Numerical Simulation of Heat Transfer in Microchannel with Twisted Tape Insert

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Numerical Simulation of Heat Transfer in Microchannel with Twisted Tape Insert

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By

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Under the Guidance of
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ODISHA, INDIA

CERTIFICATE

This is to certify that the Thesis Report entitled "Numerical Simulation of Heat Transfer in Microchannel with Twisted Tape Insert" submitted by Mohammad Azaruddin bearing roll no 213ME3423 in partial fulfillment of the requirement of the award of Master of Technology in Mechanical Engineering with specialization in "Thermal Engineering" during session 2013-2015 at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

Date:

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Place: Rourkela

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ABSTRACT

A 3D microchannel in transient condition with hydro dynamically fully developed was investigated. The main aim to increase the turbulence of fluid with a helical twisted tape insert and compare with the channel without twisted tape. Since the more the turbulence in fluid more the convective heat transfer. A commercial CFD package is used for investigation. An isothermal wall condition with Re equal to 100 which is equal to inlet velocity of 0.67m/s is taken as boundary condition. The main aim is to compare the heat transfer rate, axial wall shear stress, skin friction coefficient, Nusselt number, wall fluxes and heat transfer coefficient for the channel with twisted tape with respect to the without twisted tape. It is found that the increase in turbulence occurs in microchannel due to the twisted tape insert. Also it is found that heat transfer characteristics like axial wall shear stress, skin friction coefficient, surface nusselt number and surface heat transfer coefficient are greater in with twisted tape with respect to without twisted tape.

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CHAPTER-1

Introduction

Chapter 1

1. INTRODUCTION

The study of compact devices has been prominence in the past two decade. We all know that the main cause for damaging the device's component is the high heat flux generated in the devices.to save the component from the damage the heat removal mechanism must be analyzed.

Micro devices are micron in size and have many application in micro electro mechanical system, integrated circuit, biochemical application because it is most suitable method for removing heat flux.

1.1. CLASSIFICATION OF MICROCHANNEL

It is a very debatable topic between the researchers to define a definition of microchannel. Mehendale et al. (2000) used a classification technique which is based on manufacturing to obtain various varieties of channel dimensions, where D is the smallest channel dimension.

$1\ \mu m < D < 100$:Microchannels

$100\ \mu m < D < 1\ mm$: Minichannels

$1\ mm < D < 6\ mm$: Compact Passages

$6\ mm < D$: Conventional Passages

Kandlikar and Grande (2003) adopted a different classification based on the rarefaction effect of gases in various ranges of channel dimensions, "*D*" being the smallest channel dimension:

1 μm <D < 10 μm : transitional Microchannels

10 μm < D < 200 μm : Microchannels

200 μm < D < 3mm : Minichannels

3mm < D : Conventional Passages

1.2. Heat transfer enhancement technique

It is a technique used to increase the thermo hydraulic properties of the heat exchanger devices. It can be classified into three ways i.e.

Active Technique

From manufacturing point of view these techniques are very complex and some external power is needed for desired flow to improve the heat transfer rate. Because of external power needed to manufacture is has very limited application

Different active techniques are as

- **Mechanical aids:** Scrapped heat exchanger and rotating tube heat exchanger are manufactured by mechanical aid techniques. Working principle of this techniques is stirring the fluid by means of rotating the surfaces.

- **Surface vibration:** Mostly it have been used in single phase flow. To obtain a higher convective heat transfer coefficient a frequency of low or high amplitude is applied to the surface.
- **Fluid vibration:** As a replacement for applying vibration at the surface in the fluid pulsation are created. This technique is applied for single phase flow.
- **Electrostatic fields:** This technique is uses electrostatic field from an AC or DC sources to increase the heat transfer by mixing of fluid. It uses dielectric fluid of heat transfer process.
- **Injection:** By injecting the same fluid or another fluid into the main fluid by the means of a porous interface of the section of the heat transfer area increases the heat transfer rate.4
- **Suction:** This technique is appropriate for both single phase flow and two phase flow heat transfer. Removal of vapour by means of porous heated surface in two phase flow and removal of fluid by means of porous heated surface in single phase flow is done by this technique.
- **Jet impingement:** This technique is also appropriate for both single phase flow and two phase flow heat transfer**.** This method employs the cooling or heating the fluid perpendicularly or obliquely to increase the heat transfer rate at the surface.

Passive technique

These techniques uses the power from itself rather than external source which results in increase in pressure drop of fluid. Some modification in geometry or surface cause higher heat transfer rate by disturbing the behavior of fluid.

Different active techniques are as

- **Treated surface**: This techniques includes alteration of the surfaces like pits, cavity or scratches at the heat transfer area. This method are mainly used in boiling and condensation purposes.
- **Rough Surface**: By employing this method a disturbance is created in the region of viscous sub layer. This method is mainly used in single phase turbulent flows.
- **Extended surfaces**: The most commonly used extended surfaces are plain fins which is mainly used in heat exchanger. In the present era finned surfaces become very popular due to their ability to interrupt the flow field which in turns the increase the heat transfer rate.
- **Displaced enhancement devices**: this method are mainly used in forced convection. They enhance the heat transfer indirectly at the surface of the heat exchanger by shifting the fluid from the surface which is heated or cooled with the bulk fluid.
- **Swirl Flow devices:** they create the swirl flow in the axial direction of the channel. The common example of swirl flow devices are helical twisted tape and twisted ducts.it can be used in both type of flow i.e. single phase flow and double phase flow.
- **Coiled Tubes:** In single phase flow generation of vortices are caused by curvature of coiled which results in higher heat transfer coefficient. This phenomenon is mainly occurs in regions of boiling.

- **Surface tension devices:** This technique enhance the flow of liquid to boiling surface from the condensing surface. Wicked or grooved surface are the best example of this technique.

Compound Technique

When two or more techniques used simultaneously to improve the heat transfer rate which is greater than either technique is called compound technique.

