. It is done at (200 by 200) channel. The value of pressure can be seen from Figure 4.3 which becomes stable at 10.5 million mesh element.

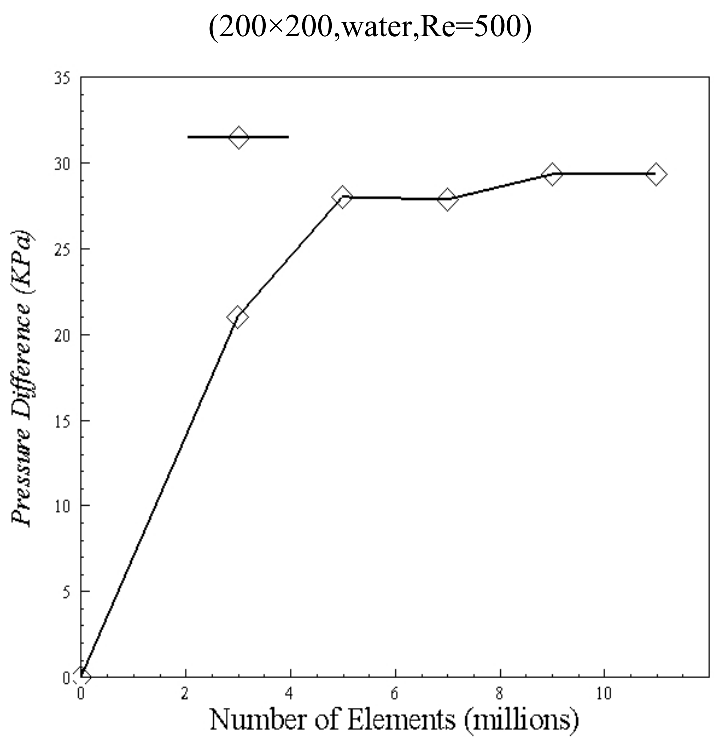
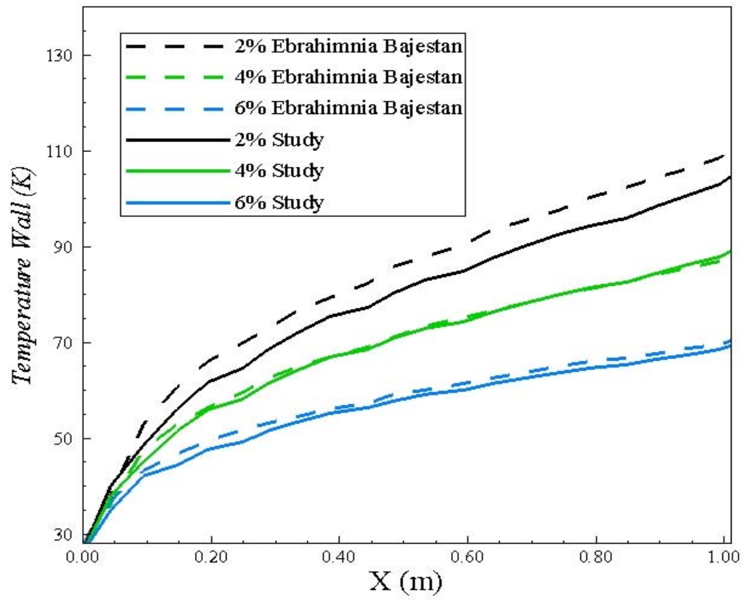


Figure .4.3. Grid indepence

4.1.11 Validation

Data is validated with analytical solution from literature. Validation is done with 2%, 4% and 6% concentration of particles with analytical solution relation. Figure 4.4 shows validation having an error of 2.5% with analytical solution.

Figure 4.4. Re=883, Hydraulic diameter (D_H)=4.5mm, Length (L)=1.01m



4.1.12 Design Matrix

Square channel (200 width and 200 height) is selected because square channel performed best in dissipating heat from inlet to outlet and high contact area with base heater. Angle is selected from design points. Optimum angle 25°C is selected while considering performance parameters. Due to angle comparison with straight channel of same length is made 5.5% increase in Nusselt number while increase in pressure drop is 3.2%. Table 4.5 and 4.8 shows design matrix of straight and bend channel.

Table .4.7. Straight channel

	Hydraulic Diameter (µm)	Reynolds Number (Re)	Nano-Particle	Vol %	Cases
1	200	100-900	Zirconia	0	4
2	200	100-900	Alumina	0	4
3	200	100-900	Zirconia	1	4
4	200	100-900	Alumina	1	4
5	200	100-900	Zirconia	3	4
6	200	100-900	Alumina	3	4

Table 4.8. Bend channel

Sr No.	Hydraulic Diameter (µm)	Reynolds Number (Re)	Nano-Particle	Vol %	Cases
1	200	100-900	Zirconia	0	4
2	200	100-900	Alumina	0	4
3	200	100-900	Zirconia	1	4
4	200	100-900	Alumina	1	4
5	200	100-900	Zirconia	3	4
6	200	100-900	Alumina	3	4

5 RESULTS AND DISCUSSION

5.1 Channel configuration

To find optimum aspect ratio, at different width and height of micro-channel studied. Nusselt number and friction factor are output parameters. When width is varied and height between (25µm to 100µm) friction factor increases slightly. When height is varied and width between (25µm to 100µm) high friction factor encountered. By varying height and width between (25µm to 100µm) gives minimum nusselt number value. However, above 140 micron width and height can be encountered maximum nusselt number due to sufficient contacting area between fluid and heater.

At high temperature low nusselt number and increase in friction factor is seen. At high temperature conductive heat transfer increased and convective heat transfer is reduced. Varying height and width near 25µm results in high pressure drop while, varying width and height near 25µm results in less pressure drop because contact area increase with heater with increase in width.

Rectangular channel (250micron width and 200 micron height) is unable to sufficient dissipating heat due to less base contact area of fluid with heater. Square channel (200micron width and 200micron height) is able to sufficient dissipating heat due to high contact area of fluid with heater. Square channel performed better than rectangular channel due to high base contact area.

Bend channel performed better than straight due to bend dean vortices are produced. Vortices help in diffusion of heat and increase convective hear transfer. Due to more vortices dispersion in square channel more heat diffusion is possible. Fluid movement in channel causes heat to diffuse passing through the bend. Bend is suitable application because heat is diffuses from center to outwards in chips to be cooled this cooling effect.

