



NUMERICAL INVESTIGATION OF HEAT TRANSFER ON LAMINAR FLOW IN CIRCULAR TUBE FITTED WITH CONICAL SPRING INSERTS AND NANOTECHNOLOGY

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Abstract: Numerical investigation have been worked to study the process of heat transfer by using laminar forced convection of nanofluid, using the water as a basefluid and Alumina (Al_2O_3) as nanoparticles in a three dimensional tube fitted with conical spring inserts under a constant heat flux. A Solid Works Software2012 is used to draw the geometries of heat exchanger in plain tube. Dimensions of 100cm, 2.2cm and 2.4 cm represent the straight copper tube length, inner diameter and outer diameter respectively. The conical spring inserts of 16mm-6mm coil diameter, 15cm length, pitch of 20mm and 4mm wire diameter. Those inserts were arranged into eight types. To predict the pressure of flow, heat transfer of heat exchanger and temperature distribution, numbers of governing equations under assumptions were utilized, such as energy equations, momentum and continuity. To get all of the computational results, commercial ANSYS Fluent copy package 14.0 with the assistance of solid works and Gambit software program along with the finite volume approach is used. Under constant heat flux, a constant heat flux of 10000 W/m^2 and constant Reynolds' number of 2000, heat exchanger performance are investigated under the effect of different parameters. Including arrangement of conical spring inserts (A1 to A8) and volume consternation of nanoparticles (0.1%, 0.2%, and 0.3%). Significant improvement in the water heating process shown with the use of conical spring insert, indicating the enhancement of heat transfer between the water and hot tube surface.(A5) arrangement is the best type as shown in this study due to the increase in water temperature. Also, results show that the heat transfer is increases by using nanofluid and conical spring inserts together.

Keywords: Conical Spring Inserts, Fluent, Nanofluid, Enhancement of Heat Transfer

تحقيق عددي لانتقال الحرارة لجريان طباقى خلال أنبوب دائري بوجود حشوه لولبية مخروطية باستخدام تقنية النانو

الخلاصة: أنجزت دراسة عددية لانتقال الحرارة لجريان مائع نانوي طباقى باستخدام جزيئات (Al_2O_3) والماء خلال أنبوب مزود بحشوة لولبية مخروطية الشكل تحت ظروف فيض حراري ثابت. تم استخدام برنامج (Solid Works Software2012) لرسم شكل المبادل الحراري. أنبوب الاختبار أفقي مصنوع من النحاس بطول 100سم وقطر داخلي 2.2سم والقطر الخارجي 2.4سم. يبلغ طول الحشوة اللولبية المخروطية 15سم، بينما يتغير قطر لفة الحشوة اللولبية من 16سم إلى 6سم، ويبلغ قطر سلك الحشوة 4مم، ومقدار خطوة اللفة

20م. تم ترتيب الحشوات داخل الانبوب بثمانية أصناف . تم حل المعادلات الحاكمة بموجب عدة فرضيات للتنبؤ بضغط الجريان ، توزيع درجات الحرارة ، و الحرارة المنقلة خلال المبادل الحراري . استخدم برنامج ANSYS Fluent لأيجاد النتائج المحوسبة. تم دراسة تأثير عدد المتغيرات على أداء المبادل الحراري تحت تأثير فيض حراري ثابت مقداره (10000 واط/م²) وعند عدد رينولد ثابت وقدرة (Re=2000) عند تغيير التركيز الحجمي للجزيئات النانوية (0.1%، 0.2%، 0.3%) وعند تغيير تصنيف ترتيب الحشوات (A1-A8). أظهرت النتائج تحسين في انتقال الحرارة بين سطح الأنبوب الساخن والماء . كما أظهرت ان الترتيب (A5) هو أفضل ترتيب لتوزيع الحشوات داخل الانبوب حيث يعمل على أكبر زيادة لدرجة حرارة الماء . كما أظهرت النتائج الى وجود تحسين في انتقال الحرارة عند استخدام الحشوات والمائع النانوي معاً.

1. Introduction

The process of heat transfer intensification or enhancement, augmentation is the study of improved heat transfer performance. Generally its mean that the coefficient of heat transfer will be increased [1]. Sidi et al. [2] investigated numerically the hydrodynamic and thermal performance of turbulent flow in a constant tube wall heat flux using (AL₂O₃/water) nanofluid. Numerical results demonstrate that an enhancement in heat transfer, which has been found to increase significantly with an increase in volume concentration. Lazarus et al. [3] investigated the convection of heat transfer of de-ionized water with the use of low volume fraction of copper oxide (CuO) nanoparticles. Experimented the flow of Nanofluids inside a copper tube under laminar flow and heat flux conditions. The results showed that even with a low volume concentration 8% (0.003% by volume) of CuO nanoparticles there will be an increase in convective heat transfer coefficient of the nanofluid. Also, as the Reynolds number increased, the heat transfer enhancement was increased significantly. Kapatkar et al.[4]studied experimentally the heat transfer inserts for Reynolds number range laminar flow (20-2000) , range of mass flow rate (2gm/s - 20gm/s) under uniform wall heat flux condition and friction factor of a smooth tube fitted with full length twisted tape. An enhancement in average Nusselt number for the flow in smooth tubes was resulted with full-length twisted tapes and it increases with the increase in Reynolds number and mass flow rate. Almohammadi et al. [5] studies the pressure drop of(AL₂O₃/water) nanofluid and heat transfer in laminar flow region under constant heat flux conditions inside a circular tube. (AL₂O₃/water) nanofluid with 1% and 0.5% volume concentrations were used as working fluid.

The results showed that the average heat transfer coefficient increases about 16-27% with 1% volume concentration and 11-20% with 0.5% volume concentration in comparison to distilled water. No statistically significant increase in friction factor for nanofluids because the ratio of nanofluid friction factor to the friction factor of base fluid is about 1.1 for 0.5% volume concentration. Sami et al. [6]investigated numerically the characteristics of friction factor and heat transfer for copper-water nanofluid passing through circular tube with constant wall heat flux fitted with two different types of vortex generator, which are classical twisted tape (CTT) and parabolic-cut twisted tape (PCT). The results showed that at lower twisted ration a higher values for Nu and friction factor. Dhirajkumar et al. [7] offered review of researches work of modern techniques in heat transfer enhancement. Many researchers have used different techniques to enhance heat transfer.