1.3. Heat transfer enhancing mechanism

To enhance the heat transfer twisted tape has been widely used. These twisted tape causes the flow to swirl which improve the mixing the fluid an also increases the fluid velocity.

The stream line and velocity of flow field for a swirl flow induced by the twisted tape is higher than the plain tube. This phenomena affects the heat transfer coefficient by increasing the turbulence higher tangential velocity near the walls.

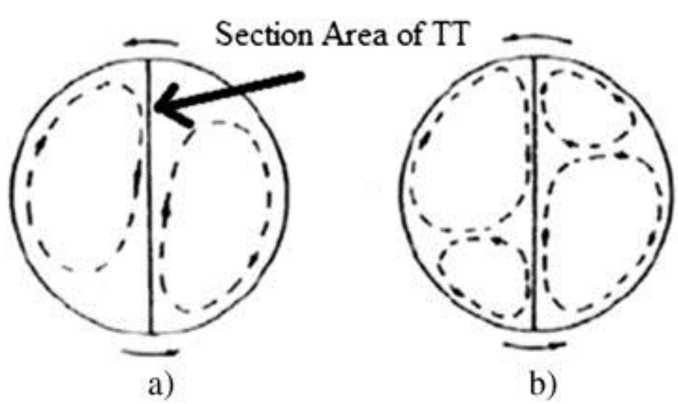

Figure 1.1The secondary induced flow patterns by twisted tape

1.4. Application

From the era 1960s researchers have been aiming for the instrument that enhance the mixing and turbulence of fluid intensity which results in higher heat transfer properties.

So the twisted tape have ability to increase the turbulence of fluid that increases the heat transfer performances and because of this ability it is using in many devices like heat exchanger, boiler shell and car radiator.

Material used for making the twisted tape are Aluminum, copper, stainless steel carbon steel. Al and stainless steel are very commonly used twisted tape because Al has light weight property, ease of accessibility and rate of corrosion is very low and price is also low. Same mechanical properties are found in stainless steel but only difference is the cost of manufacturing is high. So for industrial and laboratory purpose there two materials are very commonly used.

CHAPTER-2

LITERATURE REVIEW

Chapter 2

2. LITERATURE REVIEW

1. Orhan Aydin , Mete Avci : they examined analytically for a Newtonian fluid flow from two parallel plates for forced convection heat transfer in laminar condition. They investigated the slip velocity, viscous dissipation effect, and temperature jump. While performing the experiment they consider hydro dynamically and fully developed condition. The condition for wall is constant heat flux and constant temperature. They gave the result of several of Nusselt number with respect to Brinkman number.
2. Nicolas G. Hadjiconstantinou , Olga Simek : For a nano channel and 2 D microchannel the convective heat transfer coefficient for a gaseous flow for constant wall temperature they investigated slip flow regime. The flow condition is hydro-dynamically fully developed thermally fully developed. For calculating the nusselt number they used the axial heat conduction condition.
3. Gokturk tunc , Yoldiz Bayazitoglu : They have also examined for rectangular microchannel the slip flow heat transfer for thermally fully developed and hydro dynamically fully developed. At the wall of the microchannel the H-2 boundary is applied.
4. V.P. Tyagi and K.M. Nigam : For a circular tube the sludge flow for steady state condition they used both axial coordinate and Laplace transform. Calculation tells that exact analytical solution matches with 2nd approximation.
5. Ho-Eyoul Jeong , Jae-Tack Jeong : In their work hydro dynamically developed convective flow through a micro-channel with isothermal wall or constant heat flux boundary

condition is considered. They analyzed extended Graetz problem in micro channel with Eigen function expansion for calculating the energy equation .The property of slip velocity and temperature boundary condition on the micro channel wall are explored . taking into consideration stream wise conduction & viscous dissipation The effect of nusselt number on peclet number & brinkman number was transferred in their work , which in turn helped to calculate both of the boundary condition based on the dimensionless number

6. Tuckerman and Pease : They asserted that h for turbulent flow through conventionally sized micro-channels is lower than the laminar flow via micro-channels Bas on the calculation the determined that 790W/cm2 heat flux dissipation is possible that too without a phase change .
7. Pfahler : His main focus was on calculating the length of scale at which the layer separation occurs He calculated & found that the Fluid Flow In a rectangular cross section micro tube channel with an cross section of 80 to 7200 micron/m2 .the assumption of navier –stokes equation was directly related by him. Even for the tiniest of the channel large fall of was noticed from the equation. For a Micro tube filled with nitrogen, H was found to be on larger side for the macro tube then to the micro tube. He Calculated value of turbulent heat flow transfer coefficient ,And found out that it was seven time greater than the value obtained by equation
8. Randall f.Barron , X.M.Wang and Roberto Warington :Gratez formulated to include the effect of slip flow of in a low pressure gas & the general problem of formulating thermally the heat transfer flow through a micro tube. The eigen value was calculated through different method. For Solving the hydro-dynamically formulated laminar flow inter relation was made with help of integral transformation method which a used at first with a

constant heat flux & isothermal wall a stable state flow in a micro tube was considered. For both heating & cooling case Viscous heating was implemented .temperature Jump effect was found to be vanishing the Nusselt number was increase thus it was proved that at high prandlt number the temperature jump phenomenon was not found.