5.2 Thermal Performance Factor

TPF (thermal performance factor) is the ratio of nusselt number (bend channel to straight) and friction factor (bend channel to straight). TPF shows the performance of bend channel. If TPF value is greater than 1 show bend channel performed better than straight channel. If value is less than 1 it shows straight channel performance is better than bend channel. TPF greater than 1 shows dominance of Nusselt number (Nu).Figure 5.1 shows TPF value according to Reynolds number (Re). Figure shows TPF bend channel (no nano fluids) with straight channel (no nano fluids).

Figure.5.1. TPF bend with straight channel (no nano fluids)

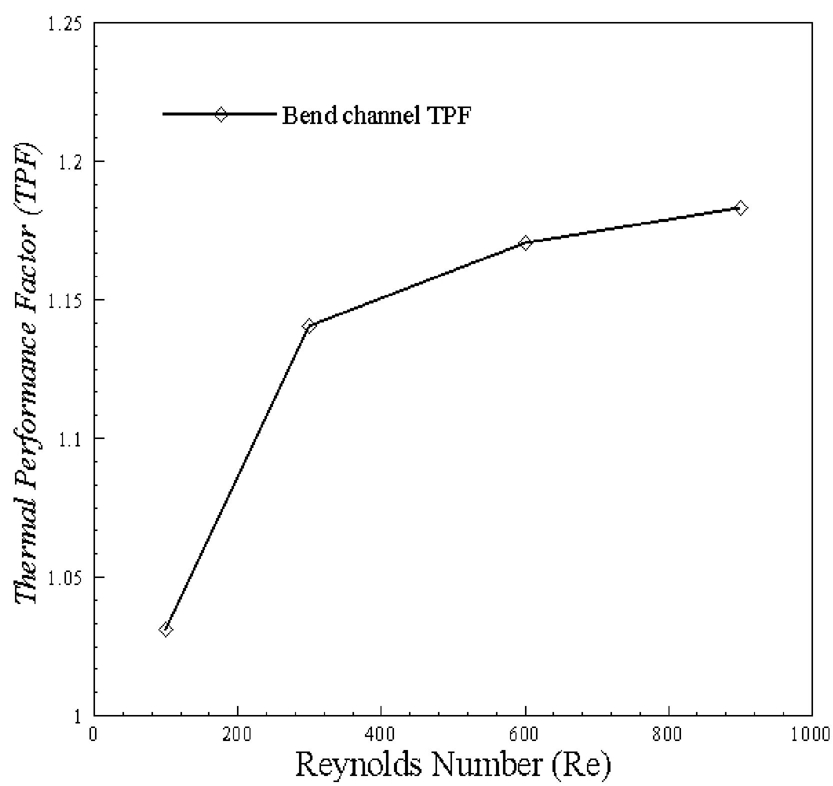
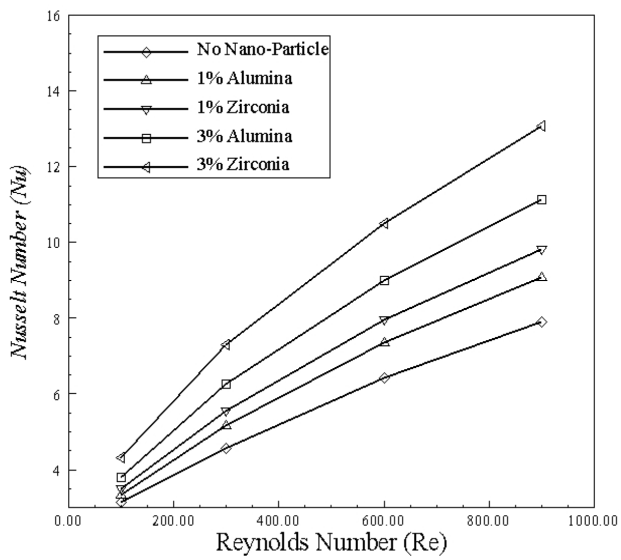


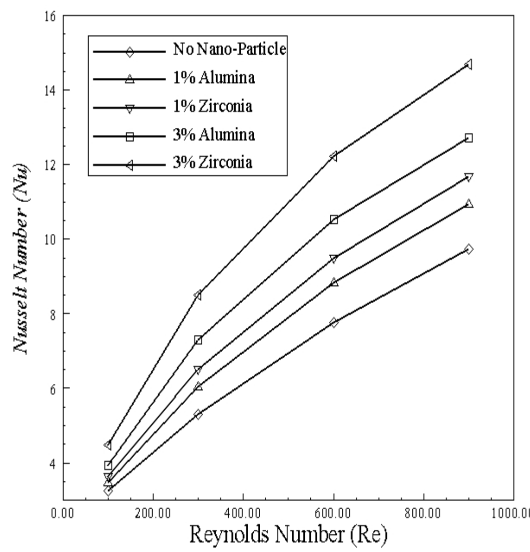
Figure .5.1. shows TPF value greater than 1 it means bend channel performance is good.

Comparison of straight channel and bend channel with nano-fluids are done. Different concentration of nano-fluids is used in this work. Alumina-water with concentration (1%, 3%) and zirconia-water with same concentration are studied in present work. Zirconia-water gives higher value than alumina-water. Figure 5.2 shows straight channel value of nusselt number (Nu) according to Reynolds number (Re) and figure 5.3. shows bend channel value.

Figure 5.2: straight channel

Figure 5.3: bend channel





Comparison of nusselt number in straight channel (without and with nano fluid) and bend channel (without and with nano fluid) shows nusselt number (Nu) in bend channel gives higher value than straight channel. Figures shows zirconi-water gives better value than alumina-water.

TPF between bend channel (with nano fluids) and straight channel are studied. Comparison of bend channel with nano-fluids (alumina-water and zirconia-water) and straight channel without nano-fluids are done. Figure 5.4 shows comparison of bend channel with nano-fluid (zirconia-water) and straight channel without nano-fluids. Figure 5.5 shows comparison of bend channel with nano-fluid (alumina-water) and straight channel without nano-fluid.

