INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 8, Issue 3, 2017 pp.253-270
Journal homepage: www.IJEE.IEEFoundation.org

Experimental and numerical investigation of temperature distribution through shell and helical coil tube heat exchanger using Lab VIEW as a data acquisition program. Part II: Parametric investigation

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Received 20 Oct. 2016; Received in revised form 12 Dec. 2016; Accepted 28 Dec. 2016; Available online 1 May 2017

Abstract
An experimental and numerical study had been done on shell and helical tube heat exchanger. The perplex tube of 1000 mm length, 150 mm diameter and 2 mm thickness was used as shell. The helical tube was made of Cu material. Its diameter is 12.7 mm and 0.1 mm thickness. The working fluid was water for both shell and tube sides. The experimental rig consist of two water tanks to supply the cold water to the shell (35^{o}C) and hot water to the tube (65^{o}C). Eight thermocouples type K were installed at the inlet and out let of each sides and the other are distributed along the shell length. Two rotameters were used to measure the flow rate of hot and cold water. The Numerical analysis was done by using SNSYS-Fluent V.16 to predict the results of what had done experimentally. The main keys of this study were coil pitch and mass flow rate of water for both sides. Where the helical coil pitch was changed in each case. The first case the helical coil pitch was 52.7mm, in the second case the pitch was changed to 42.7mm. In the last case (case 3) the pitch distance was 32.7mm. The results compared with case 0 (straight tube). And the mass flow rat were (6, 8, 10 and 12) L/min for both sides shell and tube. The results show that an enhancement in the performance of heat exchanger with the decrease of helical coil tube pitch due to the secondary flow increase. Also the mass flow rate decrease causes an enhancement in the performance of the heat exchanger due to the contact time increase.

Keywords: Heat exchanger; Shell and helical tube; Experimental; Numerical; Parametric study.

1. Introduction
The current paper forms the second part of a two part study on a shell and helical coil tube heat exchanger. In part one of this series [1], a full three dimension, non-isothermal computational fluid dynamics (CFD) model and experimental rig preparing of a shell and helical coil tube heat exchanger.
Helical coil heat exchanger is very important type in power plants, chemical reactor and other applications. It provides more contact area between hot and cold liquids. Flowing liquids in curved pipes perform a secondary flow that enhances heat transfer. Enhancing fluid flow to be turbulent tends to destroy the thermal bounded layer over the contacted surface. So thermal bounded layer works as thermal insulation layer which reduce heat transfer. Turbulent flow can be done by increasing fluid flow velocity

and changing fluid flow path. Coiled heat exchanger provides these factors together. Coiled tube performs good variation for fluid path [2]. Helical coil heat exchanger has the following advantages:
1- Due to the lower wall resistance helical coil have better heat transfer characteristic.
2- Helical coil (no-dead zone) utilizes the whole coil surface to exchange heat with shell fluid.
3- Helical coil have a large surface area in limited volume and small floor area.
4- Helical coil have no thermal expansion problems.
5- The high turbulent flow in helical coil reduces or eliminates fouling.
Also the helical coil heat exchanger has disadvantages:
1- It is difficult to use helical coil in case of corrosive fluid.
2- It is difficult to clean helical coil in case of fouling.
3- In dense packed helical coil there will be interfering with fluid flow.
4- The design of helical coil is a little bit complex.
The helical coil heat exchanger has many applications; here are the most important application fields of helical tube heat exchanger:
1- In chemical reactors: some chemical reaction produce high temperature and in most cases these reaction have to continue at constant temperature. In those cases the helical coil heat exchanger can transfer heat at a high rate.
2- In marine cooling systems, central cooling, lubrication oil cooling, steam generation in marine and industrial application all have limited space which make the helical coil heat exchanger an excellent solution.
3- In food, beverage industries, pasteurization and storing helical coil heat exchanger is an efficient option.
4- The compact structure of helical coil heat exchanger meets perfectly the high heat transfer rate in air condition and heating systems.
5- In cryogenic application for gas liquefaction the helical coil are extensively used.
6- In the cooling process: hydrocarbon processing, CO_2 recovery and polymer industries [3].
D. G. Prabhanjan and T. J. Kennic [4] conducted an experimental research about using helical coiled heat exchanger and straight tube heat exchanger in order to make a comparison in their performance. The used helical coiled was with 10 turns, 15.7mm inner diameter, 1.2mm as wall thickness and no space between turn and the other. The results showed that increasing the heat transfer coefficient in helical coiled one as compared to straight tube for the same dimensions. Heat transfer coefficients in both heat exchangers were increased when increasing bath temperature. The heat transfer coefficient was not effected by the flow rate in the turbulent region. Increasing temperature was effected due to coil geometry and flow rate. Watcharin Noothong et al. [5] performed an experimental study of enhancement efficiency, friction factor and heat transfer characteristics of tube fitted with twisted tape inserts of various twist ratios. The rig consist of annular straight pipes made of Plexiglas, which were connected by flanges. Warm air from a blower was directed through the inside tube, while cold water was pumped through the shell. All of the experiments were carried out at the like inlet condition with the Reynolds number of the inside tube from (2000 to 12000).The results depicted the averages Nusselt numbers (of the inside tube or warm air) increment was around 188% when compared with the smooth tube. J.S.Jayakumar et al. [6] performed an experimental and numerical investigation of helical coiled heat exchanger.
Water was used as a working fluid in this investigation. Constant heat flux, constant temperature of wall was not applicable because they were not giving good satisfaction with numerical analysis. Transported media properties of heat exchanger were depended in the analysis. A numerical analysis has been done to simulate the experimental part by using FLUENT 6.2. The numerical analysis gave good predication with experimental results.
M.R. Salimpour [7] had done an experimental investigation of three helical coil heat exchangers for different pitches in each case. The working fluid was water and for counter flow process. The used pitches were (17, 21.4 and 26.7) mm respectively, the outer diameters for coils were (12, 16 and 16) mm respectively. It is found the increase of coil pitch will increase the heat transfer coefficient of the shell side. Travis J. G. [8] had done an experimental research about multiple helical coil heat exchangers. The tests included utilization of water in shell and tube side. The heat exchanger consists of a copper shell and 4 concentric helical coils with a pitch of 13.5 mm and a solid copper center rod. The coil tubing used is 9.5 mm OD copper tubing with a 6.4 mm nominal inner diameter. The coils were bent by hand and soldered into place at the inlet and outlets. The shell consisted of a 15.2 cm ID copper pipe with a length