CHAPTER-3

MATHEMATICAL MODELLING

Chapter 3

3. Mathematical modelling

3.1. Computational domain

Case 1

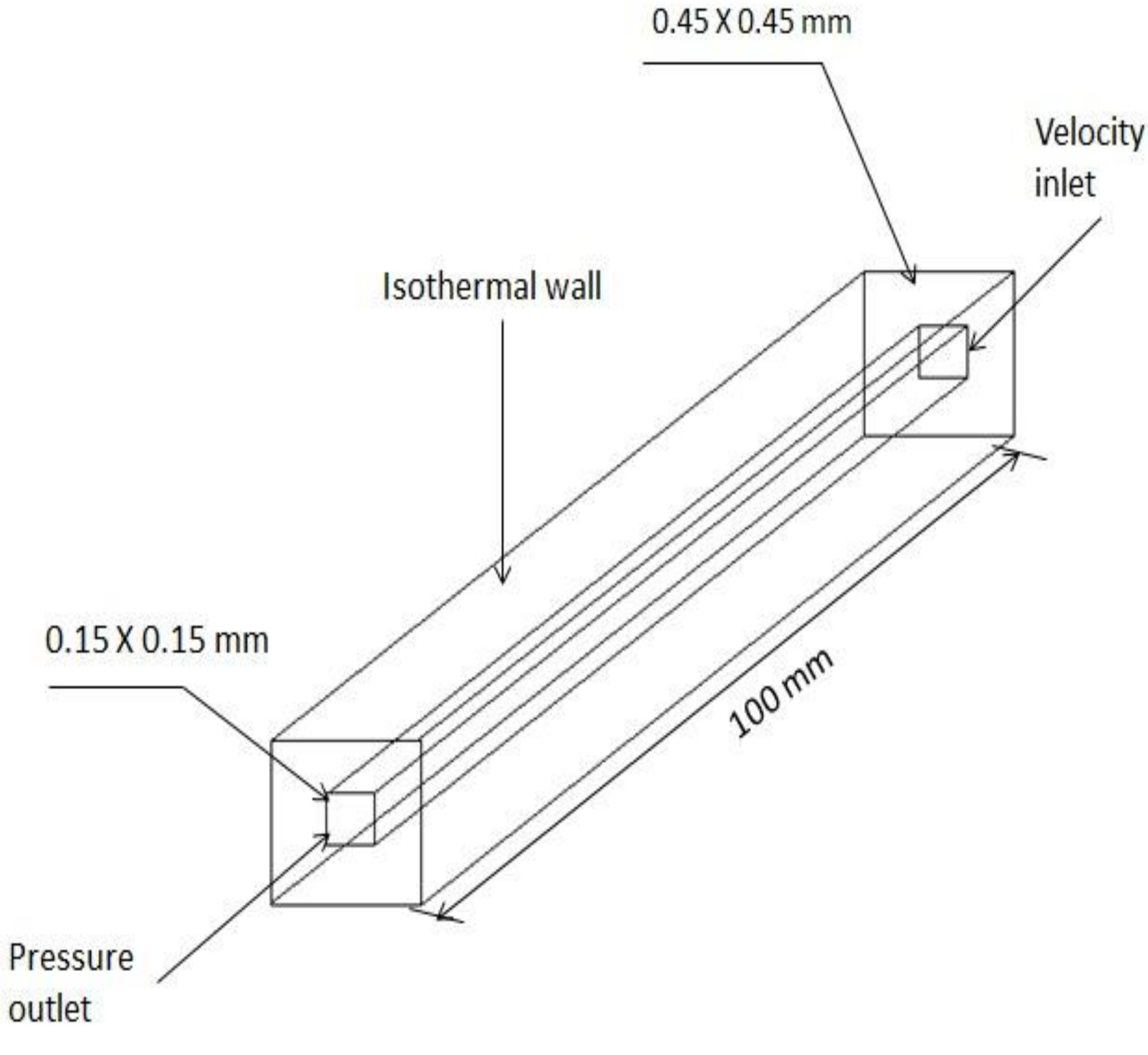

Figure 3.1 Square microchannel without twisted tape

Case 2

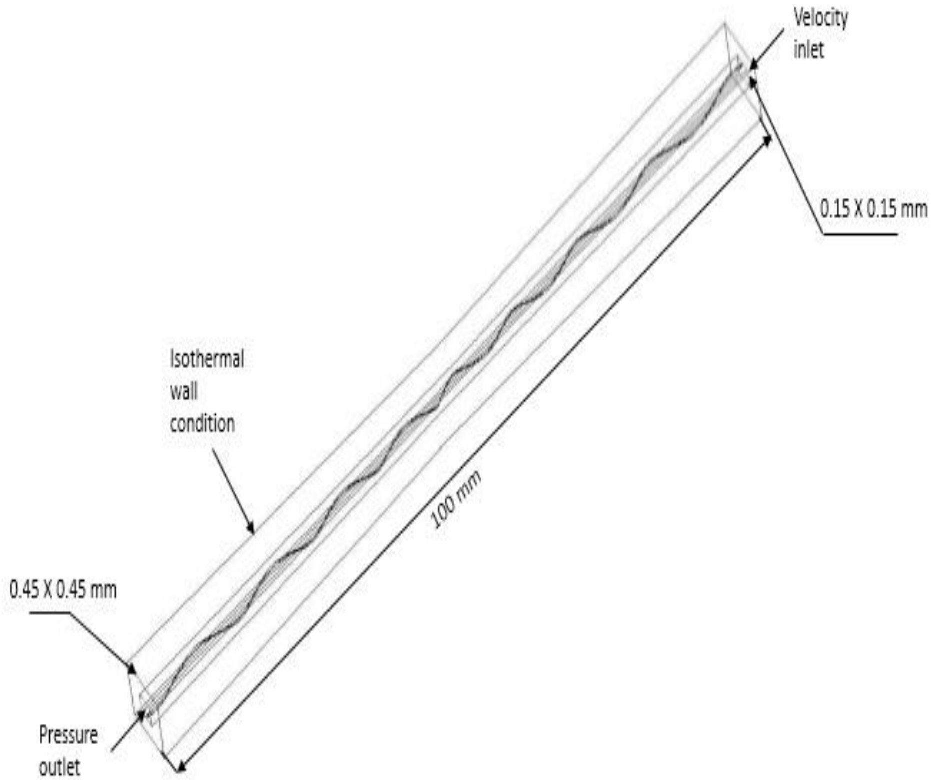

Figure 3.2 Square microchannel with twisted tape

Governing differential equation

Continuity equation

$$\frac{\partial \rho}{\partial t}+\frac{\partial (\rho u)}{\partial x}+\frac{\partial (\rho v)}{\partial y}+\frac{\partial (\rho w)}{\partial z}=0 \qquad (2)$$