Worldwide energy utilize is expected to increase by almost 1.6 times, from 4.03×10^{20} J in 1999 to 6.4×10^{20} J in 2020. Thus, if the efficiency of energy usage could improve by 10 per cent, by means of different heat transfer enhancement techniques, this will result in 6.4×10^{19} J of advantage in terms of energy utilization to the society. Special importance in this study is given on different techniques of heat transfer enhancement, developed in recent times. Qasim and Ali [8] reported the use of different kinds of tapes that are twisted and fitted through double pipe heat exchanger to increase the fluid mixing property that leads to increase the heat transfer rate with respect to that of the plain-twisted tape. Experimentally investigated the flow friction, heat transfer, and thermal enhancement factor characteristics in a double pipe heat exchanger fitted with plain and variant twisted tapes under the use of water as working fluid. Tests are done for laminar flow ranges.

V cut-twisted tape and Horizontal wing cut-twisted tape are two different variant twisted tapes with twist ratios of $y = 2.0, 4.4$ and 6.0 are used. Also, study the difference of heat transfer coefficient of copper–nanofluids with various Reynold's number and volume concentration of nanoparticles in plain tube without twisted tape. According to these studies, the main conclusion has been reached that the Nusselt number, thermal enhancement factors and friction factor of different twisted tapes are higher than that of plain twisted tape for the twist ratios of $2.0, 6.0$ and 4.4 respectively.

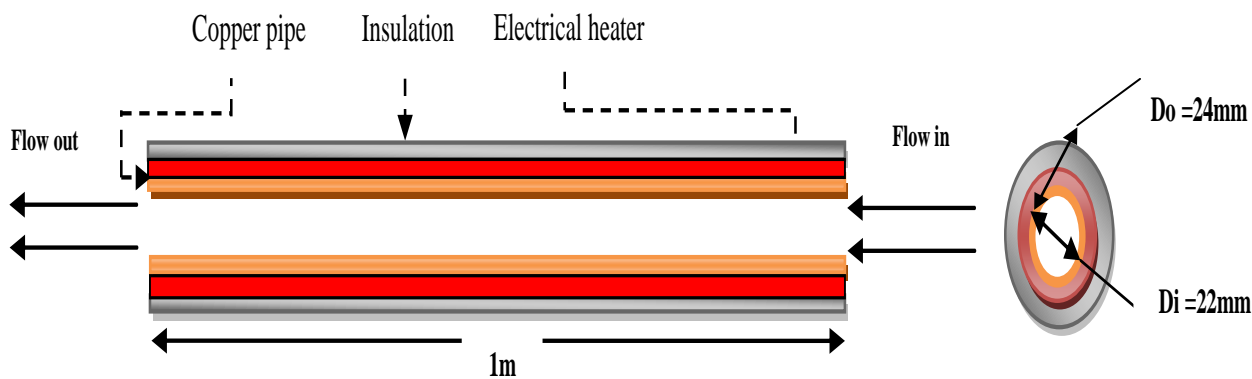
Qasim and Noor [9] investigated experimentally the characteristics of heat transfer enhancement and friction factor for completely developed laminar CuO/distilled-water nanofluid flow through horizontal tube inserted with various geometries of twisted tapes under constant condition of heat flux ranged from $4483 - 10000 \text{ W/m}^2$. Nanofluids are prepared by using Different volume concentrations of CuO nanoparticles that are suspending in distilled water. The results revealed a significant increase of both Nusselt number and convective heat transfer in terms of friction factors with inserting twisted tape and nanofluids as working fluid in comparison to nanofluids in plain tube condition. Also the overall enhancement occurs as both Reynolds number and volume concentration increases.

New Empirical correlations have been established for an average Nusselt number and friction factor in terms of the factors mentioned earlier. The purpose of the present work is to study the overall thermal performance of tube with conical spring insert in various orientations under constant heat flux, with and without nanofluids. ANSYS FLUENT. 14 package Numerical simulations are used to mimic the system then using laminar flow with and without nanofluids.

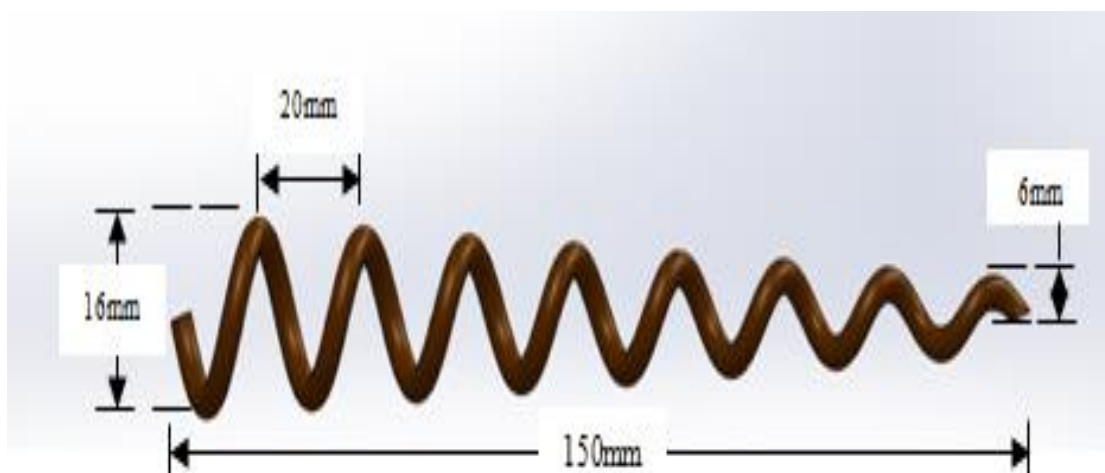
2. Mathematical Modeling and Numerical Simulation

ANSYS FLUENT. 14 packages have been directed to accomplish numerical simulation through constant heat flux tube using 3–D model. The solution of conservation continuity, momentum and energy equations are used to evaluate the heat transfer of laminar flow in circular tube fitted with conical spring inserts with nanofluid taking Alumina (Al_2O_3) as nanoparticles and the water as based fluid. Evaluation of heat transfer for plain, inserted tube with / without nanofluids is performed. Numerical procedure will be expressed in the

following sections. Software 2012 solid works is used to outline the geometries of this work. Computational domain in the current study is shown in Fig.1-a. Fig.1-b shows the shape of conical spring insert with dimensions. It is made of copper material.



(a) Computational Domain in The Present Study



(b) Conical Spring Insert with Dimensions

Fig. 1 (a) Computational domain in the present study (b) Conical spring insert with dimensions

Fig.2 illustrates eight type of tube arrangement with conical spring insert and the plane tube (A1 -A8). The orientation of conical spring insert in any type is unlike the other. The objective is to verify the best type that works to improve the heat transfer with less pressure loss.

Then the effect of pressure losses and the using of nanofluid on heat transfer will be examined.

