Numerical investigation of Heat Transfer Enhancement in Circular Tube using Twisted Tape Inserts and Nanotechnology

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Abstract. In the present work the analysis of three different width ratio of twisted tape in a shell and tube heat exchanger done by ANSYS FLUINT14.0. Heat exchanger type shell and tube have been widely used in industrial application such as refrigeration and environment protection, electrical power generation and chemical engineering. This work deals with the theoretical investigation, which was to evaluate the benefit of changing the width of twisted tape in the heat exchanger and the improving the heat transfer by using water as the working fluid in the first case, then using Nano fluids as a heat transfer working fluid. From the use of the condition in table (1) the simulation shows results of enhancement in heat transfer rate ranging from (53.24% to 55.55%) at width ratio 0.71, (53.62% to 56.09%) at width ratio 0.854 and (52.44% to 57.17%) at width ratio 1, for plain tube with twisted tape with respect to plain tube without twisted tape by using water as cooling fluid. By using Nano- fluid (AL_2O_3) the enhancement in heat transfer is (69.14% to 60.44%) at width ratio 0.71, (58.36% to 61.51%) at width ratio 0.854 and (56.76% to 63.35%) at width ratio1, for plain tube with twisted tape with respect to plain tube without twisted tape.

التحقيق العددي لتعزيز انتقال الحرارة في انبوب دائري باستخدام الاشرطة الملتوية وتقنية النانو

الخلاصة. في العمل الحالي تحليل ثلاثة نسبة العرض مختلفة من الشريط الملتوي في مبادل حراري نوع قشرة وانبوب .ANSYS FLUINT14.0 يستخدم هذا النوع من المبادل الحراري على نطاق واسع في التطبيقات الصناعية مثل التبريد وحماية البيئة، وتوليد الطاقة الكهربائية والهندسة الكيميائية . في هذا العمل نقوم بدراسة تأثير عرض الشريط الملتوية في المبادل الحراري وتحسين نقل الحرارة باستخدام الماء في الحالة الأولى، ثم استخدام الماء والنانو(AL_2O_3) كسائل لنقل الحرارة .من استخدام النتائج في الجدول رقم (1) لتعزيز معدل انتقال الحرارة تتراوح ما بين (53.24٪ إلى 55.55٪) في نسبة0.854، (53.62٪ إلى 56.09٪) في نسبة العرض0.71 و(52.44٪ إلى 57.17٪) في نسبة العرض 1، لأنبوب عادي مع الشريط الملتوي مقارنة بالأنبوب الدائري بدون الشريط الملتوي الماء كسائل تبريد. (69.14٪ إلى 60.44٪) في نسبة العرض 0.854، (58.36٪ إلى 61.51٪) في نسبة العرض 0.71و(56.76٪ إلى 63.35٪) في نسبة العرض 1، لأنبوب عادي مع الشريط الملتوية مقارنة بنفس الانبوب بدون الشريط وبوجود الماء و النانو كوسط لنقل الحرارة.

Introduction

A heat exchanger is a device that is used to transfer heat between two or more fluids that are at different temperatures. Heat exchangers are essential elements in a wide range of systems, including the human body, automobiles, computers, power plants, and comfort heating/cooling equipment **[1]**. The most common used type of heat exchanger is the shell-and-tube heat exchanger the enhancement of heat transfer rate which is the main objective of this study **[2].**

The fundamental basis for this statistic is shell and tube technology which is a cost effective, proven solution for a wide variety of heat transfer requirements. There are limitations associated with the technology which includes inefficient usage of shell side pressure drop, dead or low flow zones around the baffles where fouling and corrosion can occur, and flow induced tube vibration, which can ultimately result in equipment failure. A heat exchanger is a component that allows the transfer of heat from one fluid (liquid or gas) to another fluid**.** Increasing heat exchanger performance usually means transferring more duty or operating the exchanger at a closer

The present work deals with finding the effect of change width in heat transfer in the heat exchanger with different mass flow rate with and without Nano fluid and comparing those results with plain tube without twisted tape tube.

In [3] employed titanium dioxide (TiO2) in water as N F for enhancement of HT together with the overlapped dual twisted-tapes (O-DTs). The study of encompassed Reynolds NO.s from 5400 to 15,200, The use of the O-DTs at small overlapped twist-ratio of 1.5 enhanced HT rates up to 89%, friction f actor by (5.43 times). The simultaneous use of the O-DTs have TR 1.5 with the NF with TiO2 volume concentration of 0.21% resulted in HT enhancement around 9.9e11.2% and thermal performance improvement up to 4.5% as compared to the use of O-DTs alone .

In .[4] By doing HT and overall HT in the double pipe HE that fit ted with twisted-tape elements and titanium dioxide N F were studied experimentally. The effects of the temperature, mass flow rate, and intensity of nanoparticles on the overall HT coeff., HT changes in the turbulent flow regime (Re ≥ 2300), and counter current flow were investigated. The experimental results also shows that (0.01% TiO2/) water N F with TT has a little higher friction factor and ΔP when compared to 0.01% TiO2/water NF without TT.

In [5]played out an experimental and numerical study to The "experimental work included constructing" research centre shell and tube HE. Reynolds NO.s "running from (7000 to 15000) flows through the inner". The results revealed that use of spiral fluited tube W/WO TT which leads to increase in HT coeff. (37-43) % , (27-34) %respectively, above those of a plain tube .

In [6] the authors investigated empirically the fully developed laminar HT and friction factor characteristics of different volume concentrations of Al_2O_3. Experiments were performed with water and N Fin the range of Re(700-2200). The N F HT coeff. is high and compared to water and further HT enhancement is observed with TT inserts. The ΔP increases a little with the inserts. A generalized regression equation is developed depended on the experimental data for the guess of the Nusselt NO. and friction f actor for water and N F in a plain tube and with TT inserts.

The researcher in [7] Performed an experimental and numerical review to examination the HT enhancement in a horizontal plain tube with" three nanoparticle ZrO2 (80 nm), Al2O3 (20 nm), CuO (40 nm)}.Three types of TTs (typical TT, TT with V-cut and clockwise-counter clockwise TT). All the tests were executed with Reynolds NO. range (2490-0100) and uniform heat flux (2108-9280 W/m2) were utilized with (TR=4, 6, 8).The obtained maximum Nusselt NO. ratio was (2.41)which occurred in clockwise-counter clockwise TT with (TR=4) at Reynolds NO. (2490), and the maximum thermal performance factor was (1.44) at Reynolds NO. (4981) using distilled water.