Figure 5.4

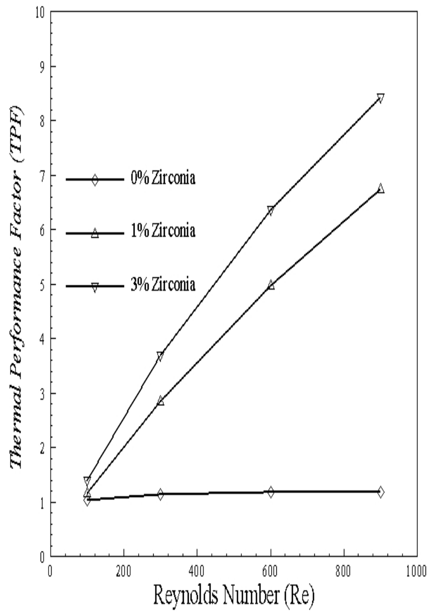
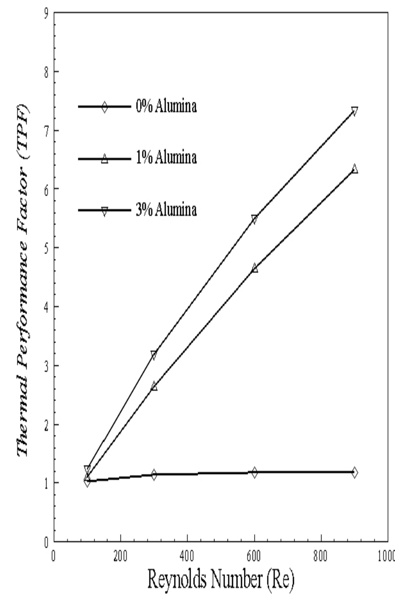


Figure 5.5



Comparison of figures shows that TPF of straight channel (without nano-fluid) and bend channel (with nano-fluids) have more gap because straight channel have no nano-fluids and bend channel have nano-fluids. This gap gives importance of nano-fluids. When straight channel without nano-fluids and bend channel without nano-fluids studied, it shows slightly change in TPF. When straight channel without nano-fluid and bend channel with nano-fluid is studied, it gives effectively change in TPF due to nano-fluids.

TPF between bend (with nano-fluids) and straight (with nano-fluids) are studied. Both channels have nano-fluids.

Figure 5.6 shows TPF between bend (with zirconia-water) and straight channel (with zirconia-water). Figure 5.7 shows TPF between bend (with alumina-water) and straight channel (with alumina-water).

Figure 5.6

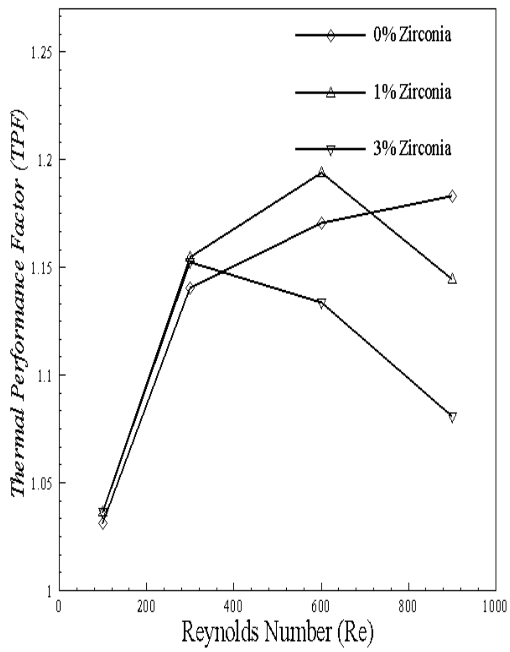
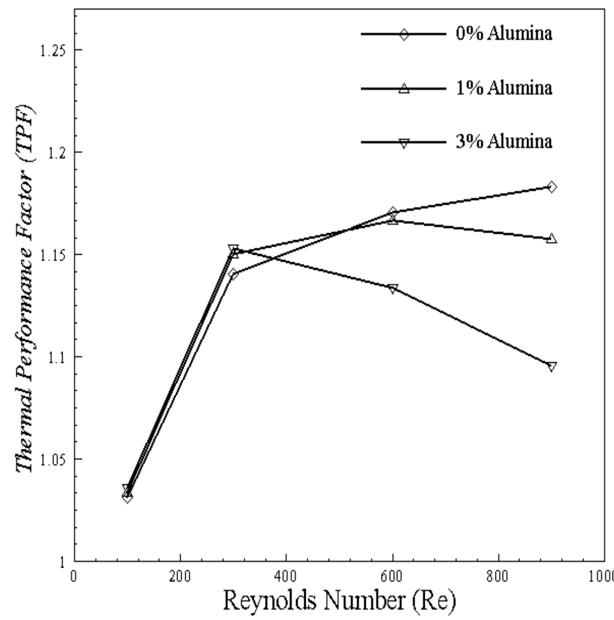


Figure 5.7



Figures show comparison of TPF of nano-fluids (zirconia-water and alumina-water). At different Reynolds number TPF values changed. Temperature distribution of zirconia nano-fluid is studied. Figures (5.8, 5.9, 5.10, and 5.11) show temperature distribution of zirconia-water nano-fluid at different Reynolds number and different concentration of nano-fluids.