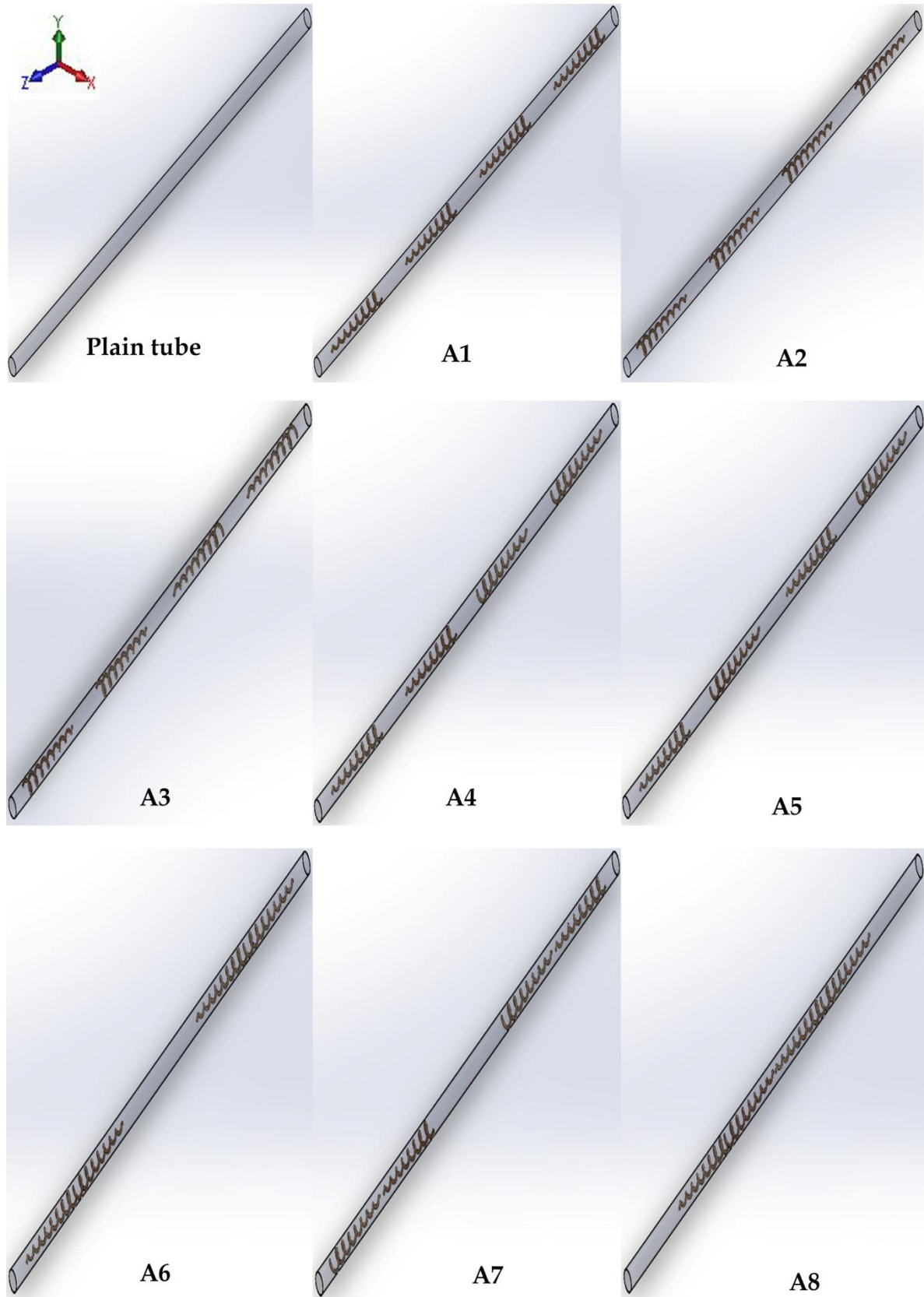


Fig. 2. The Plane Tube (A1-A8) with Conical Spring Inserts Arrangement.

Newtonian fluid, steady state, three dimensional, incompressible and laminar flow represent the assumptions used during the conducted study. While the radiation heat transfer is not taking into consideration. Continuity, momentum and laminar energy flow of governing equations inside an inner tube are represented below. Davidson [10]:

- Continuity Equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (1)$$

- Momentum Equations

$$\rho \left(u \frac{\partial(u)}{\partial x} + v \frac{\partial(u)}{\partial y} + w \frac{\partial(u)}{\partial z} \right) = -\frac{\partial p}{\partial x} + \mu \frac{\partial}{\partial x} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) \quad (2)$$

$$\rho \left(u \frac{\partial(v)}{\partial x} + v \frac{\partial(v)}{\partial y} + w \frac{\partial(v)}{\partial z} \right) = -\frac{\partial p}{\partial y} + \mu \frac{\partial}{\partial y} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) \quad (3)$$

$$\rho \left(u \frac{\partial(w)}{\partial x} + v \frac{\partial(w)}{\partial y} + w \frac{\partial(w)}{\partial z} \right) = -\frac{\partial p}{\partial z} + \mu \frac{\partial}{\partial z} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) \quad (4)$$

- Energy Equation

$$\rho c_p \left(u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} + w \frac{\partial T}{\partial z} \right) = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) \quad (5)$$

Where, T: temperature,(u,v,w): velocity component, μ : dynamic viscosity, Cp: specific heat, k: thermal conductivity, and ρ :density.

2.1 Mesh generation

GAMBIT software was utilized modeling the mesh. Currently, in this work, triangular and tetrahedron element types were involved for surface mesh and three dimensional geometry respectively. Fig. 3 shows the present model mesh. Criteria of nanofluid particles shown in Table 1. In order to choose the mesh optimum size, various grid sizes were tested and now transported to software program (FLUENT 14.0). The temperature distributions of the tested grids were compared to select the optimal grid size in the study [11], [12].

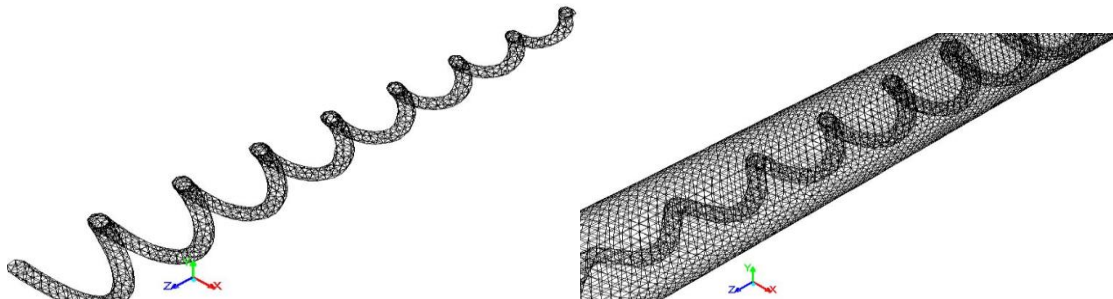


Fig. 3 Mesh of Present Model (Triangular Element Type)

Table 1 Specification of Nanoparticles [13], [14].