Numerical Models

Numerical analysis is used to simulate the heat exchange in countercurrent flow heat exchanger between water/water and water/Nano fluid [hot water with and without Nano fluid flow in inner tube and cold water flow in outer tube] through the tubes wall. The simulation is done by ANSYS-Fluent 14.0 with different conditions.

This study included different parameters such as tube types which are plain tube plain tube with and without twisted tape with three width ratio, hot mass flow rate change from (20 to 60) LPH , its temperature at (60°C) and cold water mass flow rate are constant at(60) LPH at temperature 25°C. This is done for all tubes with and without Nano particles.

Design of Geometry

The test sections for plain copper tube have (19.9, 22.2mm) as inner and outer diameter and (100, 105 mm) inner and outer diameter for P.V.C outer tube. With the length is (1m). Sketch is used a SOLI D WORK PREMIUM 2015 program, as shown in figure (2) and table (2). After the geometry is drawn and saved, it is exported to GAMBIT 2.3.6 to make meshing and other activities for all volumes and saved. Then exported to ANSYS 14.0 to read it and be ready for boundary condition.

Numerical Simulation

Numerical simulation makes an analysis of advanced phenomena in engineering implementation. It is the analysis of a system including fluid flow, heat transfer and other parameters on various departments of science. The numerical simulation across three-dimensional model for the heat exchanger were adopted by using ANSYS FLUENT 14, in order to analyze the flow field in the heat exchanger using the solution of energy equation, momentum equation and conservation continuity. The compared results for plain tube with and without twisted tape are carried out.

Assumptions

The following assumptions are used during the present study for hot and cold water:

- Steady state.
- Newtonian fluid.

- Incompressible.
- Three dimensional.
- Laminar flow in the inner side (hot water).
- Laminar flow in the outer side (cold water).
- Negligible buoyancy.

Radiation heat transfer is not considered.

Boundary Conditions

The performance rating of the heat exchanger in this work, some requirements of the physical sample are defined adequately as follows:

- Inlet Boundary Conditions

Inlet velocity was fixed for outer (cold section) and difference at (hot section) sides during this study. The temperature inlet of the hot section is (60°C) and in the cold section is (25°C).

- Pressure Outlet Boundary Conditions

The outlet domain is set as pressure outlet for the hot and cold section.

- Wall Boundary Condition

No slip boundary condition is set in the wall of the inner tube. Use this condition for both fluid and solid region.

Governing equation

The conservation equation for continuity, momentum, and energy equations can be written as follows:

Continuity Equation

$\partial u/\partial x+\partial v/\partial y+\partial w/\partial z=0$ (1)

Momentum Equation

$(u\partial u/\partial x+v\partial v/\partial y+z\partial w/\partial z)=-dP/dx+(\partial^2u/\partial x^2+\partial^2u/\partial y^2+\partial^2u/\partial z^2)$ (2)

$(u\partial u/\partial x+v\partial v/\partial y+z\partial v/\partial z)=-dP/dy+(\partial^2v/\partial x^2+\partial^2v/\partial y^2+\partial^2v/\partial z^2)$ (3)

$(u\partial w/\partial x+v\partial w/\partial y+z\partial w/\partial z)=-dP/dz+(\partial^2w/\partial x^2+\partial^2w/\partial y^2+\partial^2w\partial z^2)$ (4)

Energy Equation

$(u\partial T/\partial x+v\partial T/\partial y+w\partial T/\partial z)=(\partial^2T/\partial x^2+\partial^2T/\partial y^2+\partial^2T/\partial z^2)$ (5)

Mesh Generation

In order to investigate the accurateness of numerical simulation in this work, various grid plans are employed in the simulation". For a compound geometry, generation of such mesh is time consuming process and always needs alterations to modify the geometry. There is mostly two kinds of approaches in volume meshing. They are struchtured and formless meshing. In structured mesh, the central calculations are transformed into curved coordinate systems allied with surface. Its small for simple shapes. In unstructured method, integral form of governing equations is discretized and also a finite-volume system used. Unstructured grids in overall effective four compound geometries, for example the result that was used in the present work **[8]**

Table (1) Number of cells generated during mesh.

Case	Number of nodes	Number of elements	Total number of cells
Plain tube	232485	1260236	1312671
Twisted tape tube	698113	3370178	3948491