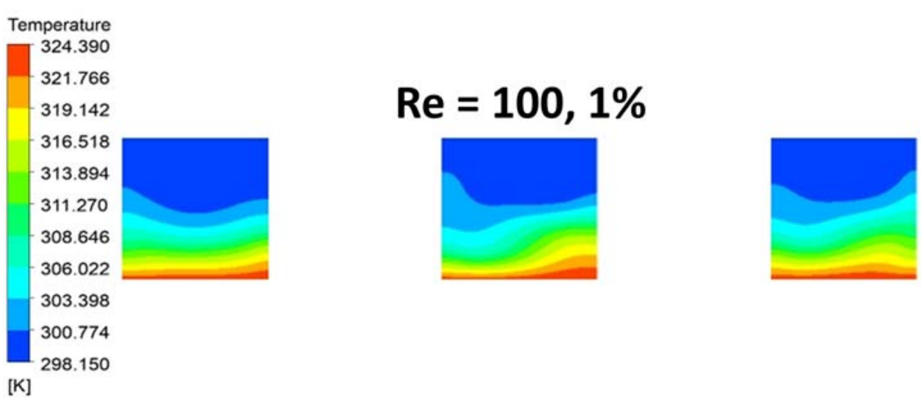


Figure 5.8

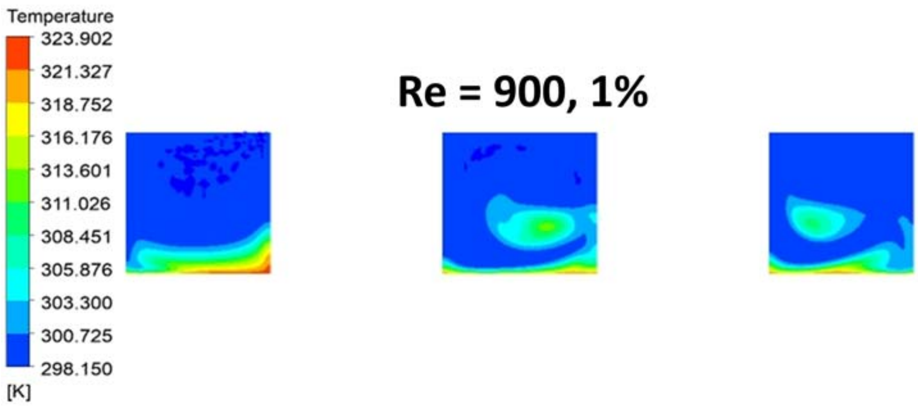


Figure 5.9 temperature distribution of zirconia at (Re=900, 1%)

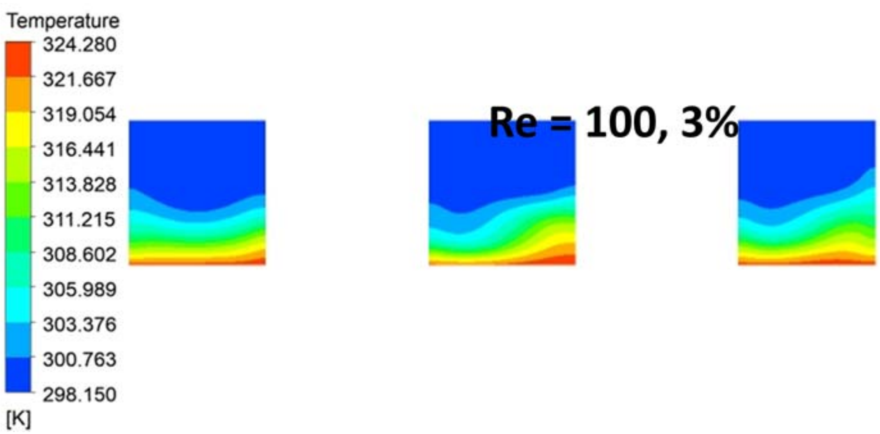


Figure 5.10 temperature distribution of zirconia at (Re=100, 3%)

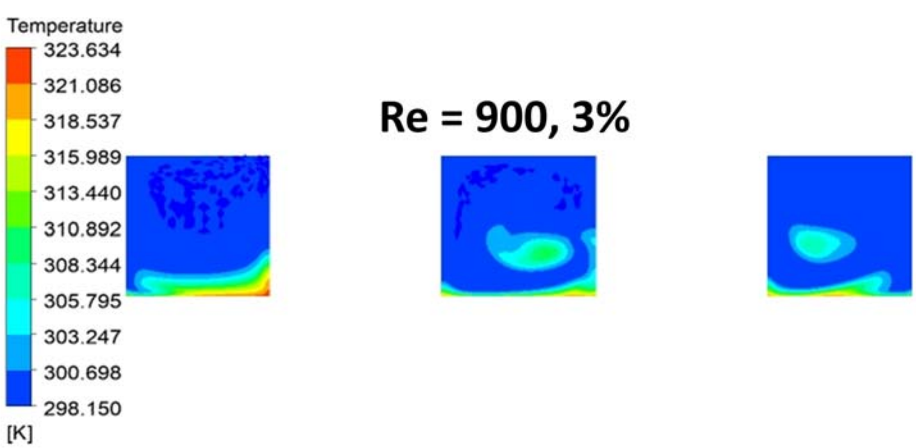


Figure 5.11

Figures show at high Reynolds number dean vortices are produced at bend. More heat transfer due to dean vortices.

Velocity distribution of zirconia nano-fluid is studied. Figures (5.12, 5.13, 5.14, 5.15) show velocity distribution of zirconia at different concentration and different Reynolds number.

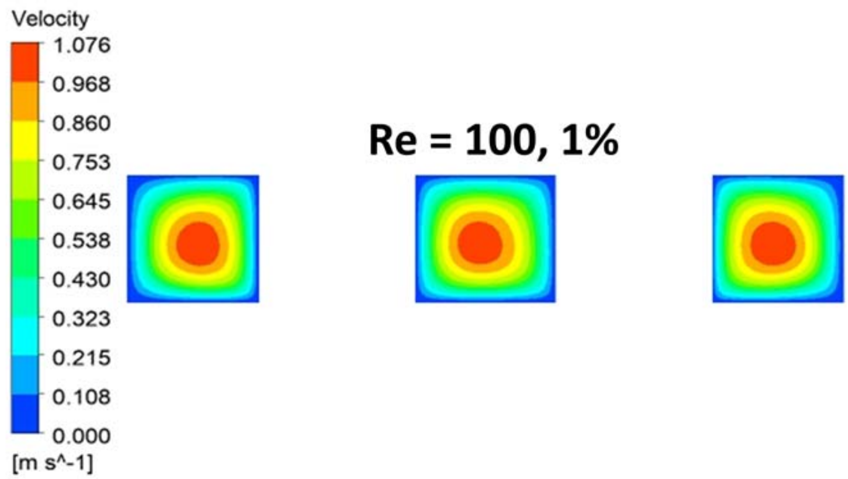


Figure 5.12 velocity distribution of zirconia at (Re=100, 1%)

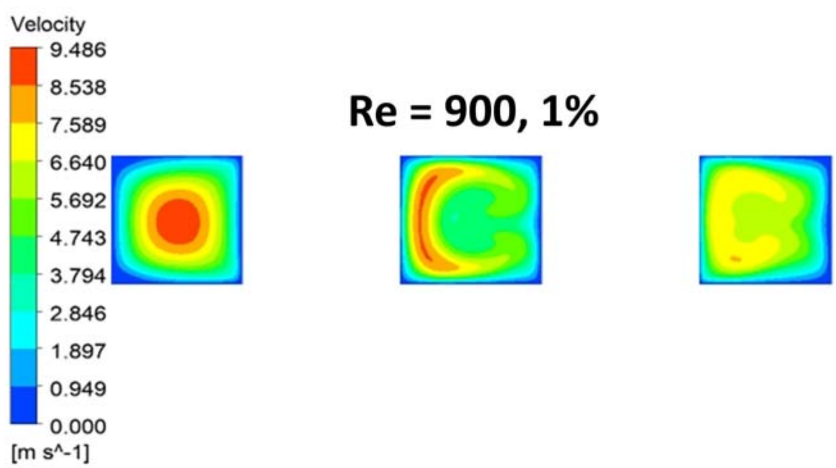


Figure 5.13 velocity distribution of zirconia at (Re=900, 1%)