Type	D (nm)	ρ ($\frac{\text{kg}}{\text{m}^3}$)	k ($\frac{\text{W}}{\text{m}\cdot^\circ\text{C}}$)	Cp ($\frac{\text{J}}{\text{kg}\cdot^\circ\text{C}}$)
Al_2O_3	< 80	3700	46	710
Al_2O_3 + water (0.1%)	-----	1268	0.652	3834
Al_2O_3 + water (0.2%)	-----	1538	0.696	3487
Al_2O_3 + water (0.3%)	-----	1808	0.734	3140

In this investigation, an average of (1.25) million cells are utilized and it is represent the highest number of iterations done to achieve the solver terminates. As shown in Fig. 4, (1600) iterations are required in this work.

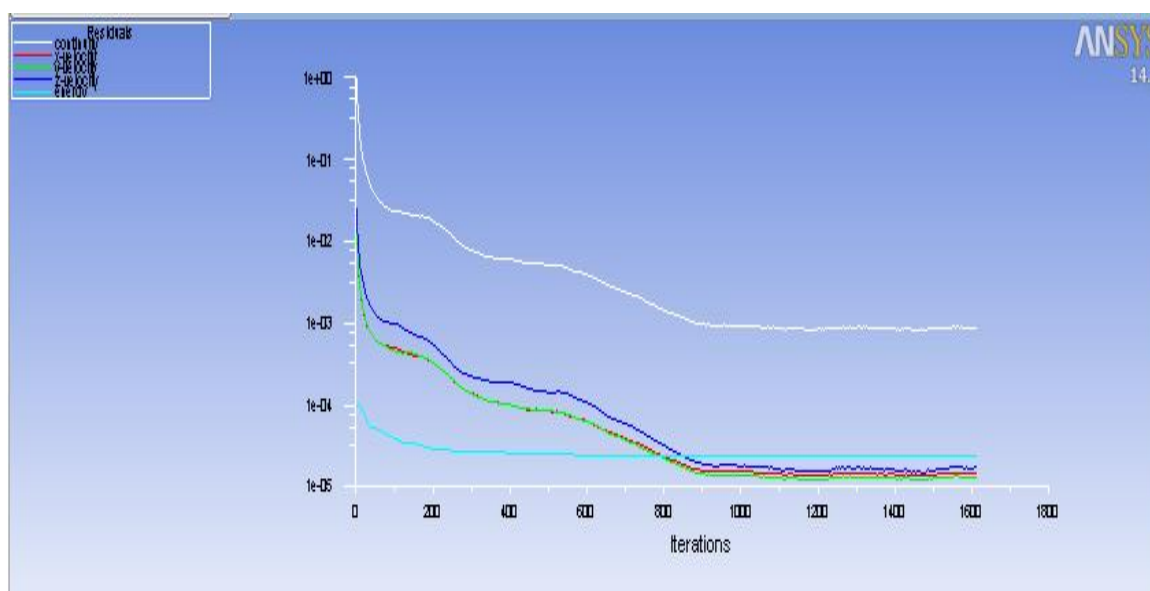


Fig. 4 Residual for Numerical Simulation of Present Study

3. Model Validation

A comparison has been carried out in order to authorize the current numerical simulation according to the former numerical results, achieved by ref. [9].

In Fig. 5 a good agreement has been found between these results which indicate the acceptable validations of the present simulation.

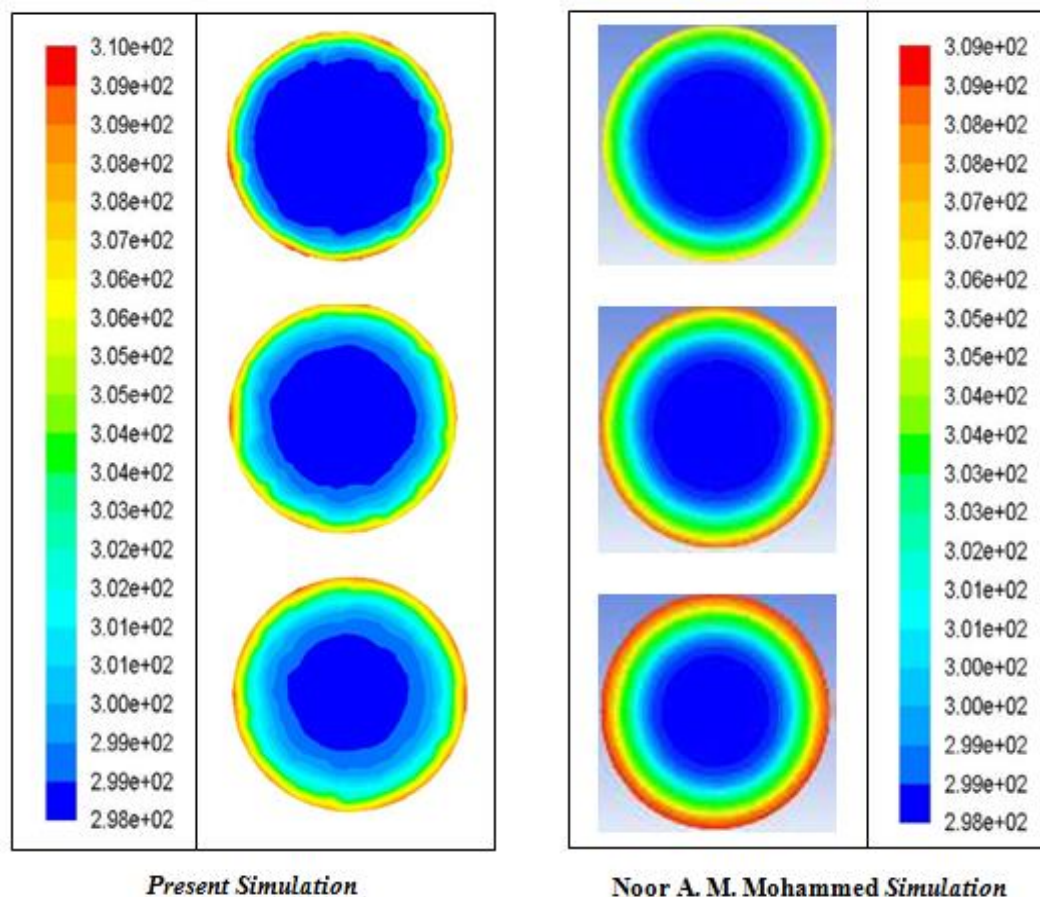


Fig. 5 Numerical Simulation Validation.