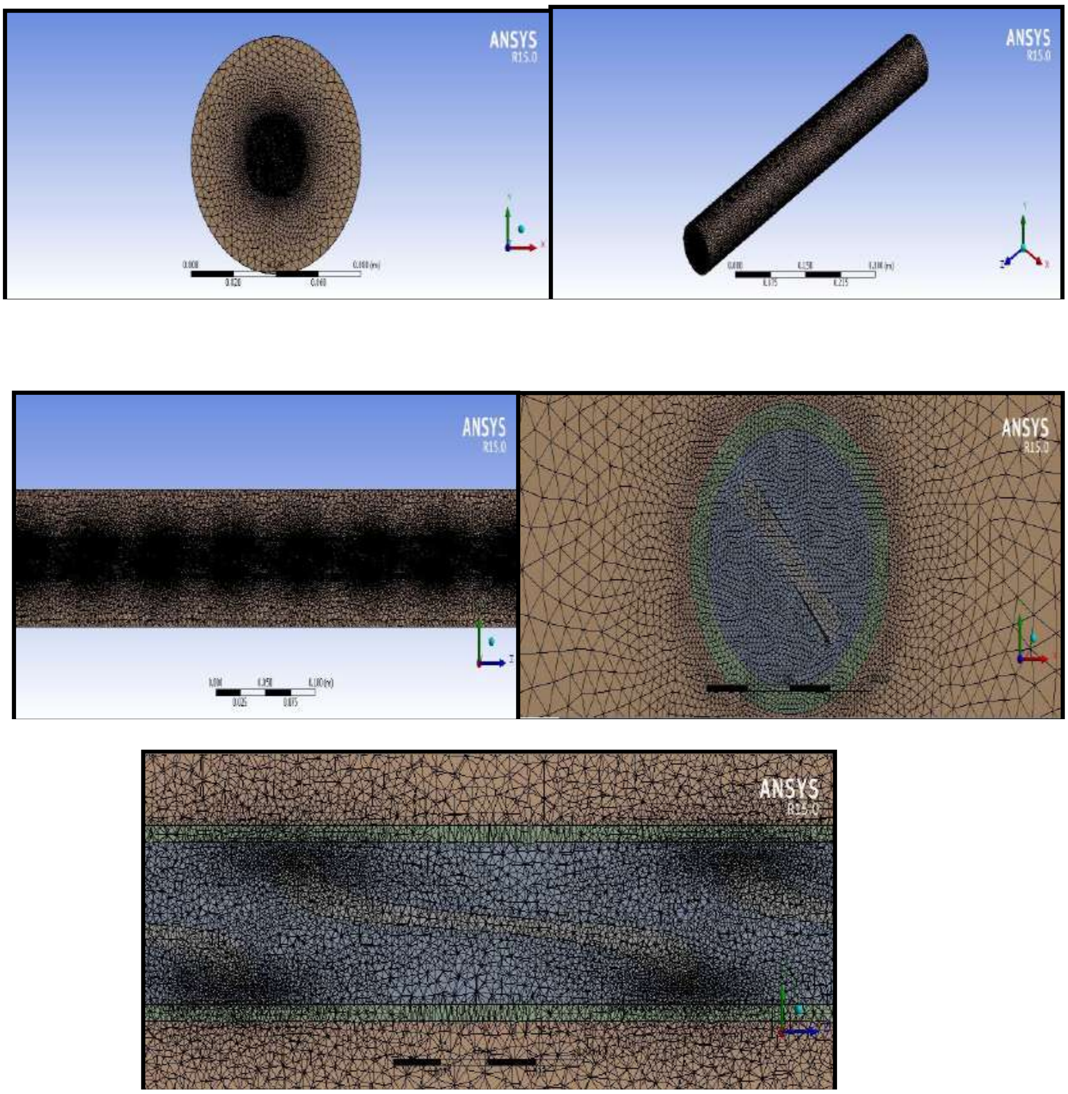

Fig.(1) Mesh generation of the persent work geometry

Numerical Results Analysis

Figure (1) to (5) show both temperature and pressure drop contours of plain tube heat exchanger at different axial distance at hot water mass flow rate (0.022kg/s) for three width of twisted tape (14,17,19.9)mm without NF. It can be noted that the maximum cold water and hot water temperatures appear at Z/d = 0 while the minimum temperatures appear at Z/d = 45 .

Figure (5) "shows both temperature and ΔP contours of Plain tube with twisted tape tube heat exchanger at hot water mass flow rate (0.022kg/s) at different axial distance with nano fluid". "Results showed a significant heat transfer augmentation in heat exchanger at Z/d from 0 to 45 for cold water and hot water sides". The effect of twisted tape on heat transfer enhancement is apparent in both sides. Also it can be noted that the maximum cold water and hot water temperatures appears at Z/d = 0 while the minimum temperatures appears at Z/d = 45. Thermo physical properties of nanofluid have the main reason of this enhancement in spite of the fact that thermal conductivity enhancement is low. This is due to experimental limitations of preparing nanofluids. This augmentation heat transfer behavior can be increased by the increase in thermal conductivity of basefluid (distilled water).

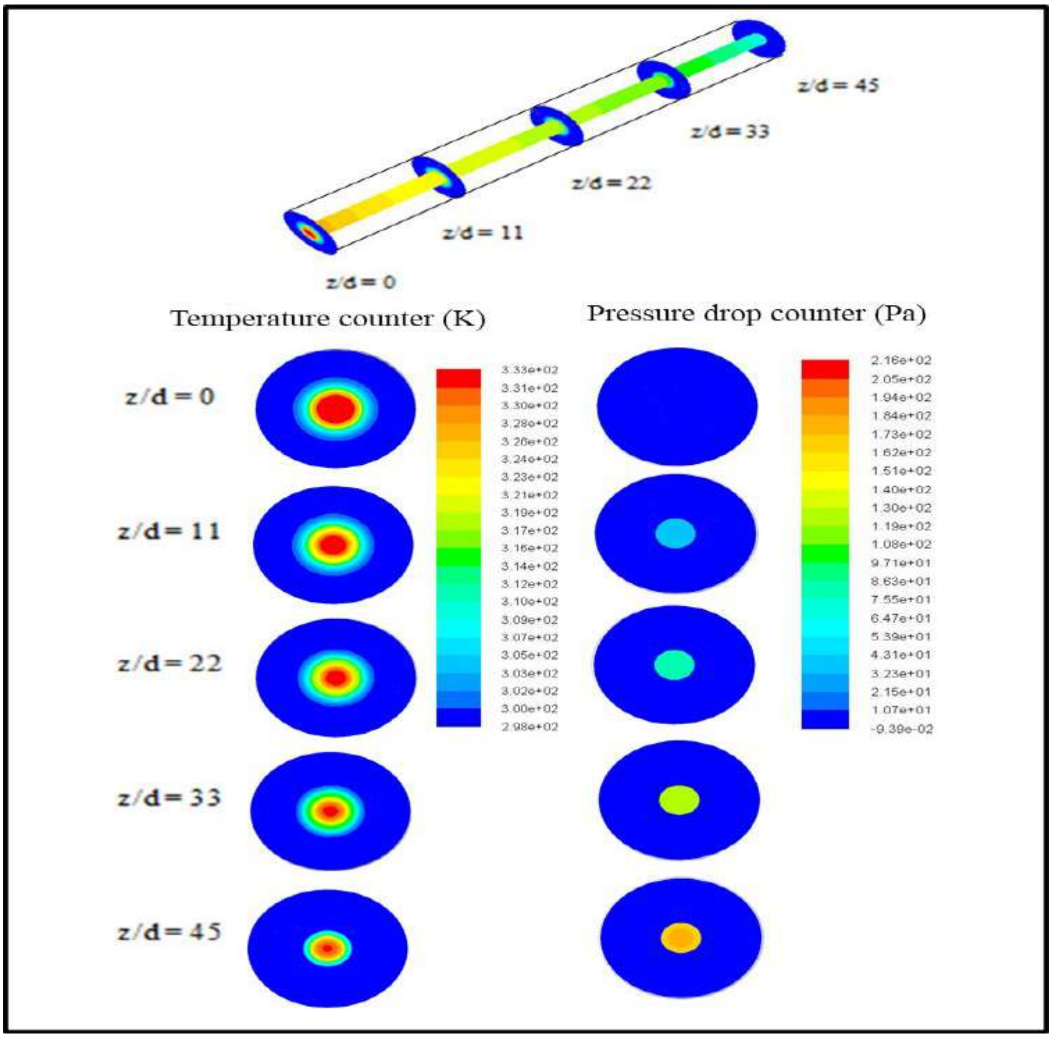

Figure (2) Temperature and pressure drop at m_c=0.022kg/s and various axial distances for plain tube heat exchanger.