of 70 cm. also, another heat exchanger is used in same dimension and material but, the working fluid was water. The results show that increasing in heat transfer coefficient with mixed working fluid as compared to single phase fluid. This conclusion is supported by considering that slurry specific heat is larger with respect to single water. Srbislav B., Branislav [9] had done a study on shell and helical coil heat exchanger. The study investigated the heat transfer coefficient in shell side. This study showed that heat transfer coefficient is directly proportion with the hydraulic diameter of shell side. Also, a mathematical relation was found which was based on shell side parameters $Nu = 0.5. Re^{0.55}. Pr^{1/3}. (\eta/\eta_w)^{0.14}$. So the operation range for dimensionless parameters were Re=1000-9000 and Pr=2.6-6. Pramod S. et al. [10] performed a numerical analysis about helical tube heat exchanger by depending on tube diameter variation. Diameter of helical shape is 200mm, tube length is 2m, water is the working fluid, the average temperature was (60, 30) ^{o}C for hot and cold water respectively. The variation of internal tube diameter are (8, 10 and 12) mm respectively. The analysis depends on computing the enhanced heat transfer coefficient at each value of internal tube diameter verses some dimensionless parameters such as Reynolds number, Nusselt number, Dean Number and Helix number. This research concludes that helical coil is more efficient when Reynolds number is low. Also it is desirable to select high tube diameter and low coil diameter so this tends to increase the intensity of developed secondary flow which increases Nu. N.D. Shirgire et al. [11] performed an experimental study about estimating the effectiveness of two types of heat exchangers. Helical tube and straight tube heat exchangers are manufactured for this purpose. Helical tube heat exchanger is effected more than straight tube one under multi conditions like parallel and counter flow under different mass flow rates. This is due to increase the overall heat transfer coefficient. Increasing heat transfer coefficient is developed because of centrifugal forces which act on the fluid moving in the coil of helical heat exchanger causing the destruction thermal bounded layers effectively. Deepali G. et al. [12] performed an experimental study was done to improve a heat transfer enhancement technique that includes use of twisted wire brush inserts. The used rig included a horizontal annular double pipe heat exchanger with inside tube and outer tube diameters of (15 and 25) mm, respectively. The twisted wires brush inserts made of copper. The warm air flows through inside tube and cold water flows through outer tube in a counter flow double pipe heat exchanger. The warm air and cold water inlet-outlet temperatures are taken for different warm air velocities and constant cold water mass flow rates. The range of Reynolds number from 800 to 2300. Warm air pass through the inside tube, while cold water pass through the shell. The experimental results show that there is roughly 10% increment in Nusselt number for tube with twisted wire brush inserts as compared to smooth tube. From experimental investigation and results obtained from it a correlation was improved between inside tube side Nusselt number and Reynolds number. B. Chinna et al. [13] performed an experimental study on the performance of helical heat exchanger by verifying multi parameters like number of coils, temperature and flow rate of water. The developed results had compared with corresponded straight tube heat exchanger under same parameters verifying. It was found that enhancement in heat transfer coefficient in helical heat exchanger because of increasing the contacted area the order that increase the contacted time. It is found that the inside heat transfer coefficient in helical tube is about 0.35 of the straight tube. The overall effectiveness of heat exchanger in counter flow is more than that in parallel flow so they were 0.673 in helical tube and 0.498 in straight tube for counter flow. Also it is 0.631 and 0.316 for helical and straight tube respectively under parallel flow condition. Mohsen Sh. et al. [14] performed an experimental investigation flow and heat transfer in a horizontal annular tube double pipe heat exchanger. A concentric tube of the inside and outer pipes of the heat exchanger were adopted in the test rig. The inside tube is made from copper, while the outer tube is made from PVC. Pressure losses were determined by using U-manometers. The flow is designed as according to counter current flow and turbulent flow. Warm water was passed through the inside pipe, while cold air was flowing through the annulus duct. Water flow rate was varied from 120 to 200 (Lit/h) flows through the inside tube. The experimental Results depicted that Nusselt number in water side increase with increasing of temperature of the water and flow rate of water while opposite trend is noted for Nusselt number in air side. Friction factor increase with increasing of inlet velocity and inlet temperature of water. Amikumar S. et al. [15] performed a research about designing and manufacturing helical tube heat exchanger. It is tended to use cupper tube to enhance the heat transfer between two fluids. Also, the external shell surface had covered by thermal insulted layer to prevent heat losses to ambient. Coils number, shell diameters, shell length, input temperatures and output temperatures had selected by manufacturer then. The remained data such as tube length, curvature ratio pitch diameter and average heat transfer were obtained by the simple heat transfer relations. The developed results in experimental procedure provide good agreement with computed results. The overall heat transfer coefficient varied directly with the mass flow rate of hot water. The effectiveness of heat exchanger is increased by increasing hot water mass flow rate at constant cold water mass flow rate. Also the outlet temperature of hot water is increased with increasing mass flow rate of hot water. Sreejith K. et al. [16] performed an experimental investigation of helical coil heat exchanger. This study depends on a comparison between a straight tube heat exchanger and helical coil one by verifying many parameters like mass flow rate of hot and cold water also the temperature of water in both exchangers. The developed results from the experimental testing explained that helical coil heat exchanger provided good enhancement in thermal performance of heat exchanger as compared to straight tube one. This improvement was done because of many causes and they were:

1- Greater contact time between liquid and helical coil which allowed transferring additive quantities of heat.

2- Centrifugal forces which were done during liquid following through coil causing turbulence which improve heat transfer. T. Srinivas et al. [17] performed an investigation of helical coil heat exchanger has done by using forced convective Nano fluid. The used Nano particles were CuO where it was added to water in different weight percentages (0.3, 0.6, 1, 1.5 and 2 %) also, the temperature of used Nano-fluid were (40, 45 and 50) ^{o}C respectively. The Nano fluid was pumped through shell side of heat exchanger while just water was used in coil tube that was representing the cold medium. The experimental results explained some results so an enhancement in helical coil and shell side were obtained in the case of using Nano fluid, maximum heat transfer rate was recorded when the added percentage of nano particles was 2%. Wandong Z. et al. [18] performed an experimental study about using a helical coil polyethylene heat exchanger in the heat pump. This study was done in icy condition in the sea water. Different parameters had been taken in consideration in this investigation such as inlet temperature, heat exchanger length and diameter. The used heat exchanger is adopted to be as the outside part of the heat pump. It was concluded that increasing the heat transfer rate (from 0.45 to 3.2) kW by decreasing the temperature seawater (-3 to -10) ^{o}C with increasing flow rate (0.1, 0.2, 0.3 and 0.4) m/sec. Also, there was an increase in heat transfer rate (0.7/2.5) kW by increasing the pipe length (from 50 to 100) m with increasing in the diameter (from 30 to 70) mm.

In the current paper, parametric study using experimental and the CFD model have been performed and discussed in detail. The study quantifies and analyses the performance of shell and tube heat exchanger. The aim of this study is therefore:

1. Study the effect of pitch distance of the coiled tube in the heat exchanger performance.
2. Study the effect of helical coil on heat transfer rate, pressure drop, friction factor and effectiveness of this type of heat exchangers.
3. Study the effect of changing the mass flow rate in the shell and in copper helical tube sides to discover the most effecting part of the coil heat exchanger for this change on heat exchanger effectiveness and heat transfer rate.
4. Study the temperature distribution axially and radially through a helical coil heat exchanger.
5. A numerical analysis program had been used on the helical coil heat exchanger for all cases of mass flow rate to show the temperature distribution profile all over the rig by using ANSYS-Fluent program.

2. Experimental results and discussion

The main variables in this study were helical coil pitch and mass flow rate. Where the helical coil pitch was changed 3 times and compared the results with the straight tube case. Also the mas flow rate changed for each side (cold and water side). The variation of variables is shown in Figure 1.

Optimization of heat exchanger design requires intensive studies of the process variables especially those enhancing heat transfer, which is the major objective of this valuable piece of equipment.

Forty six experimental run for the rig are done. In each run the following variables are calculated:

1- Reynolds number (Re) for hot (Re_h) and cold (Re_c).
2- Nusselt number (Nu) for hot (Nu_h) and cold (Nu_c).
3- Amount of heat transfer (q) for hot (q_h) and cold (q_c).
4- Effectiveness (ϵ).
5- Friction factor (f).
6- Pressure Drop (ΔP).