4. Result and Discussions

Fig.6 demonstrate the velocity vector and the temperature contours at three locations ($Z=0.25, 0.5,$ and 0.75) for plain tube and all other types of the arrangement of the inserted tube. Fig. 6-a, demonstrated that heating of the water passing through the tube is limited for temperature contours in plain tube. So in order to reach a specific temperature difference, an increase in the length of the tube is needed.

The reason behind it is due to the high velocity of water flow through the tube, which holds the possibility of heat transfer as can be seen shown in velocity vector of flow. With the use of conical spring insert, contours show a significant enhancement in the water heating process demonstrating that the heat transfer between the hot tube surface and water has been enhanced. Fig.7 illustrates the behavior of water during heat transfer by heating the surface of the tube at longitudinal axis.

Figure shows that for all type arrangement (A1 to A8). Water temperature increases for the tube with conical spring insert. Fig.7 demonstrates that (A5) is the best arrangement, because of the increase in the water temperature. A swirl flow caused by the conical spring inserts disrupting the water boundary at tube surface due to tangential velocities enhancement. The water boundary layer disruption leads to a thinner boundary that improves the heat transfer process. Fig.8 illustrate that the drop in the pressure begins from tube inlet to the downstream of flow along the tube to the exit section due to losses of the friction

between the water viscous boundary layer and inner surface of pressure losses through a plain tube is less than

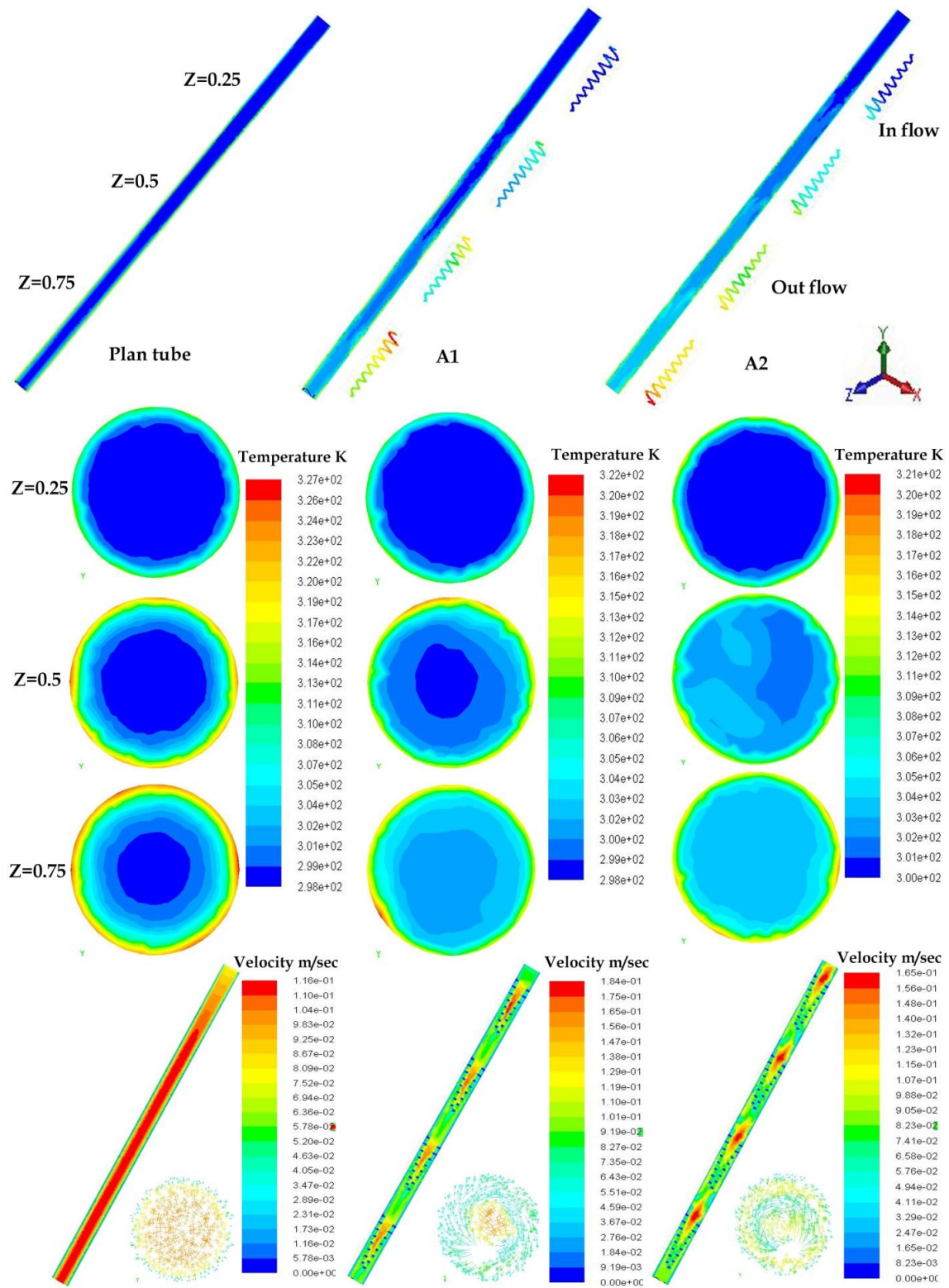


Fig 6-a Temperature Contours and Velocity Vectors.