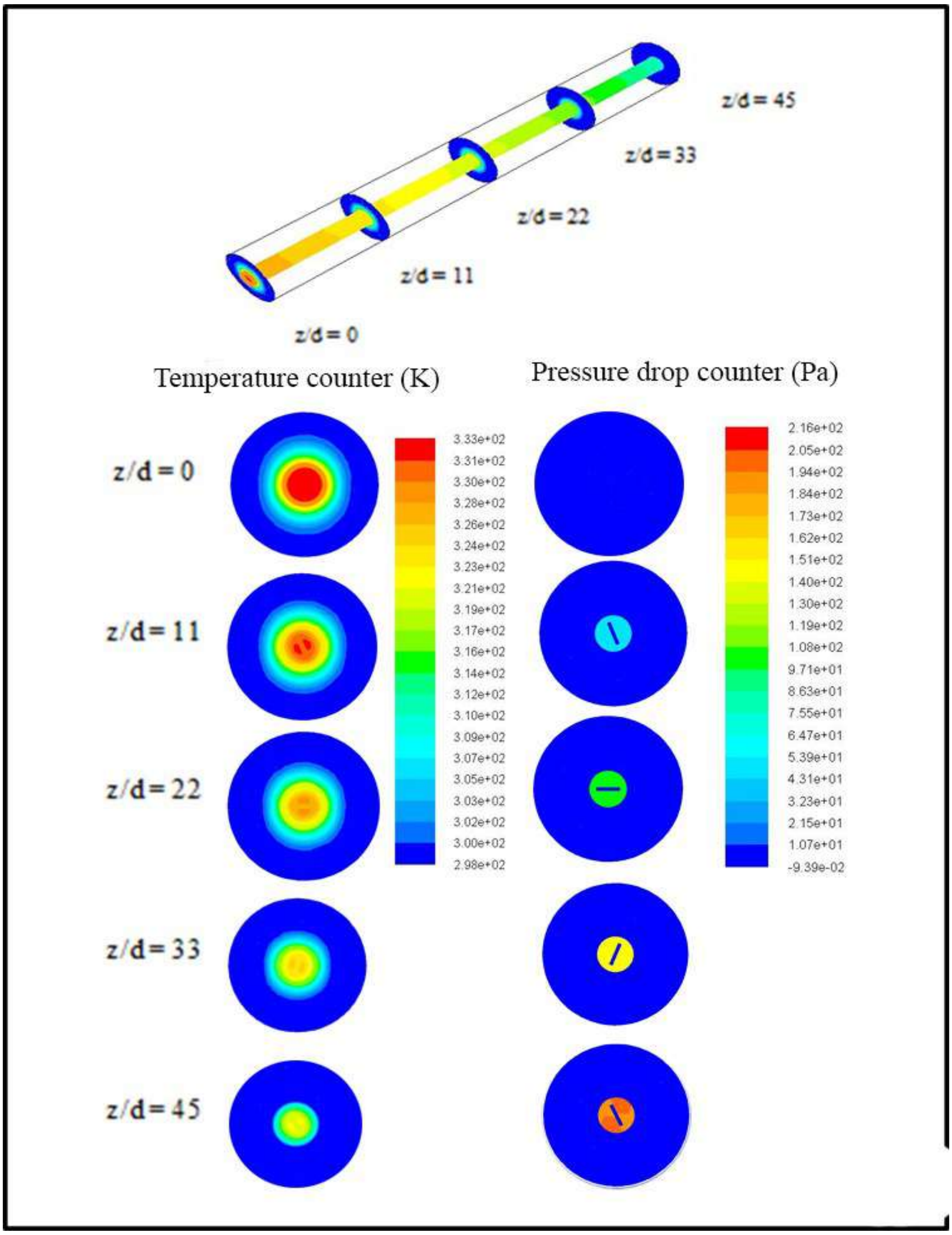

Figure (3) Temperature and pressure drop at $\dot{m}_c$=0.022kg/s and various axial distances for tube fitted with twisted tape heat exchanger (W=14mm,T.R=3.5).