Navier-stoke equation

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+F_x \qquad (3)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial P}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+F_y \qquad (4)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial P}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+F_z \qquad (5)$$

Energy equation

$$\rho c_p\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+\Phi \qquad (6)$$

Where Φ is viscous dissipation factor

$$\Phi=2\mu\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2+\frac{1}{2}\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2+\frac{1}{2}\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)^2+\frac{1}{2}\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)^2\right] \qquad (7)$$

CHAPTER-4

PROBLEM FORMULATION

Chapter 4

4. Problem Formulation

4.1. Problem Description

A 3D laminar and unsteady state flow through a square micro channel has been analysed. Dimension of the micro channel are in micro meter. The cross section of micro channel is 0.15×0.15 mm and length of the channel is 100 mm and the thickness of the channel is 0.15 mm along all four side of the wall over the entire length. The side wall of the micro channel is considered to be isothermal condition i.e. constant temperature.

At the inlet fluid is entering at ambient temperature i.e. 300 K and leaving at the outlet where the gauge pressure is zero. Pressure driven flow is considered. The isothermal wall considered as a temperature of 335 K.

The geometry is created in ANSYS WORKBENCH and simulation is done with the help of FLUENT. Flow variable like velocity, temperature and pressure have been analysed at different cross section of pipe. For convective heat transfer Nusselt number plays a very significant role are plotted. Main aim to investigate the compare Nusselt number, skin friction coefficient, axial wall shear stress, convective heat transfer for the two cases.

4.2. Simulation Approach:

The above stated 3D geometry of 2 cases is created by using ANSYS WORKBENCH 15.0. Total number of meshed cell is equal to 160000. The detailed meshed geometry is shown in fig. Apply all the boundary condition and initialize the problem by choosing a suitable solver iterate the problem. The convergence of residual is shown in fig