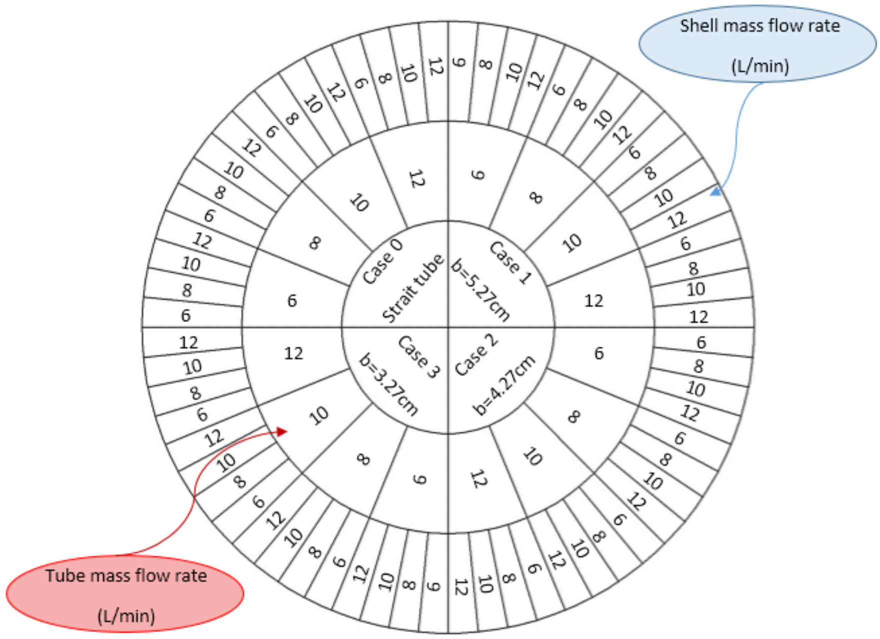

Figure 1. Tested variables identification.

2.1 Effect of Reynold's Number on Nusselt's Number

Mass flow rate (and as a result fluid velocity and Reynold's number) is proportional to the amount of heat gain or lose by the fluid in the shell or tube side respectively and this relation will be illustrated in the following section in details:

Figure 2 shows the effect of Reynold's number on Nusselt number. The increase of Reynolds number was occurred due to the increase of the water mass flow rate. The convective heat transfer coefficient increases, and it is proportional directly with the Nusselt number. When comparing the straight tube (case0) with the helical tube (case 1, 2 and 3) there was Nu_h improvement estimated by (7.2, 12.3 and 18.2) times respectively, and this was due to:

1- Longer period of contact time between liquid and helical coil which allowed to transfer additive quantities of heat.

2- Centrifugal forces happening during liquid flowing through coil forms turbulence and this increases heat transfer opportunity.

It's clear that there was an improvement in Nu_h value with every decrease in Re_c. The improvement of Nu_h in case 0 with the decrease of Re_c compared with other cases, while a gradual improvement noticed from case (1, 2 and 3) respectively. According to the above results we recommend to decrease the helical coil pitch as well as the shell flow rate to get better results for Nu_h i.e. Increase in convective heat transfer coefficient and hence increase in amount of heat transfer. The improvement of heat transfer rate with the decreasing of Re_c is increased with the cases number increment and become more sensible.

Figure 3 shows the effect of Re_c on the Nu_c. The increment of Nu_c estimated to be (2.1, 2.6 and 3.2) times for cases (1, 2 and 3) respectively compared with case 0. The same behavior for the Re_h on Nu_h will appear here for the same reasons mentioned previously.

2.2 Effect of water flow rate (Q) on the amount of heat transfer (q) for cold and hot water side

Figure 4 shows the relation between (Q_h) and (q_h), there is always an increase of (q_h) with the increase of (Q_h). This was due to additional amount of circulated water. The pitch decrease causes an increase in q_h value due to increase of turbulent and surface area. Which causes enhancement in q_h for helical coil tube compared with the straight tube. (q_h) in case 1 and 2 increases estimate to be (4.6 and 5.7) times for the straight tube (case 0), while its increases by 7.5 times for case 3 compared with case 0. Case 3 gives better effective enhancement much more than for case 1 and 2, due to the effect of high secondary flow turbulence through the helical coil heat exchanger.

Figure 5 shows the effect of (Q_c) on the (q_c). The same effect for the Q_h on q_h will appear here for the same causes mentioned previously. Q_c increase (4.5, 5.8 and 7.2) times fore case (1, 2 and 3) respectively as compared with case 0.