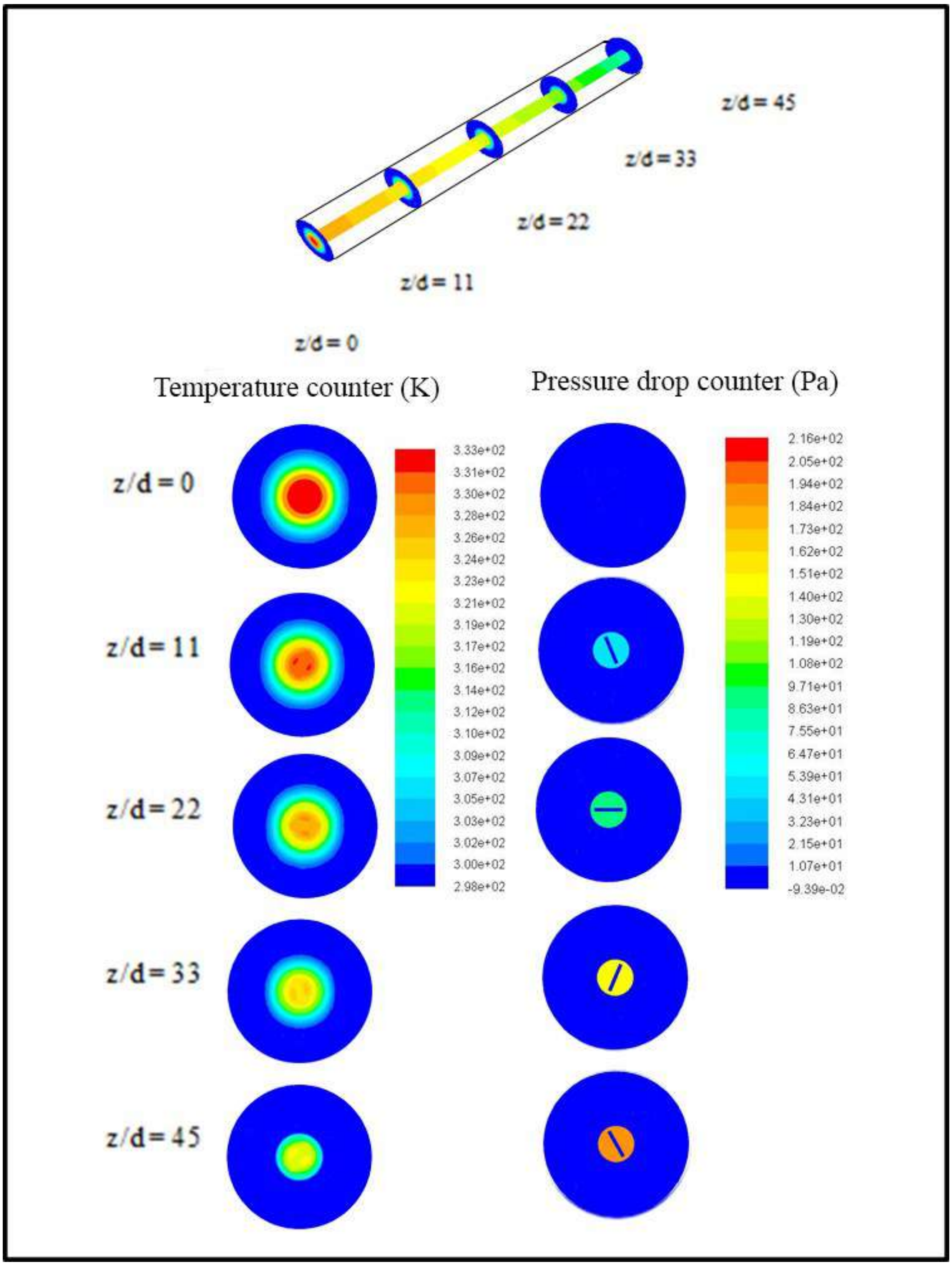

Figure (4) Temperature and pressure drop at m_c=0.022kg/s and various axial distances for tube fitted with twisted tape heat exchanger (W=17mm,T.R=3.5).

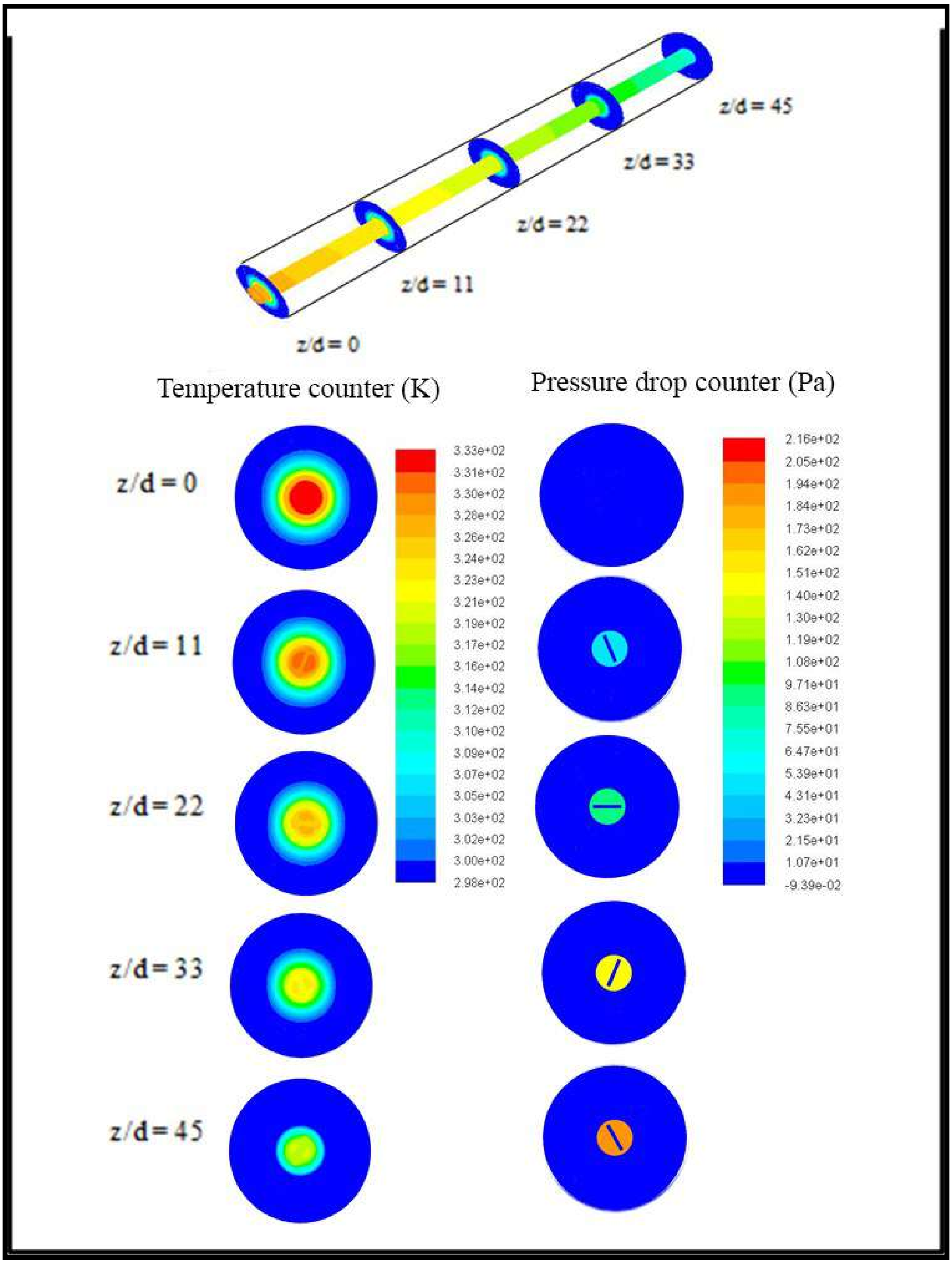

Figure (5) Temperature and pressure drop at m_c=0.022kg/s and various axial distances for tube fitted with twisted tape heat exchanger (W=19.9mm,T.R=3.5).