Case 1

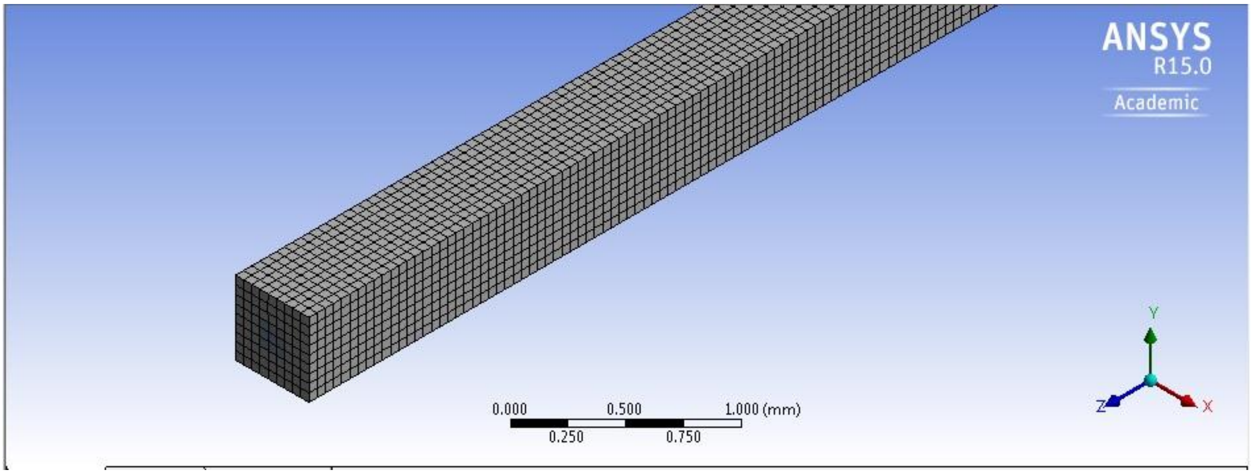

Figure 4.1 Completed meshed geometry of micro channel without twisted tape

Case 2

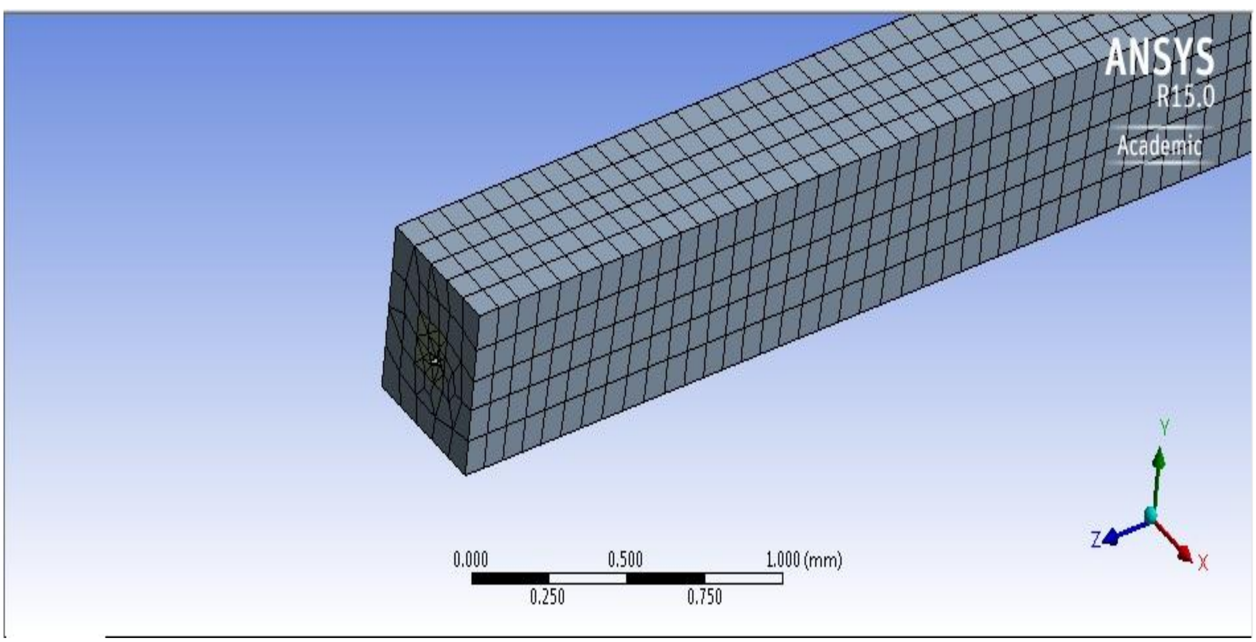

Figure 4.2 Completed meshed geometry of micro channel with twisted tape

4.3. Convergence limit

Case 1

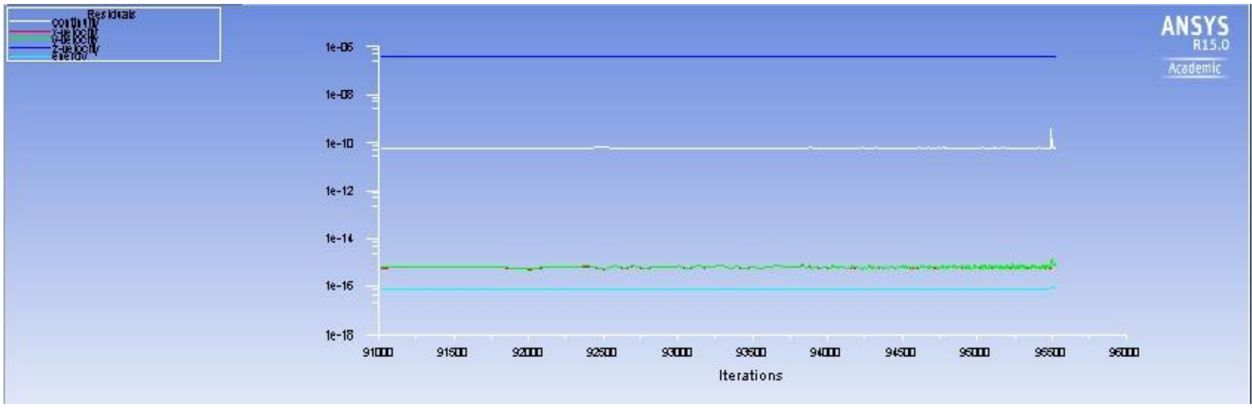

Figure 4.3 Convergence residual of microchannel without twisted tape

Case 2

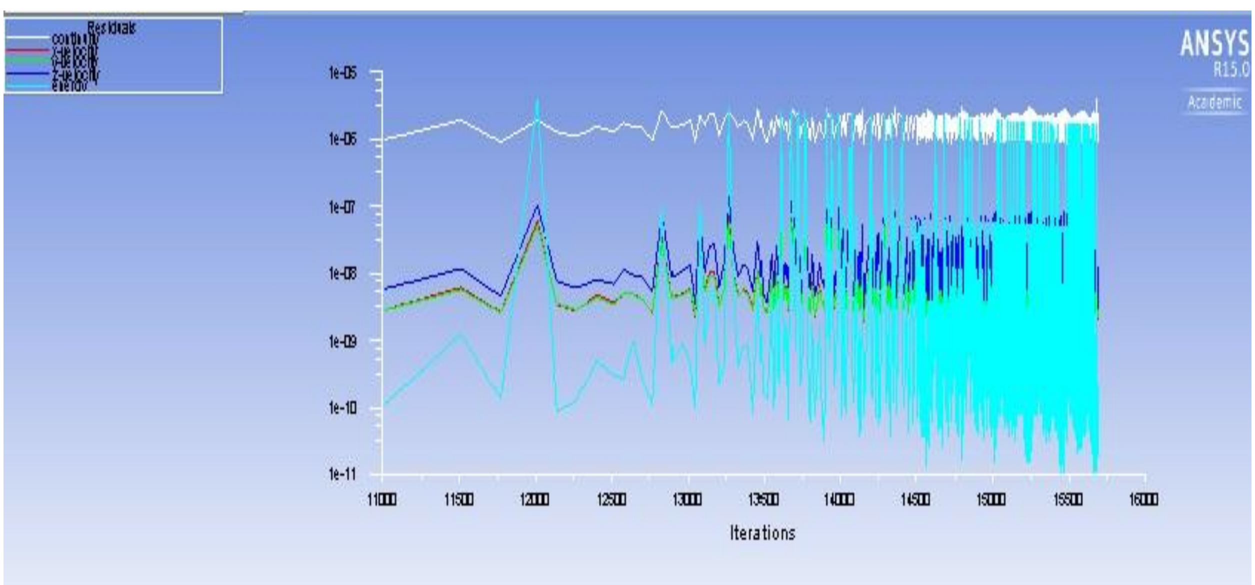

Figure 4.4 Convergence residual of microchannel with twisted tape

4.4. Velocity Simulation

Water is considered as a working fluid with pressure at outlet of 1atm.

(a) The velocity at the inlet is 0.67 m/s which is equals to a Reynolds number equal to 100.

(b) At the wall no slip boundary condition is considered.

Pressure correction based iterative SIMPLE algorithm with the 2nd order upwind scheme is for discretization. Initialization is done at the velocity inlet and performed the iteration.