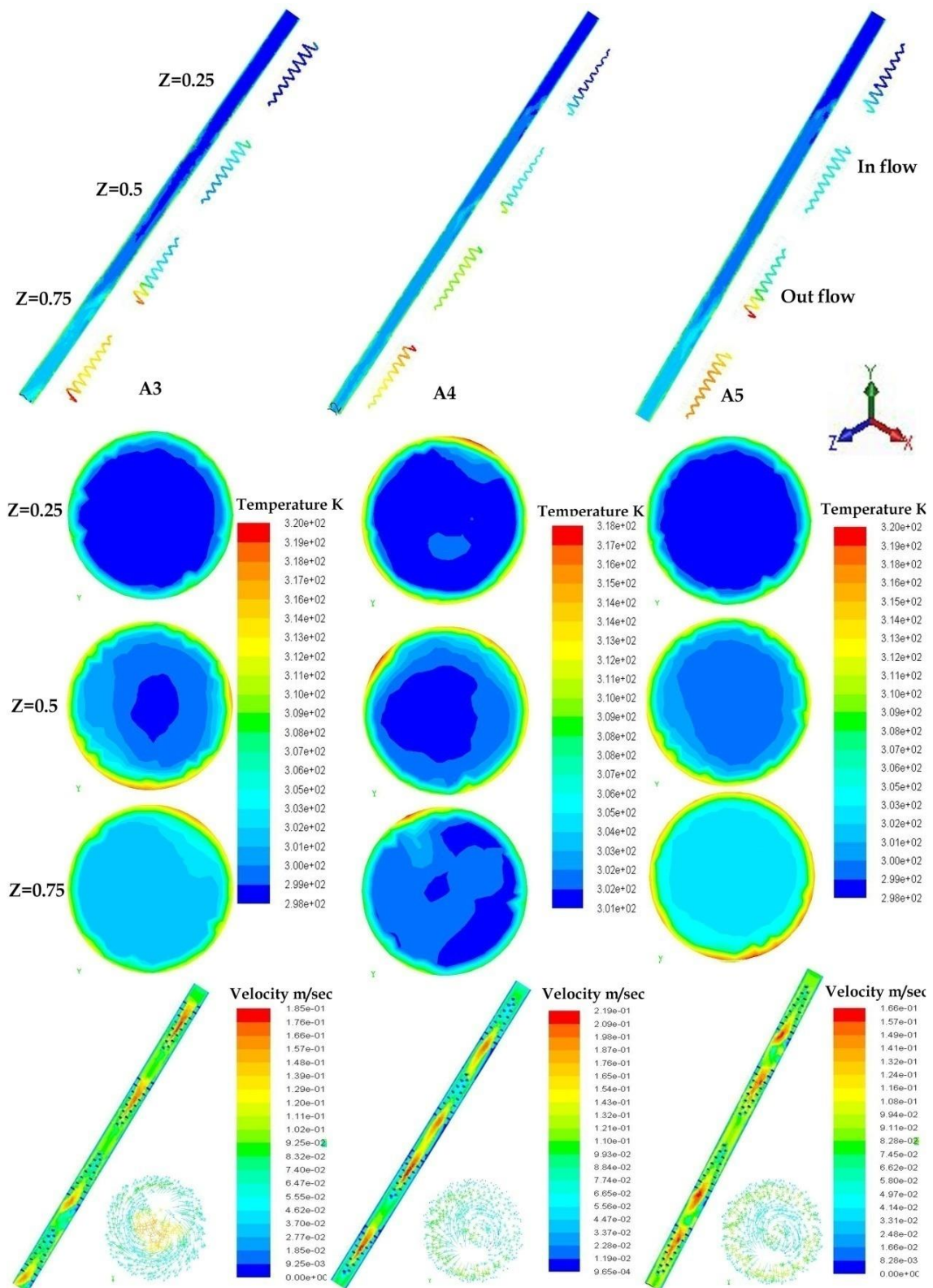


Fig 6-bContinuity.