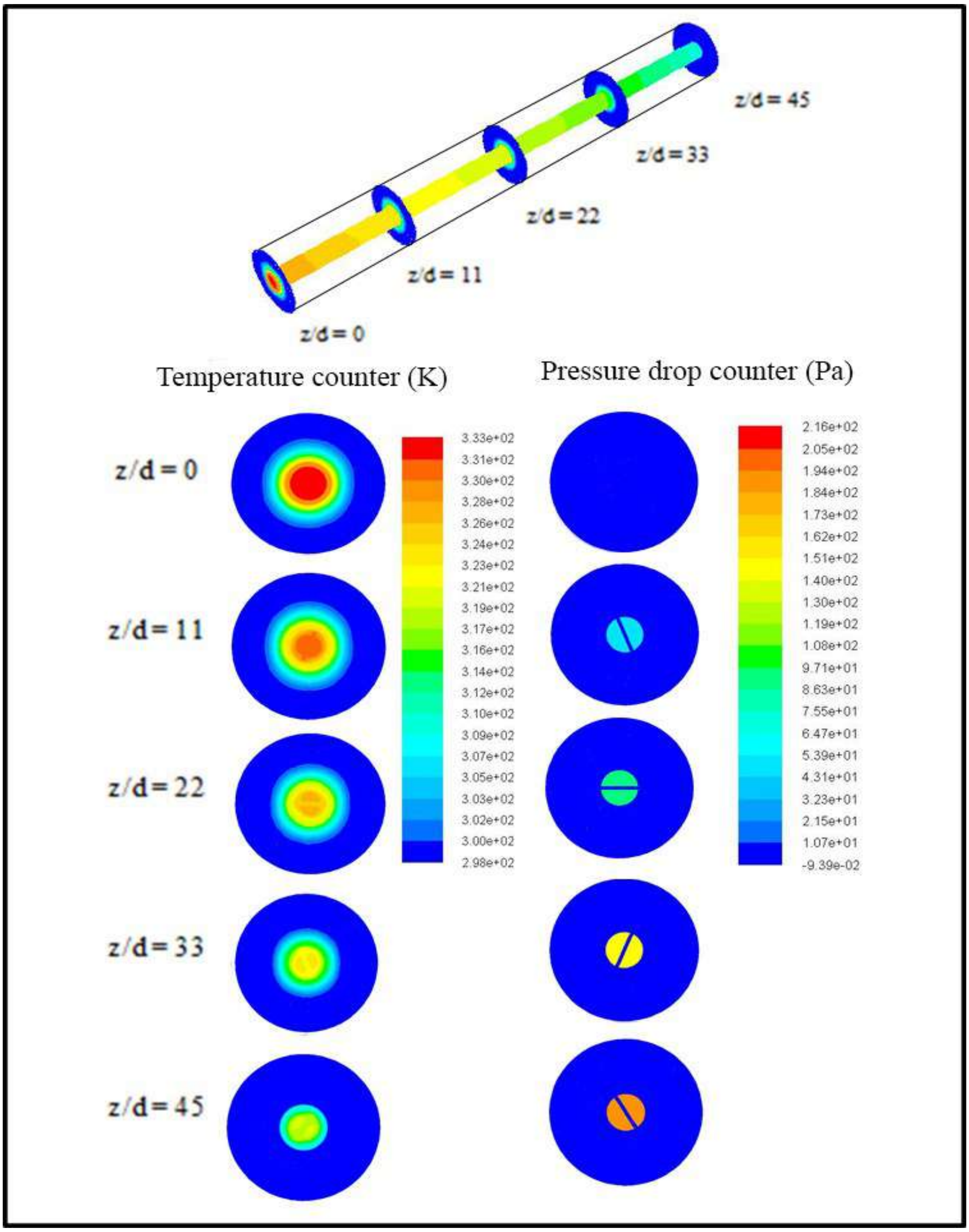

Figure (6) Temperature and pressure drop at $\dot{m}_c$=0.022kg/s and various axial distances for tube fitted with twisted tape heat exchanger (W=19.9mm,T.R=3.5) with (AL_2O_3) nanofluid..

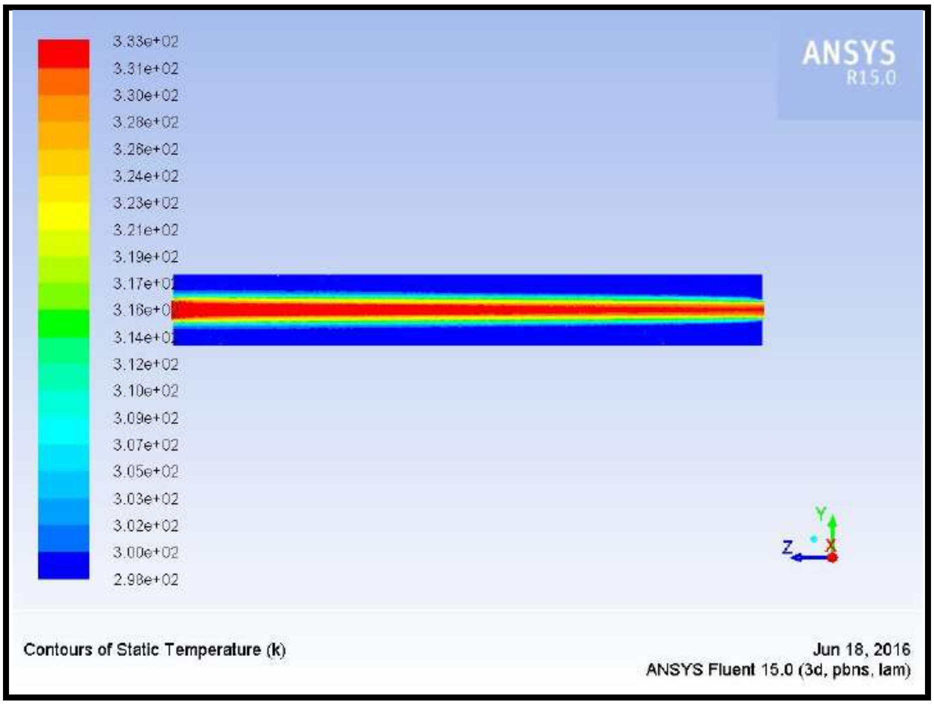

Figure (7) Temperature contours along tube at $\dot{m}_c$ = 0.022 kg/s for plain tube heat exchanger