Case 1

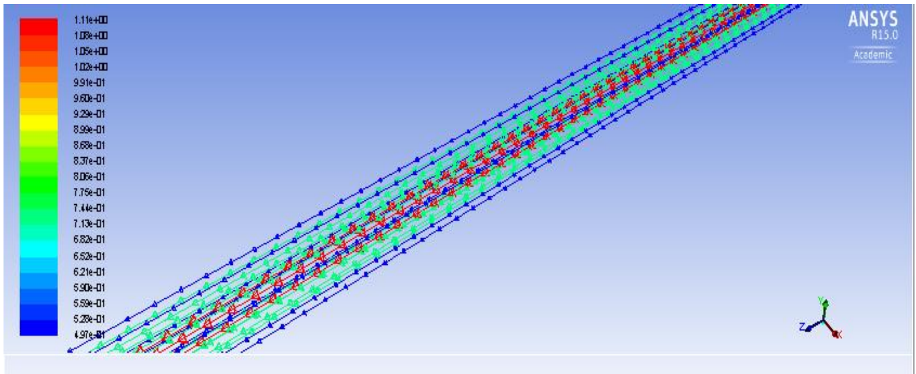

Figure 4.5 Velocity vector of microchannel without twisted tape

Case 2

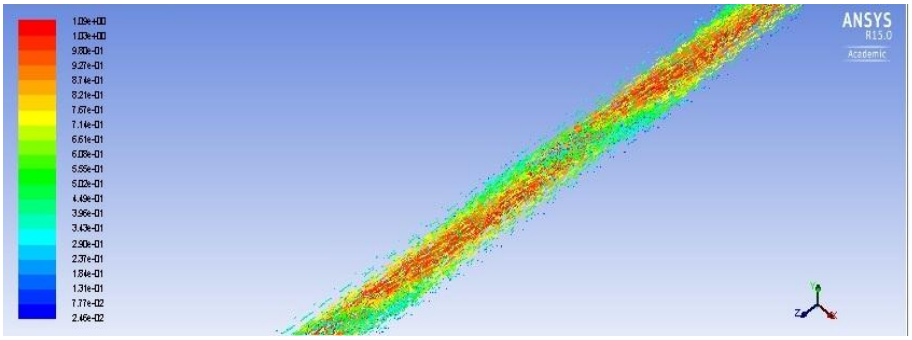

Figure 4.6 Velocity vector of microchannel with twisted tape

4.5.Temperature simulation

For the same geometry of microchannel we consider the temperature at the wall is to be constant temperature T_{wall} =335 K. The temperature of the fluid at the inlet is T_i= 300K. these boundary condition are solved by fluent and temperature contours are shown in fig