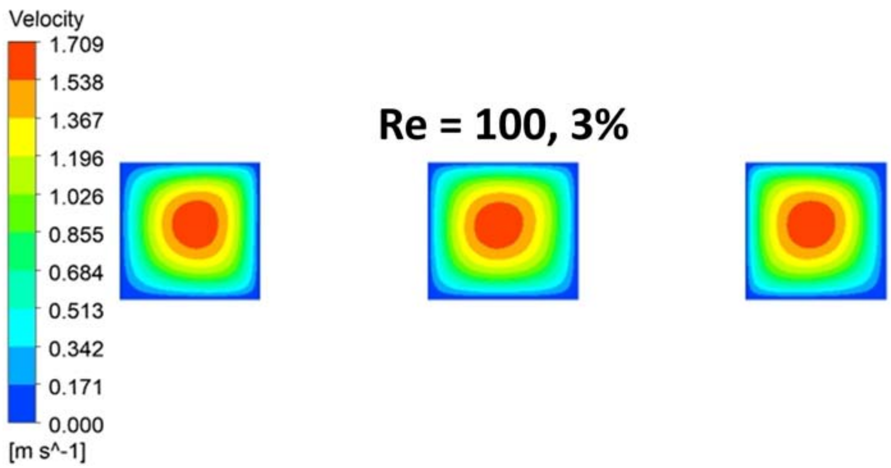


Figure 5.14 velocity distribution of zirconia at (Re=100, 3%)

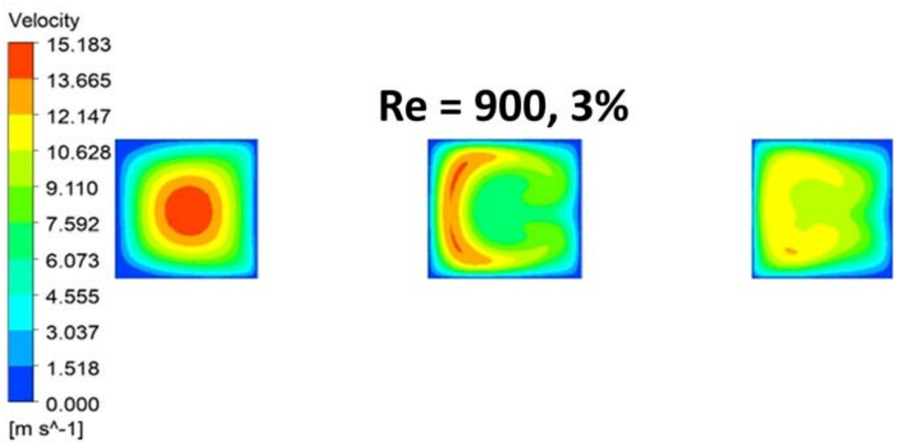


Figure 5.15 velocity distribution of zirconia at (Re=900, 3%)

Temperature distribution of alumina nano-fluid is studied. Figures (5.16, 5.17, 5.18) show temperature distribution of alumina.

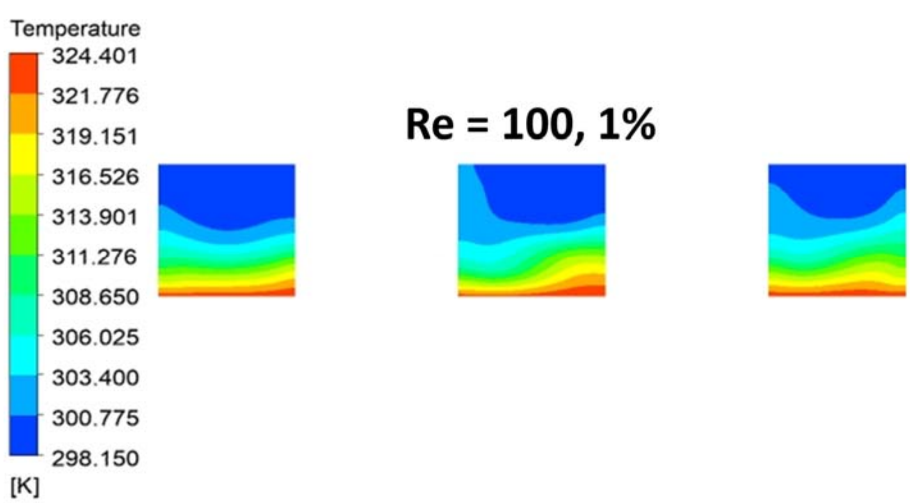


Figure 5.16 temperature distribution of alumina at (Re=100, 1%)

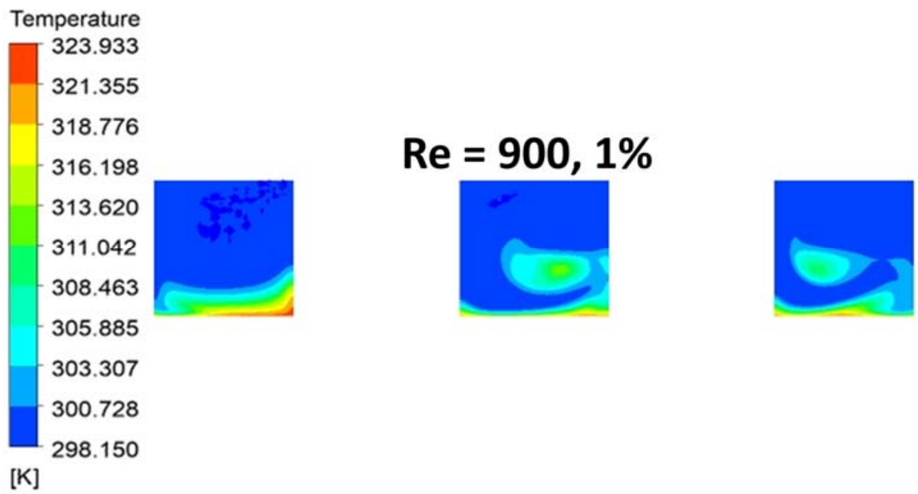


Figure 5.17 temperature distribution of alumina at (Re=900, 1%)