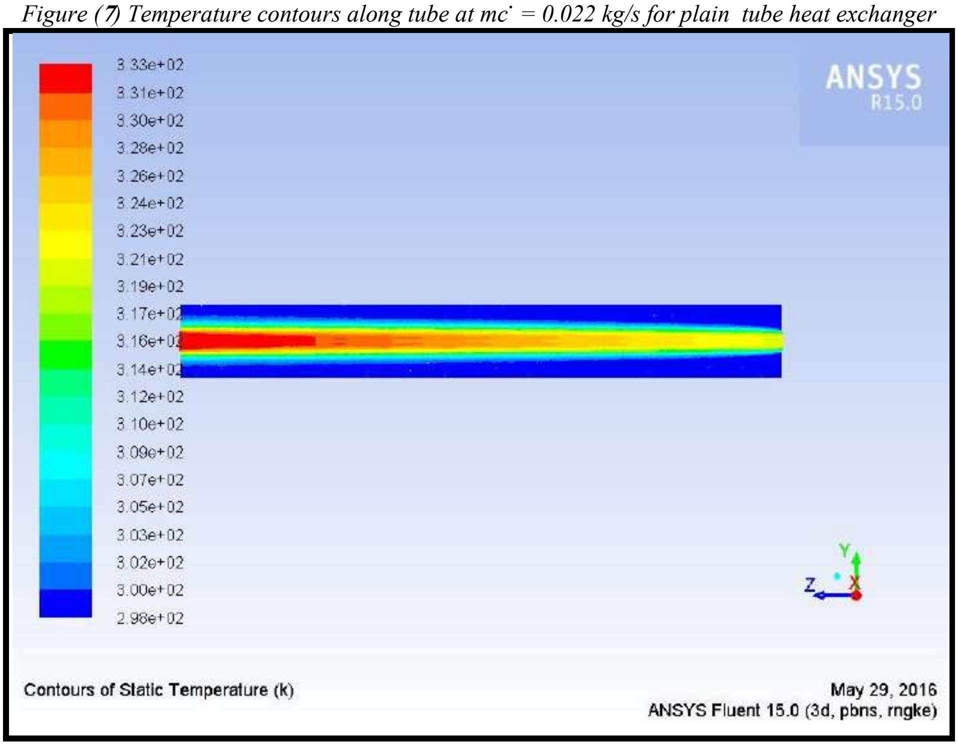

Figure (8) Temperature contours along tube at $\dot{m}_c$ = 0.022 kg/s for plain with twisted tape at width(14mm) tube heat exchanger

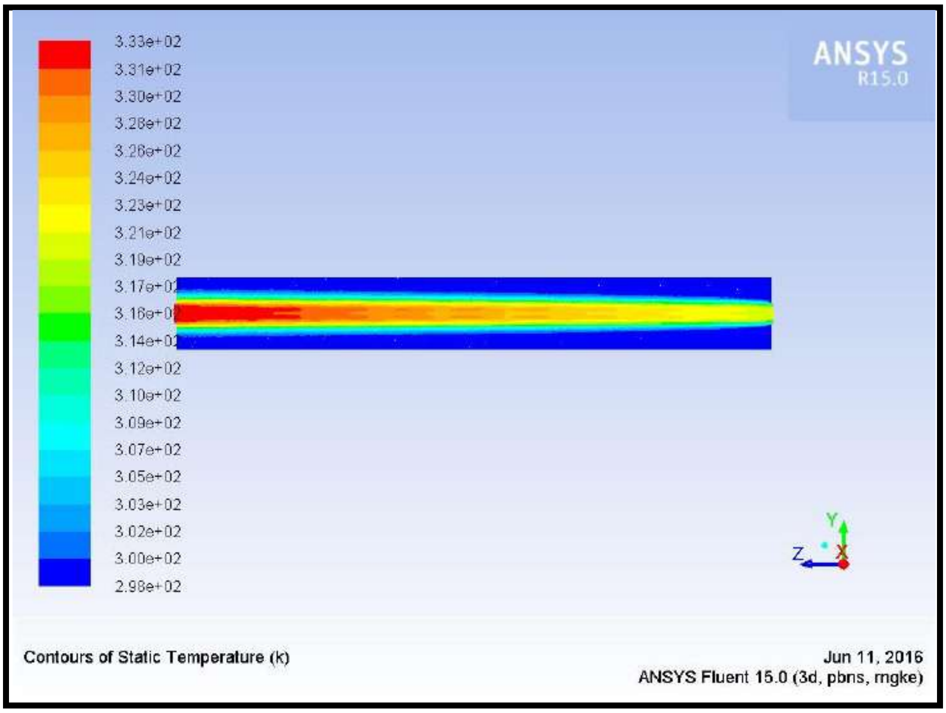

*Figure (**9**) Temperature contours along tube at mc˙ = 0.022 kg/s for plain with twisted tape at width(17mm)tube heat exchanger*