Case 1

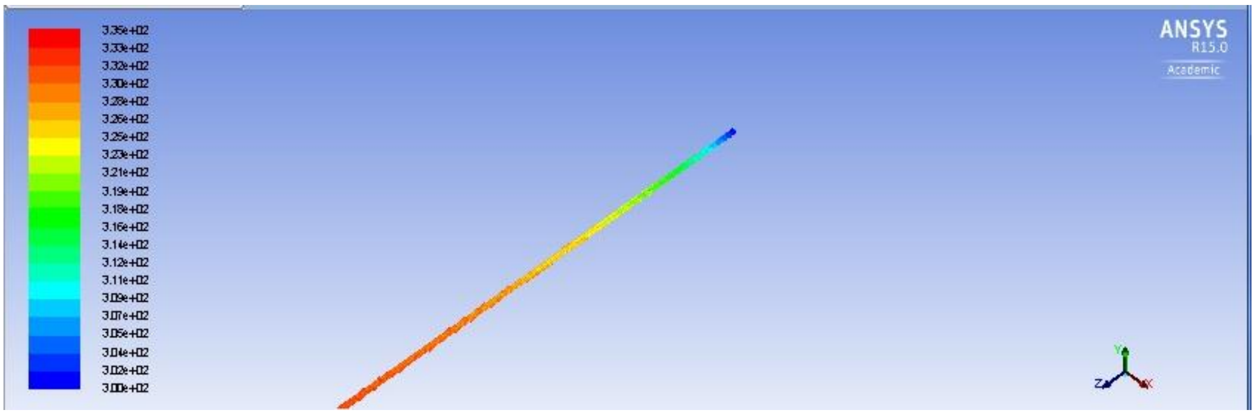

Figure 4.7 Temperature contour of microchannel without twisted tape

Case 2

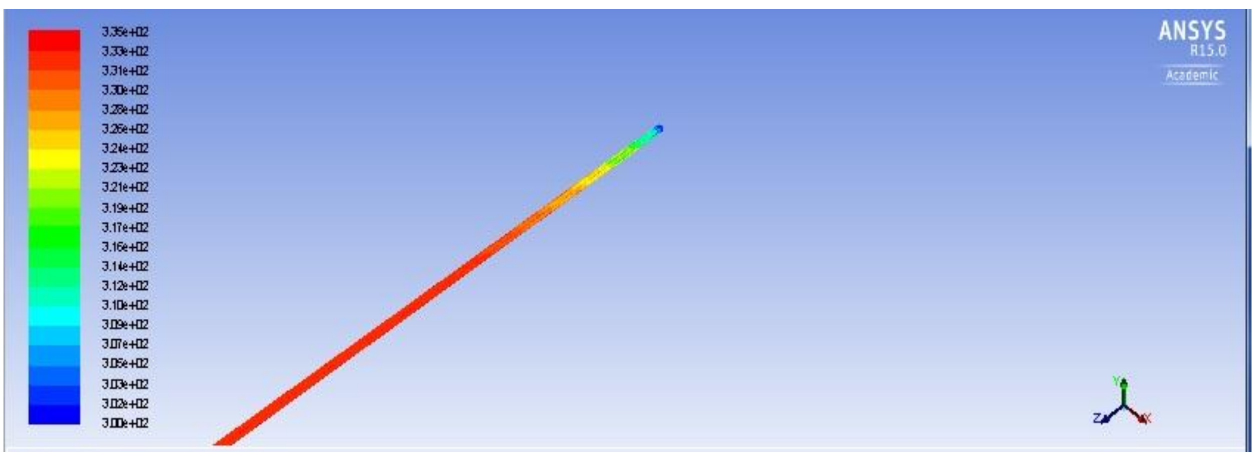

Figure 4.8 Temperature contour of microchannel with twisted tape

CHAPTER-5

RESULTS AND DISCUSSSION

Chapter 5

5. Results and Discussion

5.1. Axial wall shear stress

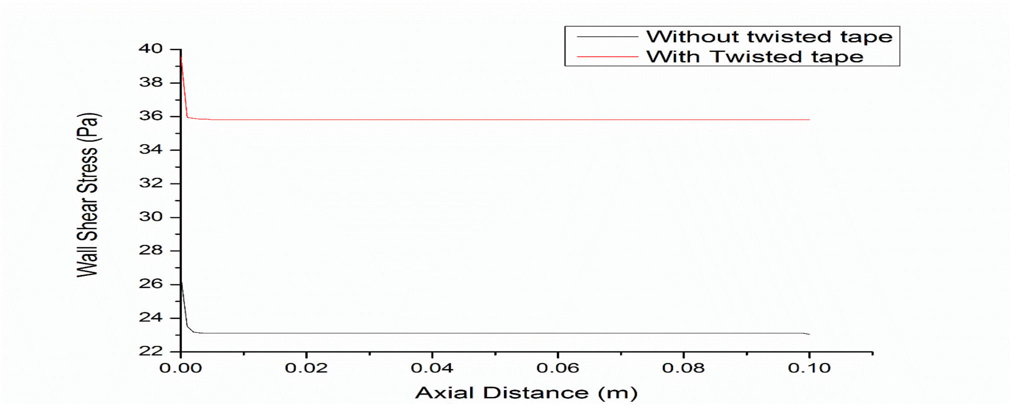

Figure 5.1 Wall shear stress vs axial distance

5.2. Skin Friction Coefficient

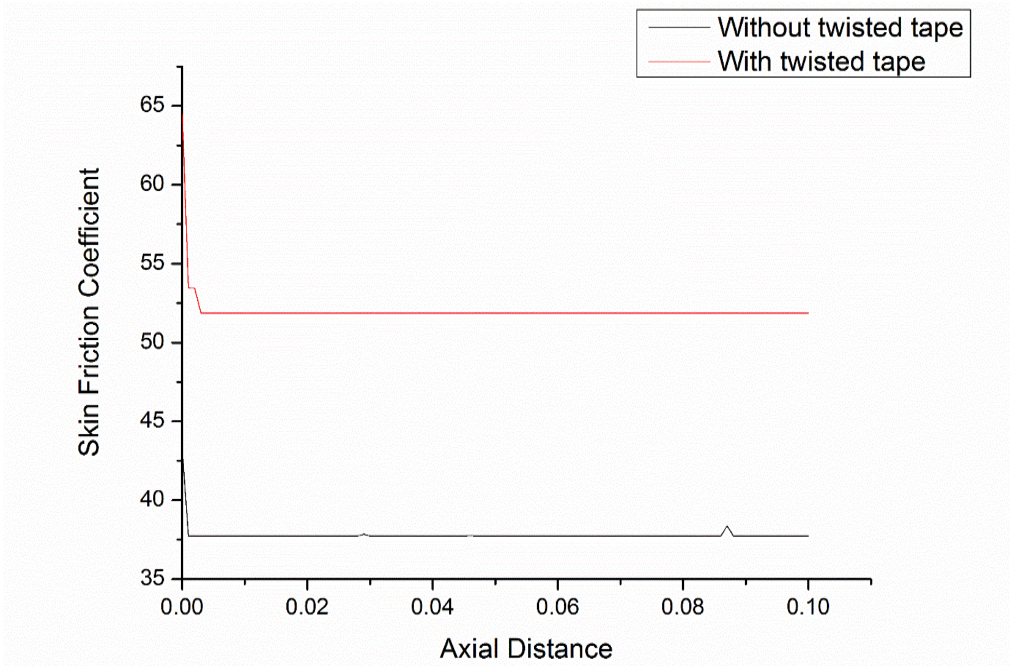

Figure 5.2 Skin friction coefficient vs axial distance

5.3. Surface heat transfer coefficient

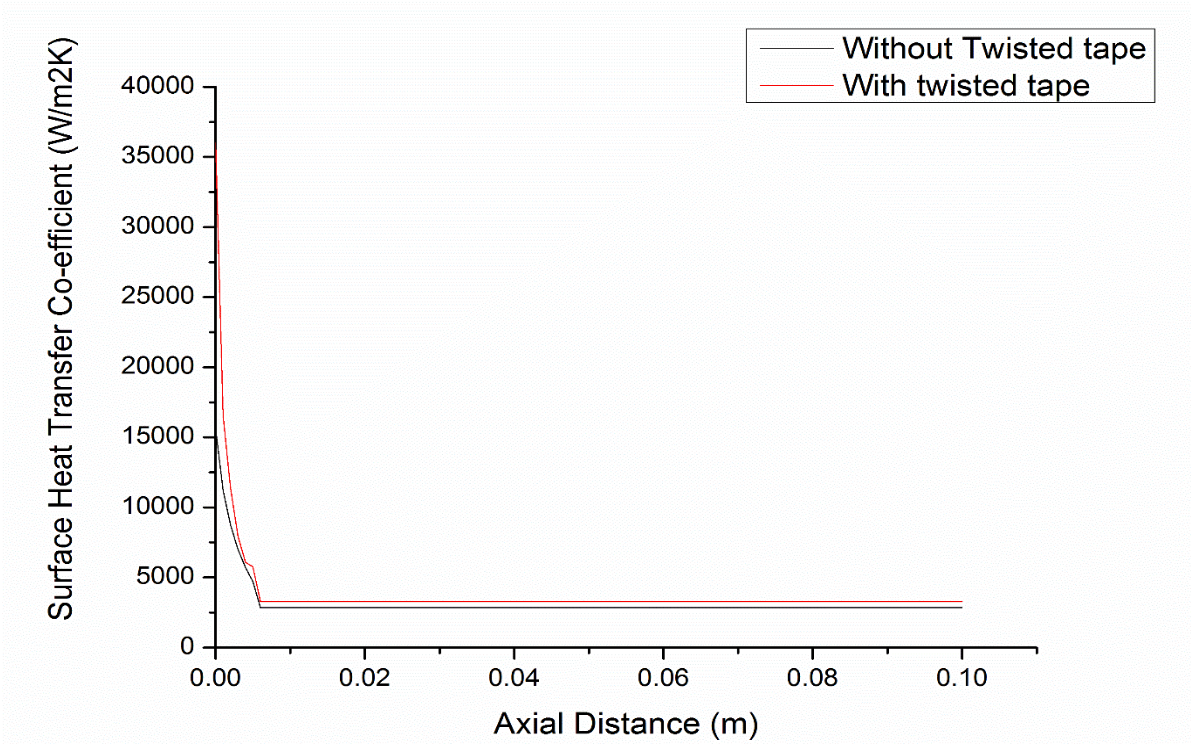

Figure 5.3 Surface heat transfer coefficient vs axial distance

5.4. Surface Nusselt number

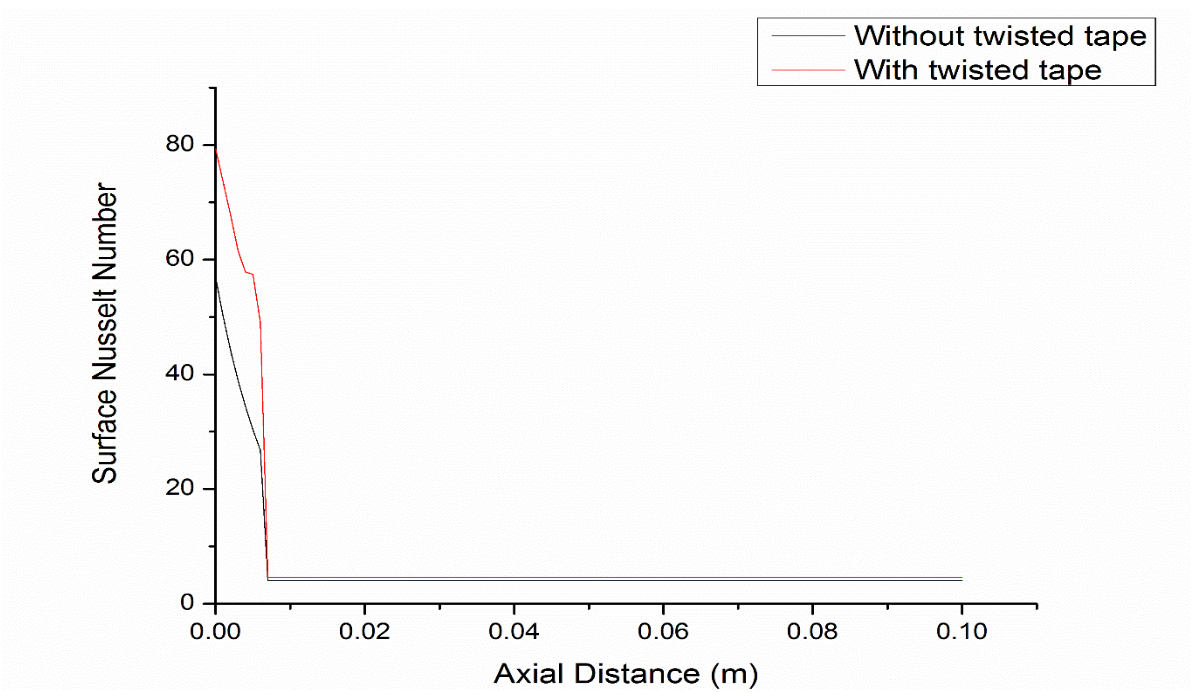

Figure 5.4 Surface nusselt number vs axial distance

Discussion

Fig 5.1 shows the trend of axial wall shear stress along the axial length. From the diagram it can be seen that the value of axial wall shear stress is more for twisted tape than the without the twisted tape. This is due to the reason of increase in velocity of at the wall by twisted tape.

Fig 5.2 shows the trend of skin friction coefficient along the axial length. From the diagram it can be seen that the value of skin friction coefficient is more for twisted tape than without twisted tape. This is due to the reason of increase in wall shear stress at the wall by twisted tape.

Fig. 5.3 shows the trend of surface heat transfer coefficient along the axial length. From the diagram it can be seen that the value of surface heat transfer coefficient is more for twisted tape than without twisted tape. This is due to the reason that the more convective heat transfer in twisted tape due to turbulence in fluid.

Fig 5.4 shows the trend of surface nusselt number along the axial distance. From the diagram it can be seen that the value of surface nussselt number is more for twisted tape than without twisted tape. This is due the reason of increase of surface heat transfer coefficient at the wall.