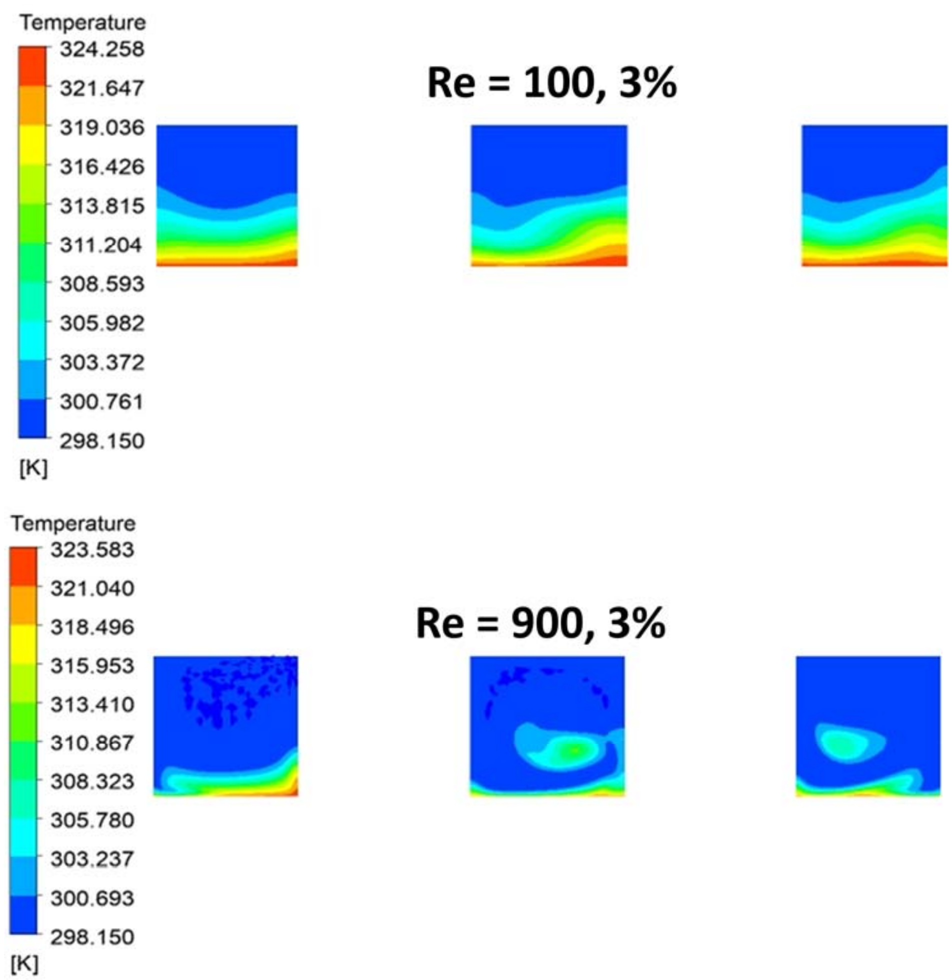


Figure 5.18 temperature distribution of alumina at (Re =100, 900 and concentration 3%)

Velocity distribution of alumina nano-fluid is studied. Figures (5.19) show velocity distribution of alumina nano-fluid at different Reynolds number and different particle concentration.

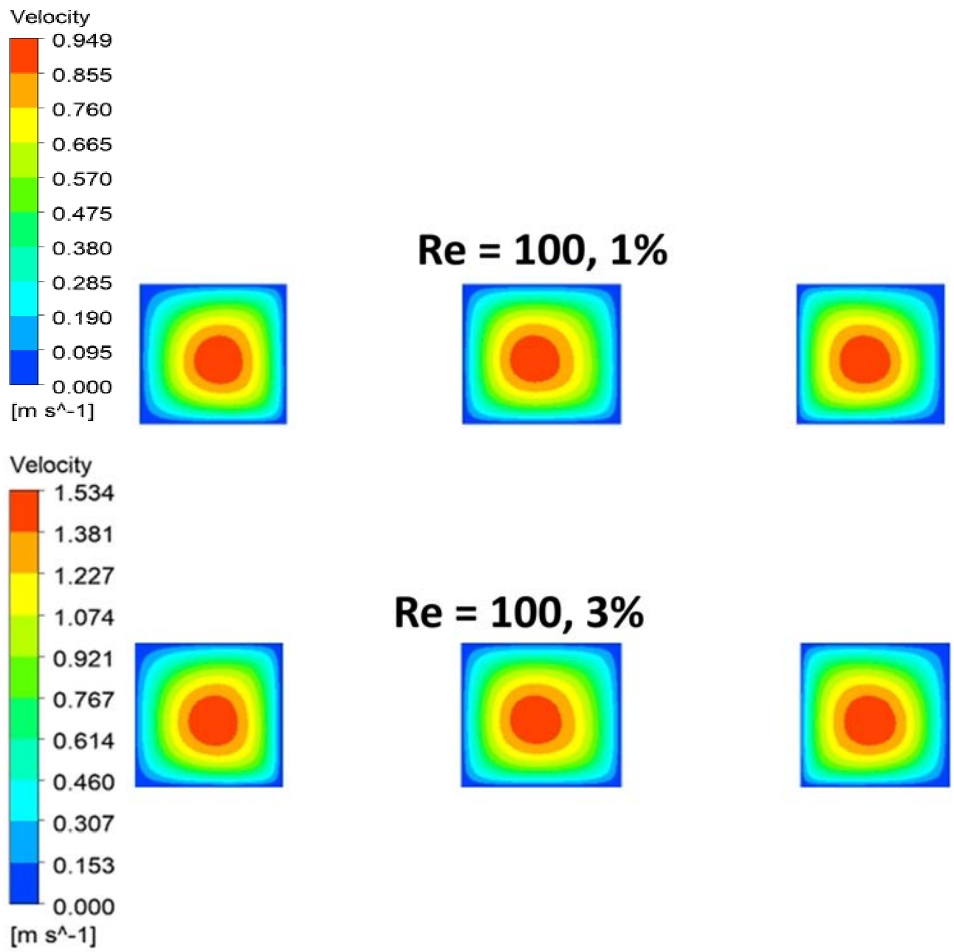


Figure 5.19 velocity distribution at (Re=100, and concentration 1%, 3%)