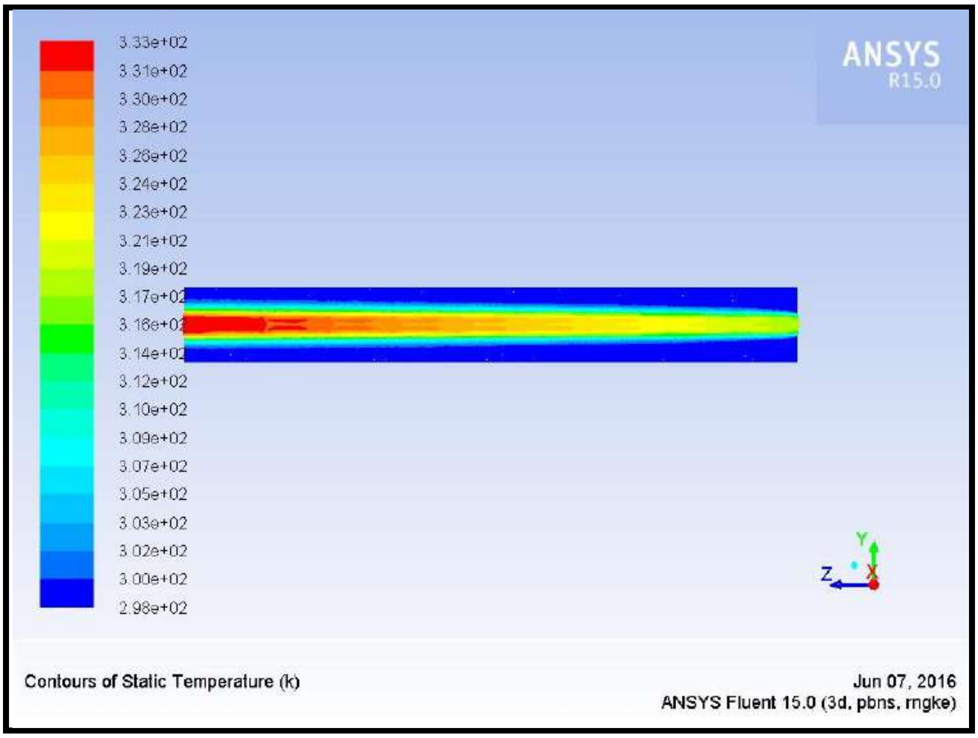

*Figure (**10**) Temperature contours along tube at mc˙ = 0.022 kg/s for plain with twisted tape at width(19.9mm)tube heat exchanger*

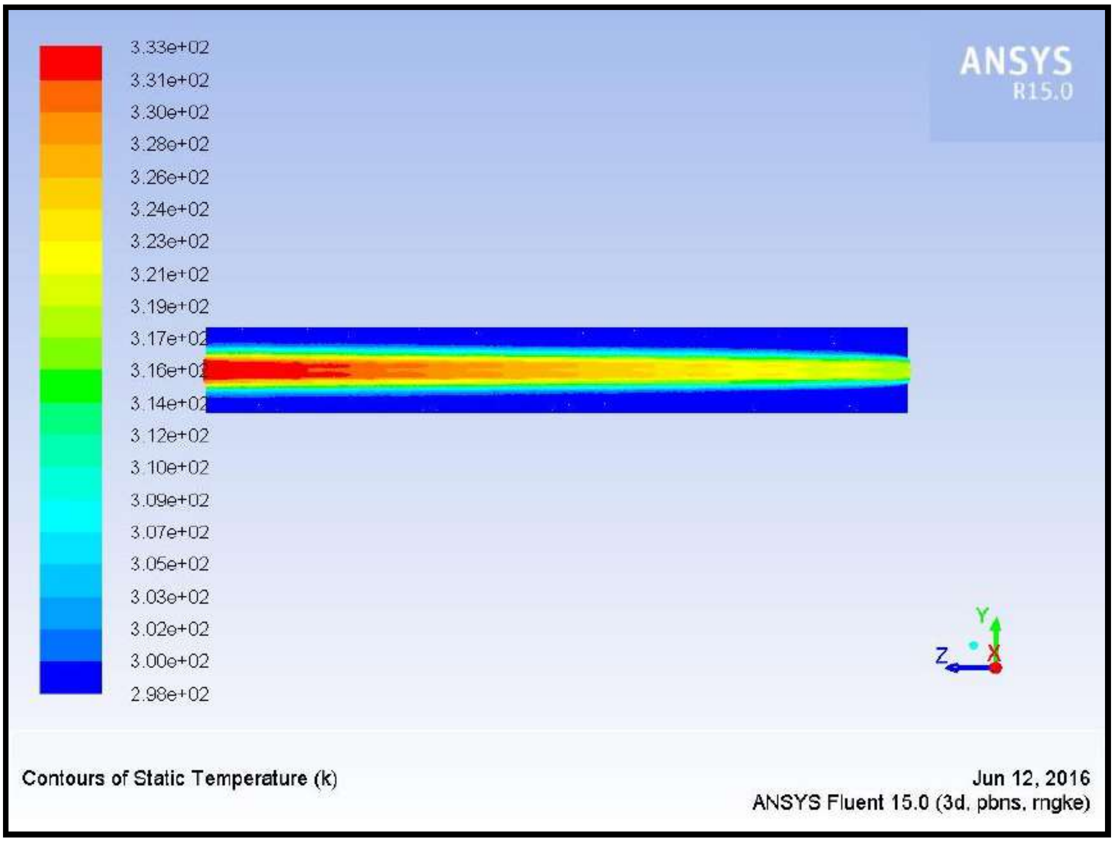

*Figure (**11**) Temperature contours along tube at mc˙ = 0.022 kg/s for plain with twisted tape at width(19.9mm)tube heat exchanger with Nano fluid.*

Conclusions

1- The significant enhancement in heat transfer of heat exchanger by using twisted tape in inner pipe has a direct proportional behavior with width ratio of twisted tape .
3- Adding AL2O3 nanoparticles to base fluid (water) causes prominent augmentation in heat transfer for heat exchanger.
4- The maximum enhancement in heat transfer rate rangs from (53.24% to 55.55%) at width ratio 0.71, (53.62% to 56.09%) at width ratio 0.854 and (52.44% to 57.17%) at width ratio 1for plain tube with twisted tape respect to plain tube without it by used water as cooling fluid.
5- The maximum enhancement in heat transfer are (69.14% to 60.44%) at width ratio 0.71, (58.36% to 61.51%) at width ratio 0.854 and (56.76% to 63.35%) at width ratio 1, for plain tube with twisted tape with respect to plain tube without twisted tape 1by used Nano fluid as cooling fluid .
6- The behavior of the hot temperature difference inversely with increase hot water mass flow rates, but the heat dissipation directly proportionally.
7- The behavior of cold temperature difference is increased directly proportional with hot mass flow rate and inversely with cold mass flow rate.

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