CHAPTER-6

CONCLUSION

Chapter 6

6. Conclusion

1. It is found that the axial wall shear stress increases when the twisted tape insert is employed with the conventional microchannel.
2. It can be concluded that the skin friction coefficient increases when the twisted tape insert is employed with the conventional microchannel.
3. From the above results it is found that surface nusselt number increases when the twisted tape insert is employed with the conventional microchannel.
4. Also Surface heat transfer coefficient increases when the twisted tape insert is employed with the conventional microchannel.
5. Due to twisted tape insert the increase in turbulence occurs which results in higher convective heat transfer.

CHAPTER-7

FUTURE WORK

Chapter 7

7. Future work

To increase the convective heat transfer characteristics the geometric parameter plays an important role. These geometric parameters are pressure required to flow the cooling fluid, mass flow rate hydraulic diameter of the channel, fluid temperature, number of turns which has to be optimized to system effective and inexpensive also ease in manufacturing

1. It is observed that by inserting the twisted tape in conventional microchannel the parameters like wall shear stress. Skin friction coefficient, surface nusselt number, surface heat transfer coefficient increases along the axial distance. The reason is increase in turbulence by inserting the twisted tape which results in increase in turbulence. Due to this fluid is mixed properly which results more convective heat transfer.
2. Present work is done with the water as working fluid, in which temperature jump and slip velocity does not play an important role. Can change working fluid as air in which temperature jump and slip velocity plays an important role.
3. Change the property like temperature and pressure by implementing the UDF.

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