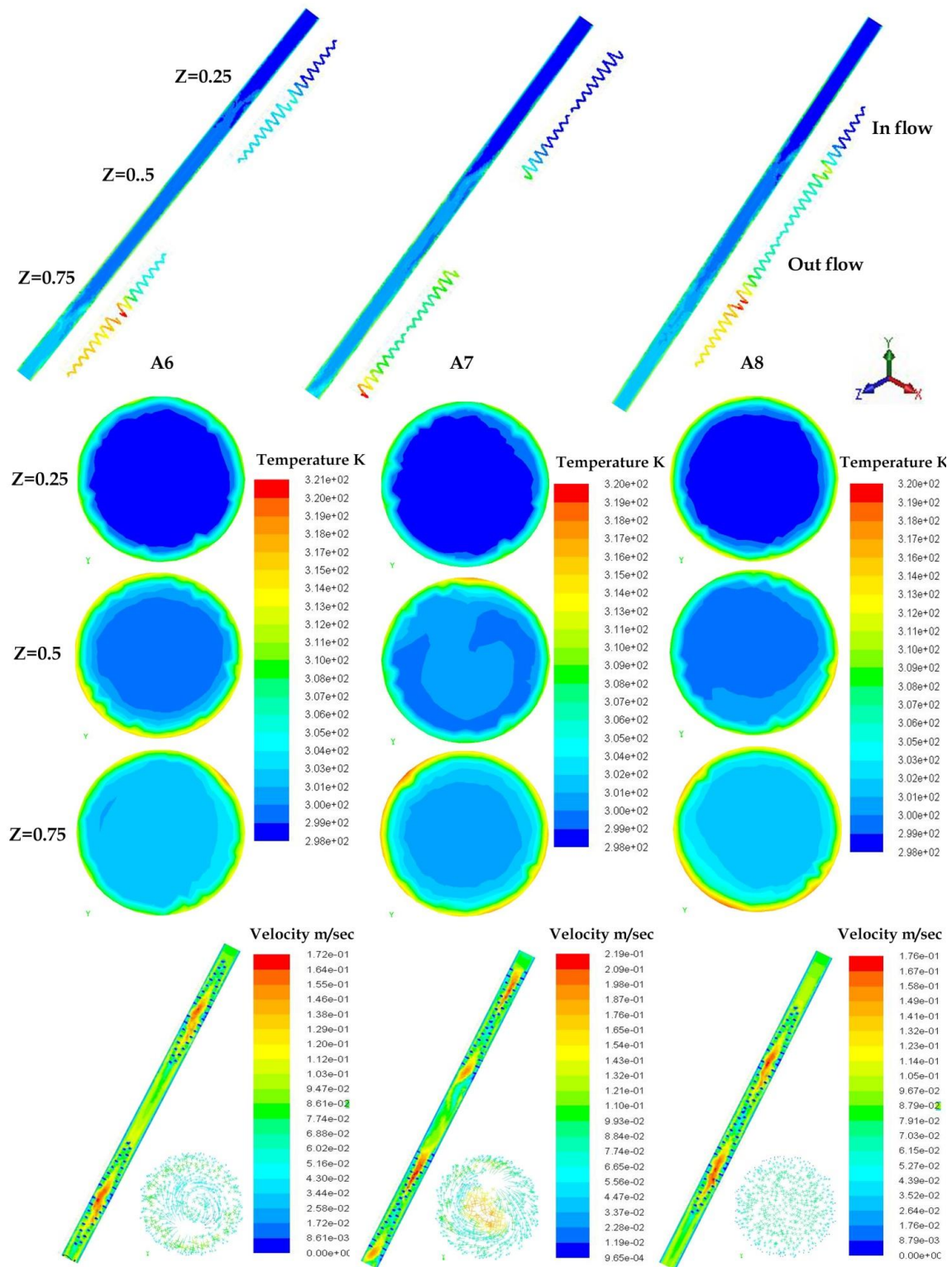


Fig 6-c Continuity

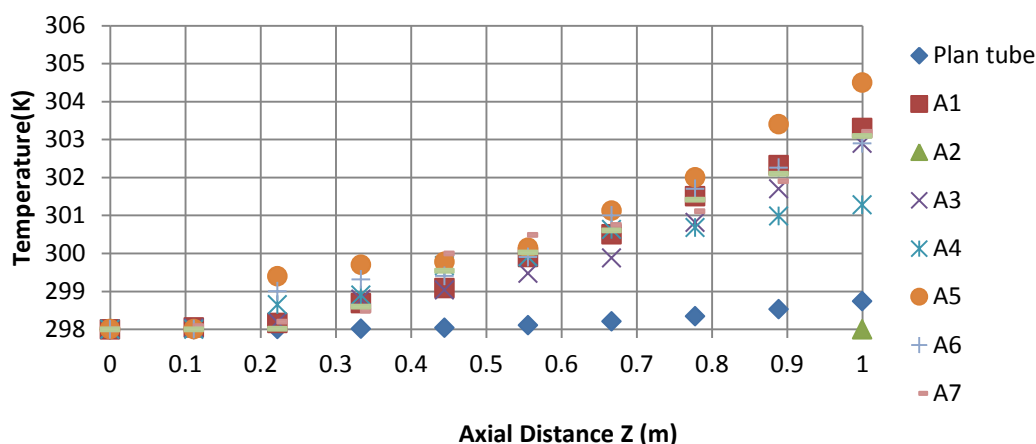


Fig.7 Heat Behavior of Water in Relation with Axial Distance.

losses in the tube with conical spring insert. This is because of the conical spring insert swirling path is generated by conical spring insert and the additional local vortices. The boundary layer of the viscous nearby the inner surface of tube is destroyed.

This caused higher contact between water and the surface then increasing friction losses. Fig.8 demonstrates that class A5 is the best classification. Fig.9 show the temperature contours at three position for A5 arrangement when water or nanowater pass through tube at ($Re=2000$) and heat flux equal to 10000 W/m^2 .

Figure shows that with the use of nanowater, the temperature of the surface of the tube decreases. Figure shows an improvement in heat transfer between the water and hot surface of tube. The difference in temperature increases will lead to the increase in the volume concentrations of nanoparticles in distilled water due to the higher thermal conductivity of these metallic solid nanoparticles which caused improvements in the thermal properties of water.

Micro convection happens from the interface of fluid layer around nanoparticles that increases the convection of heat transfer which enhance the thermal diffusion of nanoparticles.

Fig.10 illustrates the exact heat behavior for A5 arrangement with the addition of Al_2O_3 nano particles, the heat is more dissipated from inner surface of tube which enhances the heat transfer rate.

The results shows by using conical spring insert, higher heat transfer rate with nanowater than using nanowater alone. Fig.11 illustrates the pressure behavior through the tube with type A5 conical spring inserts. Figures show that the nanowater requires bigger power to pump it through the tube. This means that friction losses will be greater in the case of nanowater.

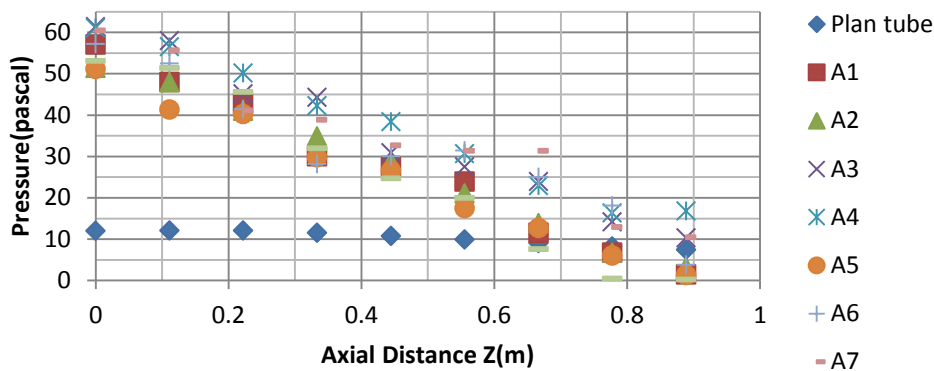


Fig.8 Pressure Behavior of Water in Relation with Axial Distance.