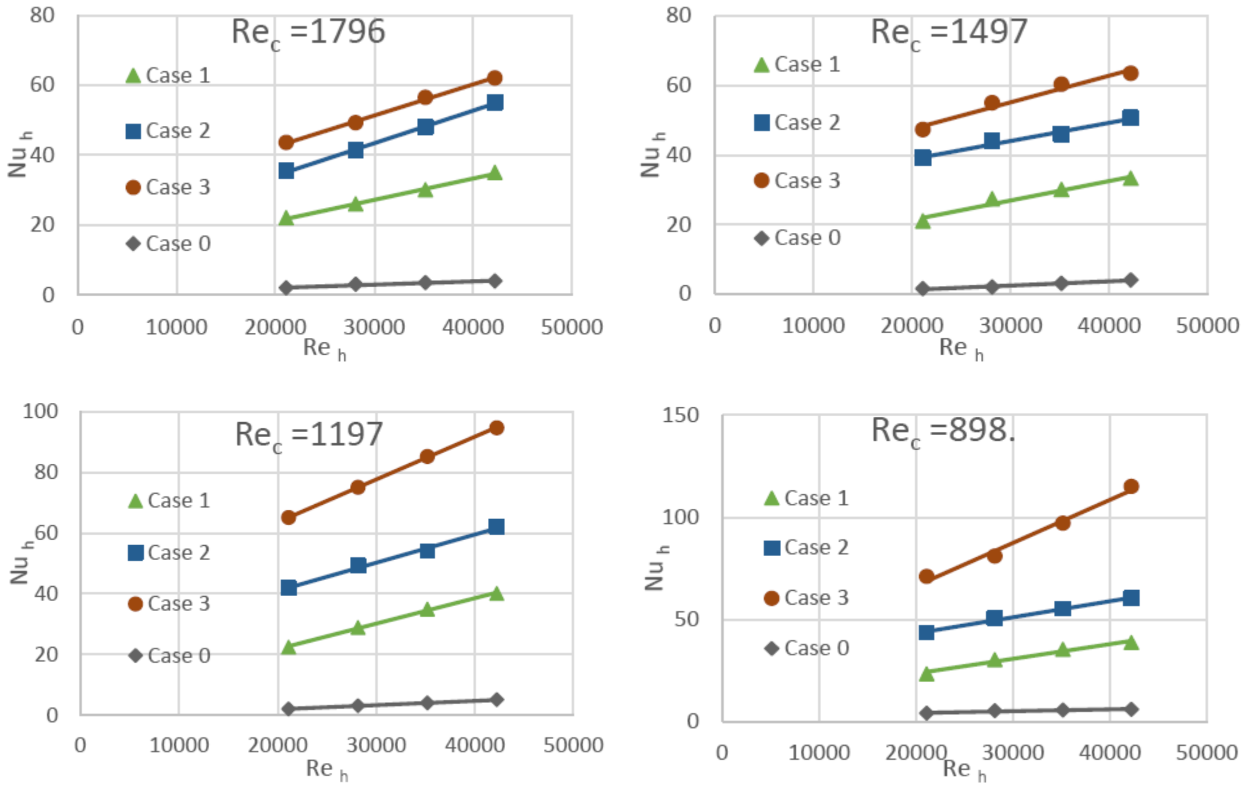

Figure 2. Variation of hot water Reynold's number with hot water side Nusselt's number at different Re_c.

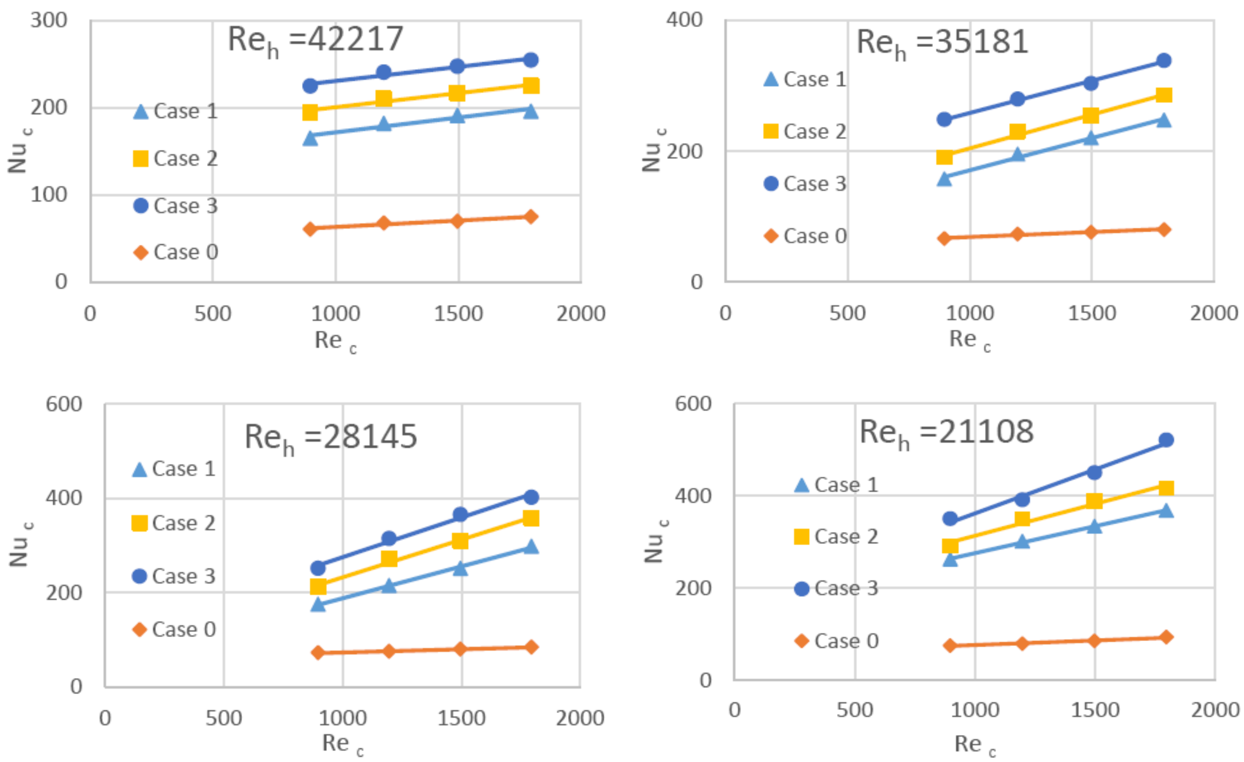

Figure 3. Variation of cold water Reynold's number with cold water side Nusselt's number different Re_h.