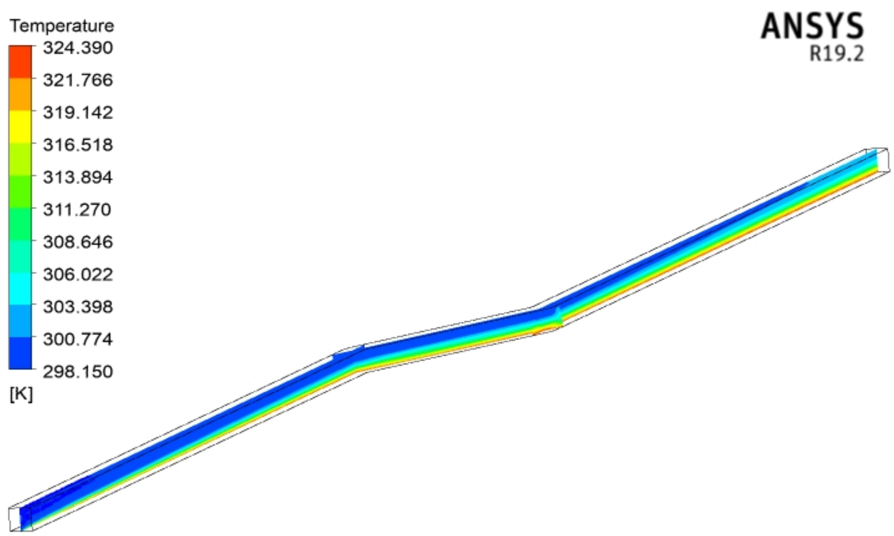


Figure 5.20 lengthwise zirconia temperature distribution at (Re=100, 1%)

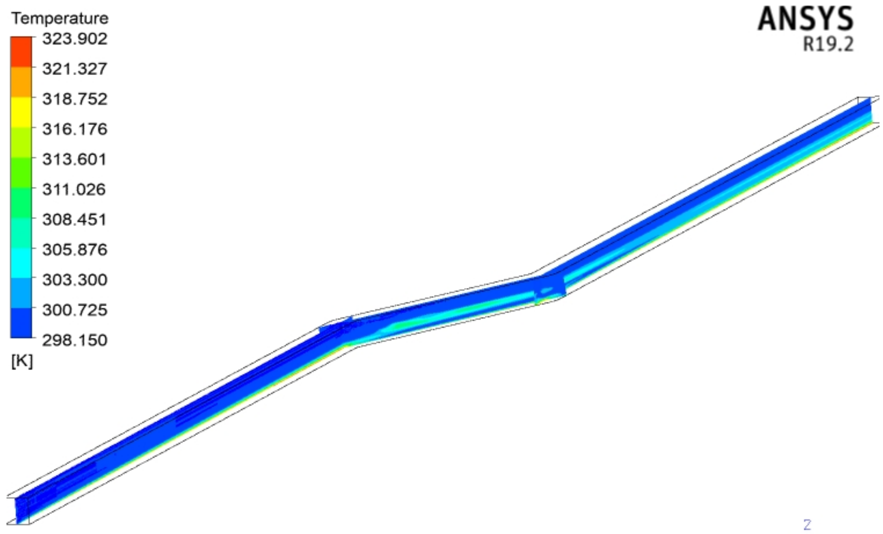


Figure 5.21 lengthwise zirconia temperature distribution at (Re=900, 1%)

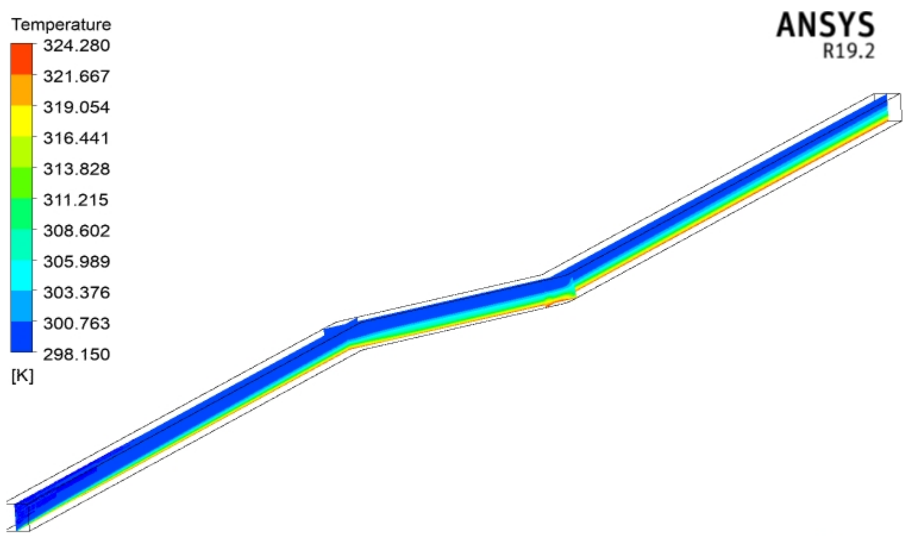


Figure 5.22 lengthwise zirconia temperature distribution at (Re=100, 3%)

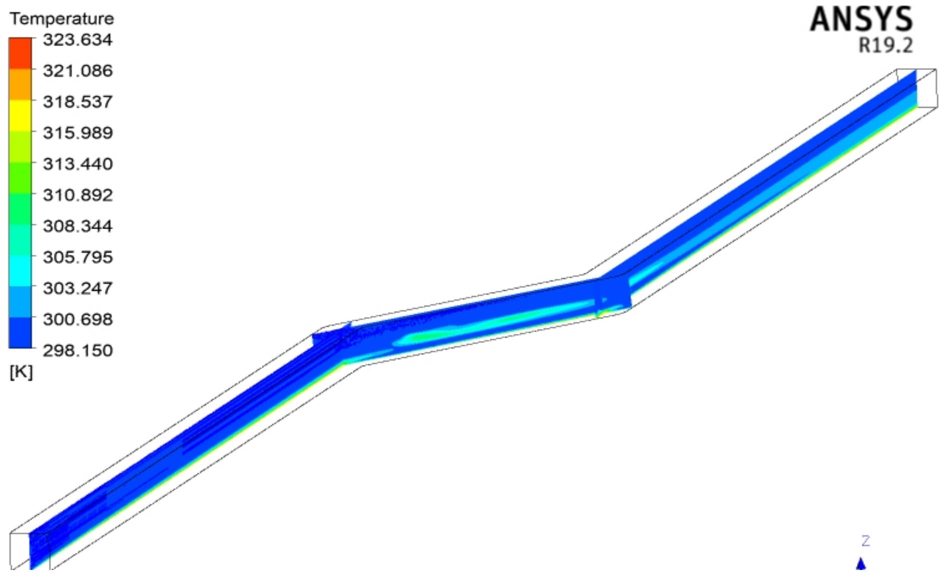


Figure 5.23 lengthwise zirconia temperature distributions at (Re=900, 3%)