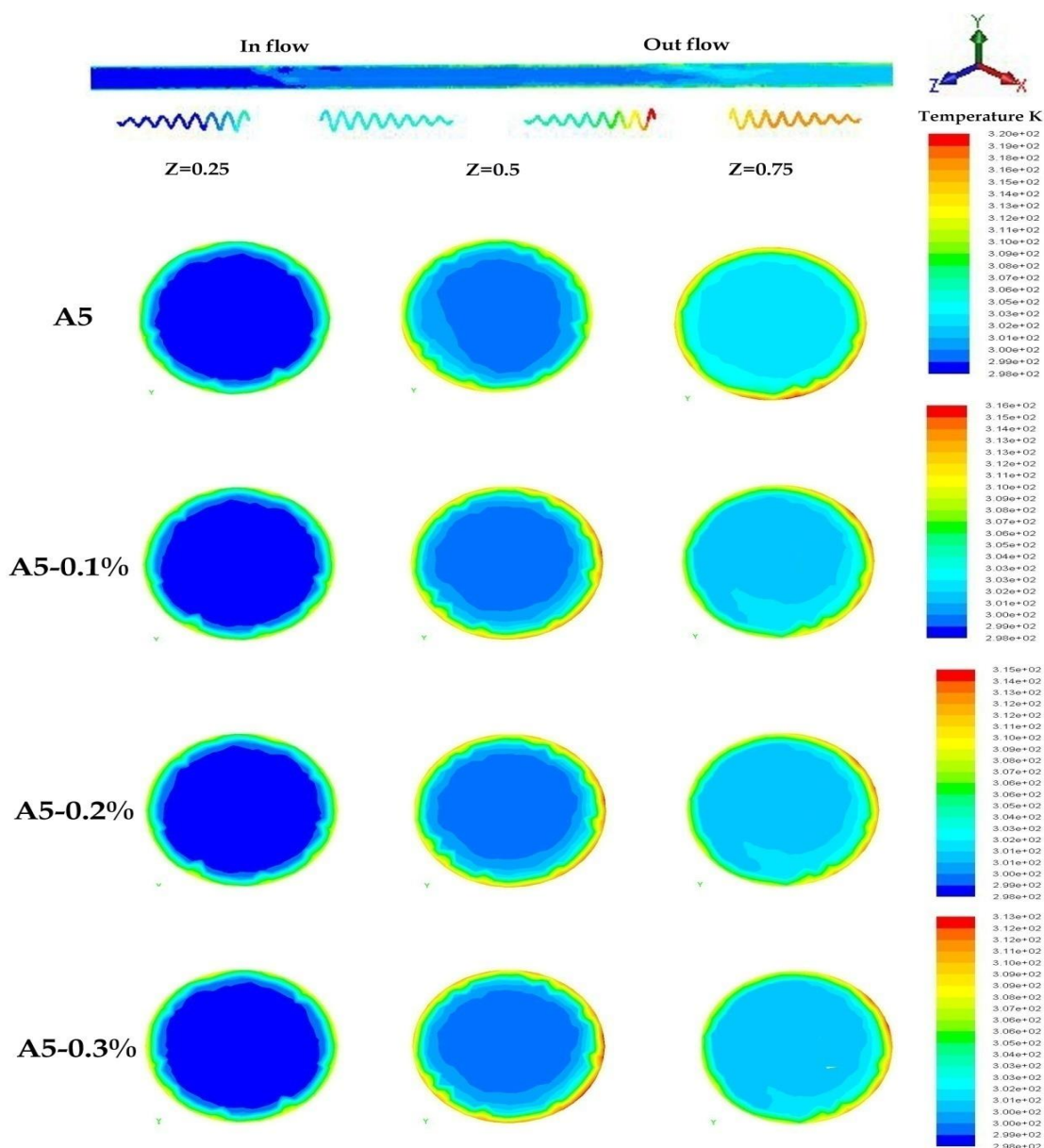


Fig.9 Temperature Contours at Three Position for A5 Arrangement When Water or NanoWater Pass Through Tube.

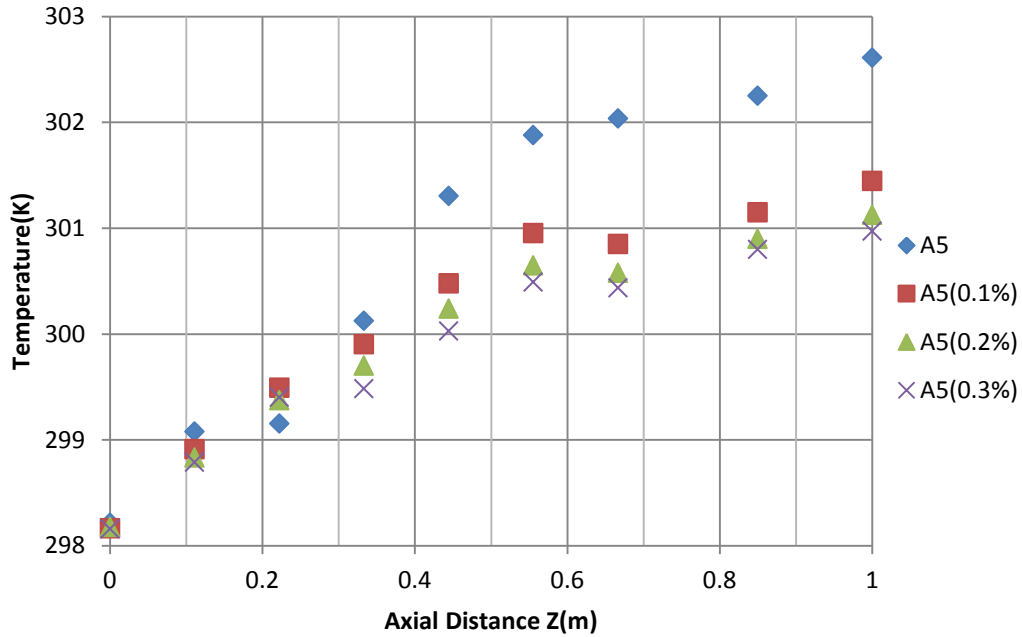


Fig.10 Heat Behavior of Water for A5 Arrangement with the Addition of NanoParticles.

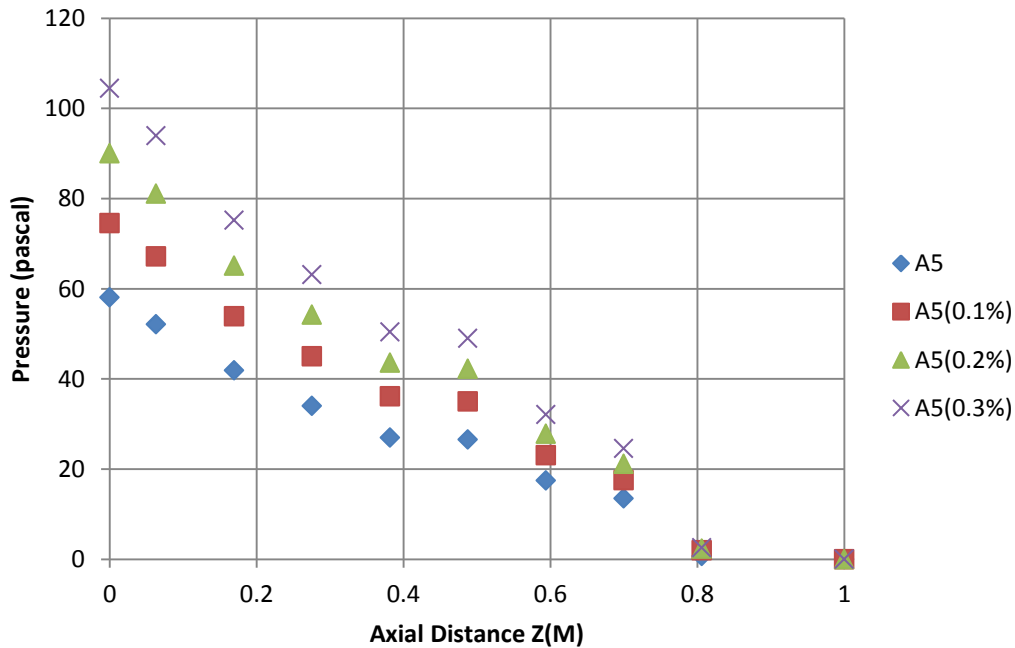


Fig.11 Pressure Behavior Through of Water for A5 Arrangement with the Addition of NanoParticles.

5. Conclusions

The results from numerical simulation indicated that more heat dissipation from the hot tube surface occur via adding conical spring insert. Also, Heat transfer enhancement could be obtained via adding nanoparticles to base fluid. FLUENT package numerical simulation is effective for calculating both fluid flow and heat transfer in the current tube. It's very clear that conical spring insert type A5 has the best enhancements in heat transfer

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