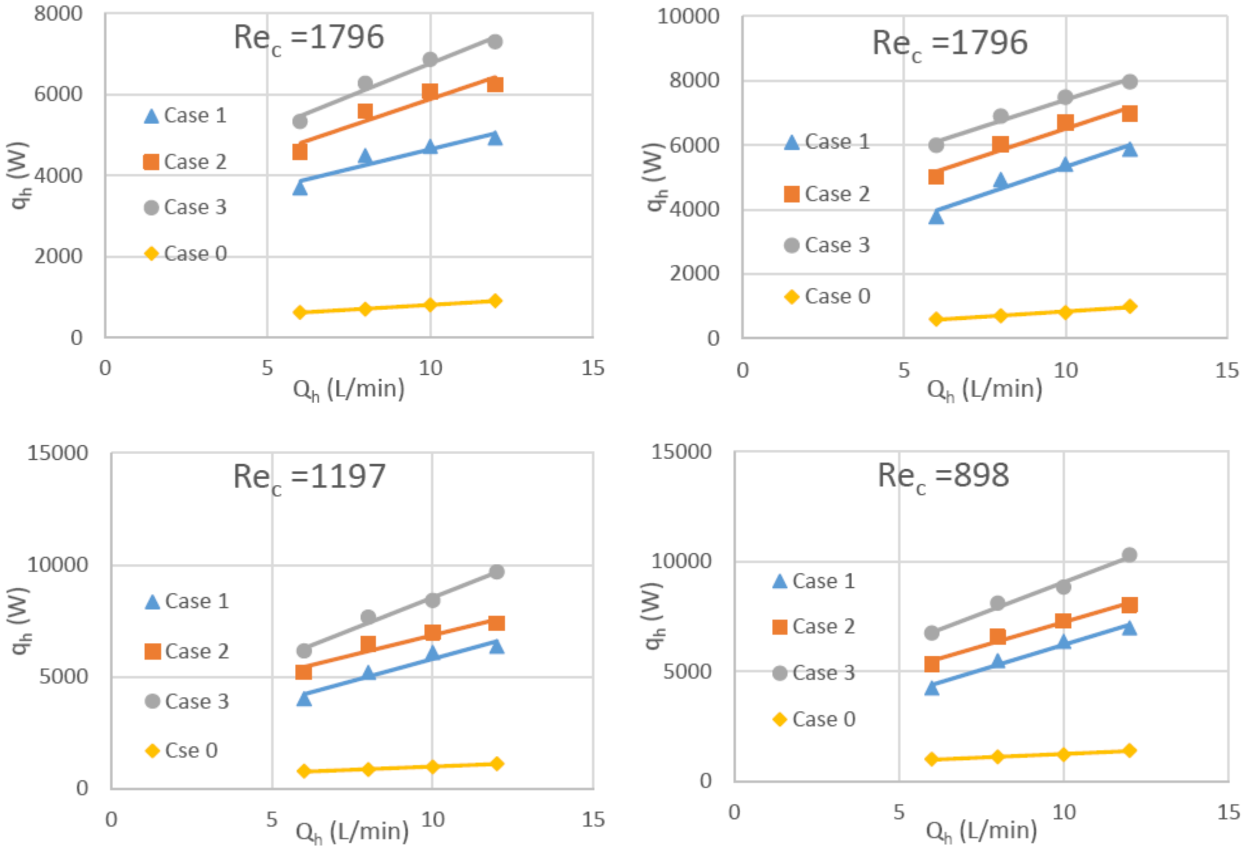

Figure 4. Variation of hot water flow rate with amount of heat transfer for hot water side at different Re_c.