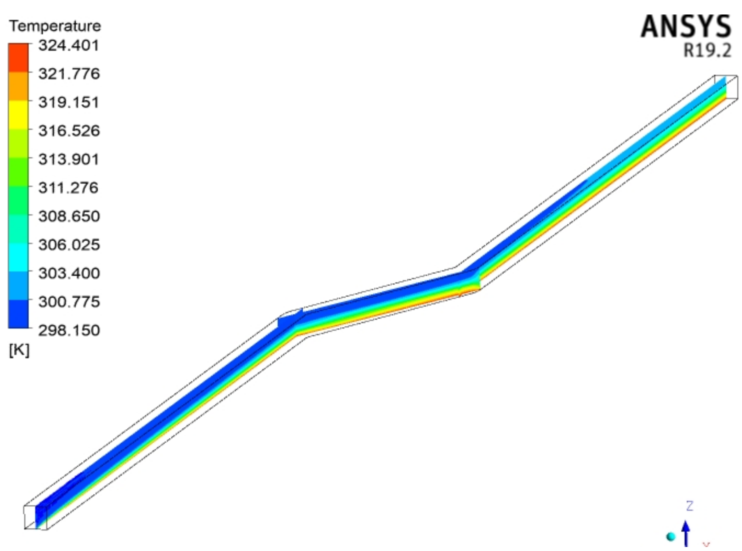


Figure 5.24 lengthwise alumina temperature distribution at (Re=100, 1%)

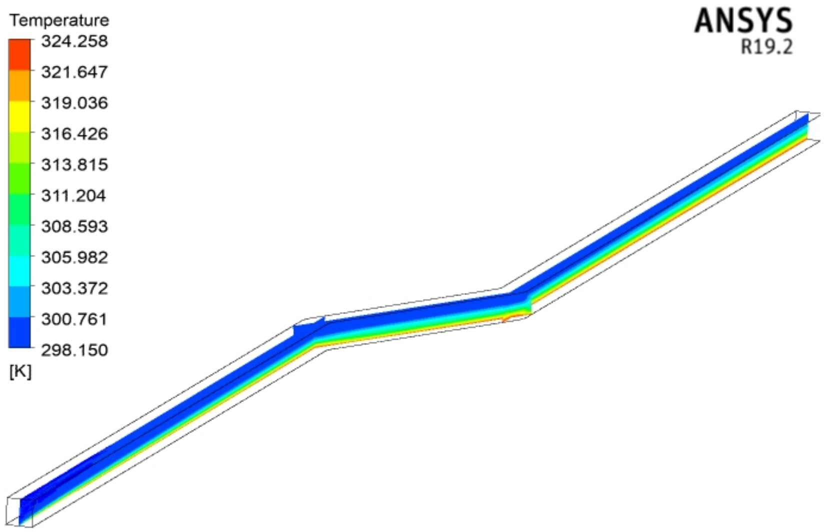


Figure 5.25 lengthwise alumina temperature at (Re=100, 3%)

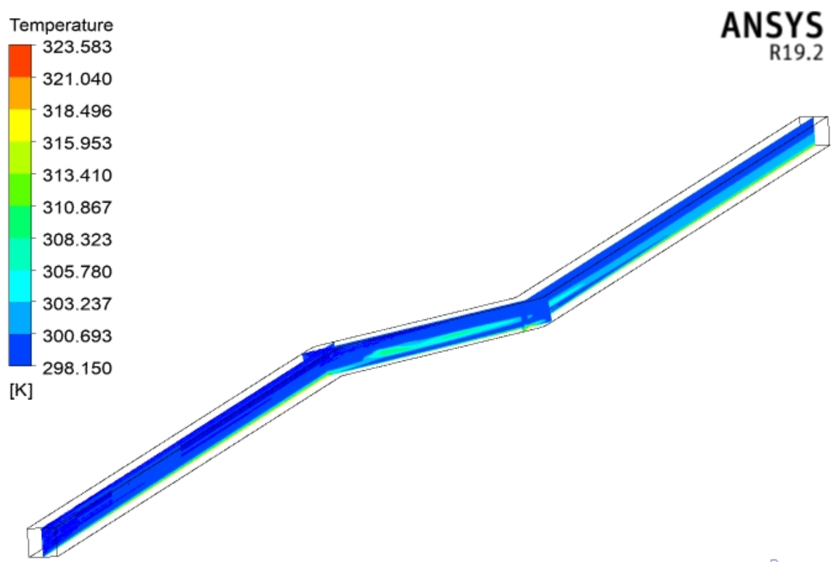


Figure 5.26 lengthwise alumina temperature distribution at (Re=900, 3%)

6 CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

Flow and heat transfer of straight and bend micro-channel with single phase laminar flow is studied. Considering copper as solid and de-ionized water as fluid, ANSYS fluent 18.1 is employed for simulation.

Following conclusion is drawn

- Convective heat transfer in Micro-channel heat exchanger increases with increase in Reynolds number (Re) pressure drop also increases
- Due to dean vortices formation, bend channel performed better than straight channel
- Nusselt number (Nu) improves 5% due to introduction of bend in single micro-channel compared to straight channel.
- Convective heat transfer 10% more increases in square channel than rectangular channel.
- Nusselt number (Nu) increases 7% due to dean vortices.
- Introduction of nano-particles in channel enhanced Nussult number compared with channel without nano-particles. This is due to dean vortices development at bend section.
- Zirconia (Zr) showed high Nusselt number both for 1% and 3% volume concentration when compared with Alumina (Al_2O_3) of same concentration.

6.2 Future Scope

- Straight channel model can be designed of multiple hydraulic diameter channels.
- Effect of multi-phase can be identified for same bend model.

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