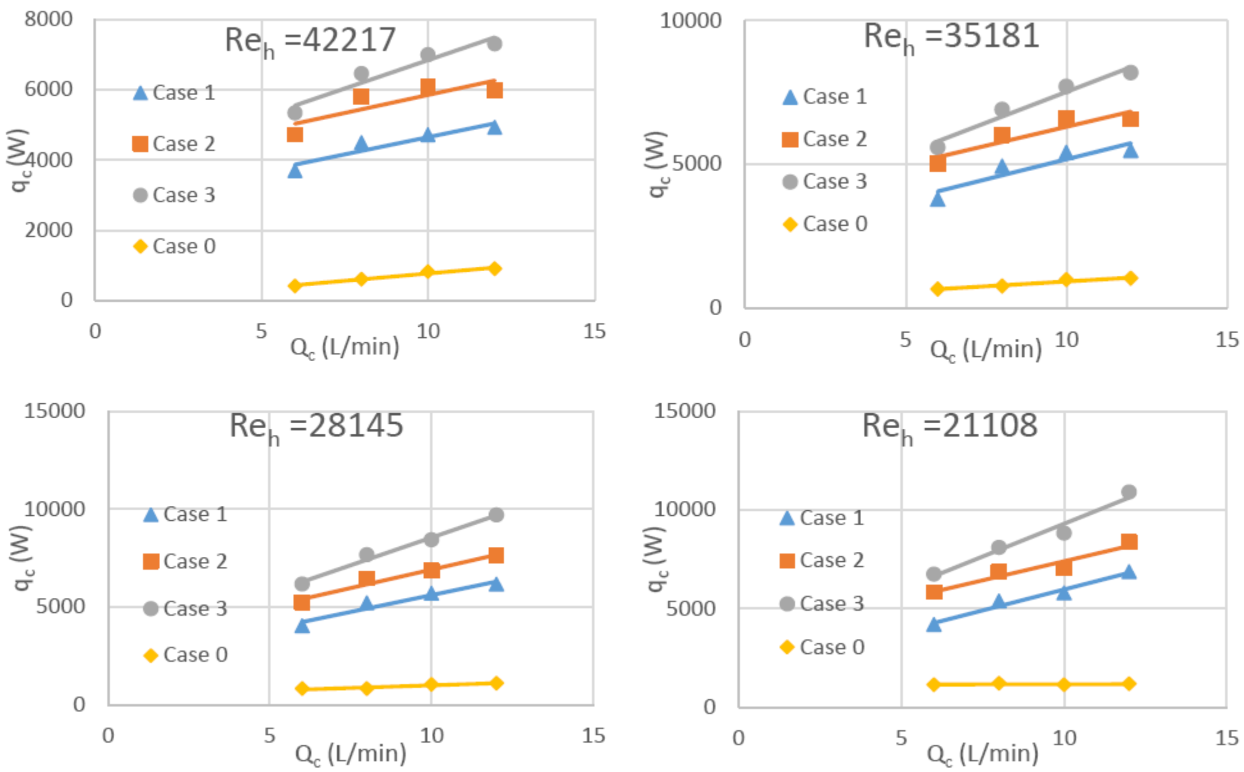

Figure 5. Variation of cold water flow rate with amount of heat transfer for cold water side at different Re_h.

2.3 Effect of hot water Reynold's number on the effectiveness of heat exchanger

The experimental data of the effectiveness of heat exchanger versus Re_h had been plotted. These data explain the relations in different flow rate for shell side. It shows that there is a decreasing in effectiveness by increasing The Re_h as shown in Figure 6. The effectiveness varies inversely with q_{max} and its clear in these figures that there is an increase in effectiveness with Re_c decrease for each case. The decreasing of effectiveness due to its varied inversely with the q_{max}. q_{max} is proportion directly with the mass flow rate. So the effectiveness increases with the decrease of Re_c and Re_h, Hence, There is a great enhancement in the effectiveness of heat exchanger in the helical coil tube if it is compared with a straight tube. The enhancement estimated to be (4.7, 5.7 and 6.8) times the value for cases (1, 2 and3) respectively. This enhancement was due to the increase of surface area, turbulent and contact time increasing.

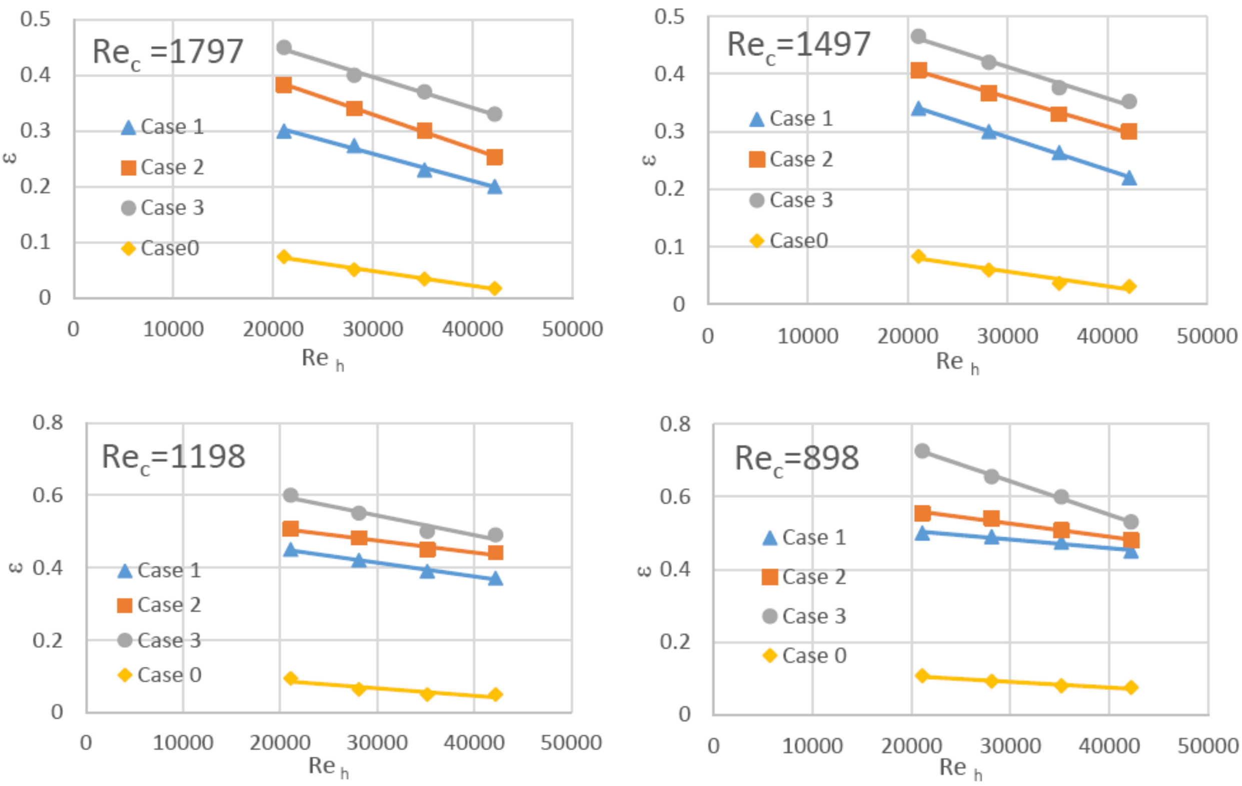

Figure 6. Variation of hot water Reynold's number effectiveness of heat exchange at different Re_c.

2.4 Effect of hot water flow rate on the pressure drop inside H.C.T

Figure 7 is a general characteristic of the system because the shell side flow rate (Q_c) has no effect on pressure drop inside the tube (helical and straight).

The increase of (Q_h) always gives increase of pressure drop. As Q_h increase velocity will increase which means an increase in Re_h (turbulent increase). Re_h is directly proportional to the velocity. The pitch decrease causes more pressure drop due to the increase of secondary flow inside the helical coil tube. The pressure drop in the straight tube was very low because the absence of secondary flow occurring in the helical tube.

The pressure drop is (4.4, 6.1 and 11.2) times for case (1, 2 and 3) respectively as compared with case0. The smaller value of the flow rate leads to less pressure drop. In case 3 with smallest pitch, when Q_h is 6 L/min the pressure drop was 12 kPa which is not of sever effect on the pump and hence it is the best case for our experimental rig.

2.5 Effect of hot water flow rate on the Friction factor

The friction factor is not affected on the shell mass flow rate. Figure 8 shows the increase of (f) as Q_h increase because of it is directly proportion to water flow rate in turbulent flow. The increase of friction factor with the decrease of helical coil tube pitch occurred due to the increase of secondary flow inside the helical coil tube. The friction factor in the straight tube is very low in comparison with the helical tube. It increases gradually by (7.5, 8.5 and 11.2) times in case (1, 2 and 3) respectively compared with case 0.

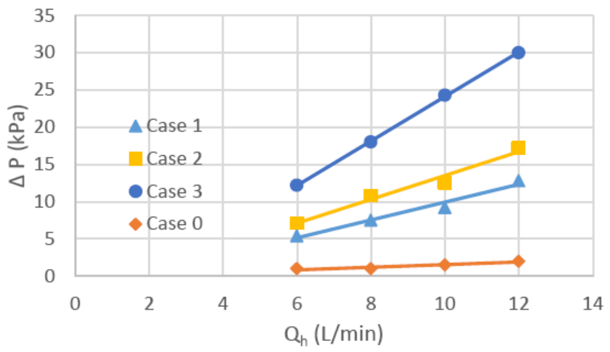

Figure 7. Variation of hot water flow rate with pressure drop on tube ends.

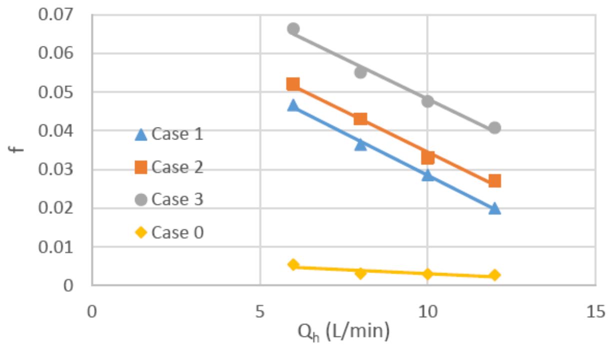

Figure 8. Variation of hot water flow rate with friction factor on tube ends.

3. Numerical results

The Following temperature contours represent the numerical results. These contours for the three cases (b=52.7mm, b=42.7mm and b=32.7mm) and selected mass flow rate (6 L/min for shell side and 6, 8, 10 and12 L/min for helical coil tube side).

Figure 9 represent the temperature contour of heat exchanger with flow rate of water at 6 L/min in the tube side and 6 L/min in the shell side. The axial cross section view of the helical coil heat exchanger, with color ranging from red to green show the gradual transition of heat and temperature through the heat exchanger. It is clearly shown that case 3 is the more effective heat exchanger compared with the other cases which agreed with measured values.

Figure 9 clearly shows the most effective case heat exchange which is case 3. Also the figure shows the amount of temperature increment from the entrance and far from the entrance.

Figure 10 represent a radial cross section of temperature and heat through the heat exchanger at (0.3 and 0.7) m from entrance.

Figure 11 represent the flow of tube side (hot water) 8 L/min, while for the shell side (cold water) 6 L/min.

The difference between Figures 9 and 11 is the mass flow rate inside the helical coil tube. It's clear that the out let temperature in Figure 9 for the helical coil tube is less than it in Figure 11 due to contact time increase with the decrease of water flow rate as shown in the experimental results previously.

The redial temperature distribution for the same flow rate of cold and hot water shown in Figure 12. The increasing of temperature will be also appear her as compared with Figure 10.

Figures 13 to 16 will show the affect of Reynolds number or changing flow rate on the temperature distribution through the coil heat exchanger.

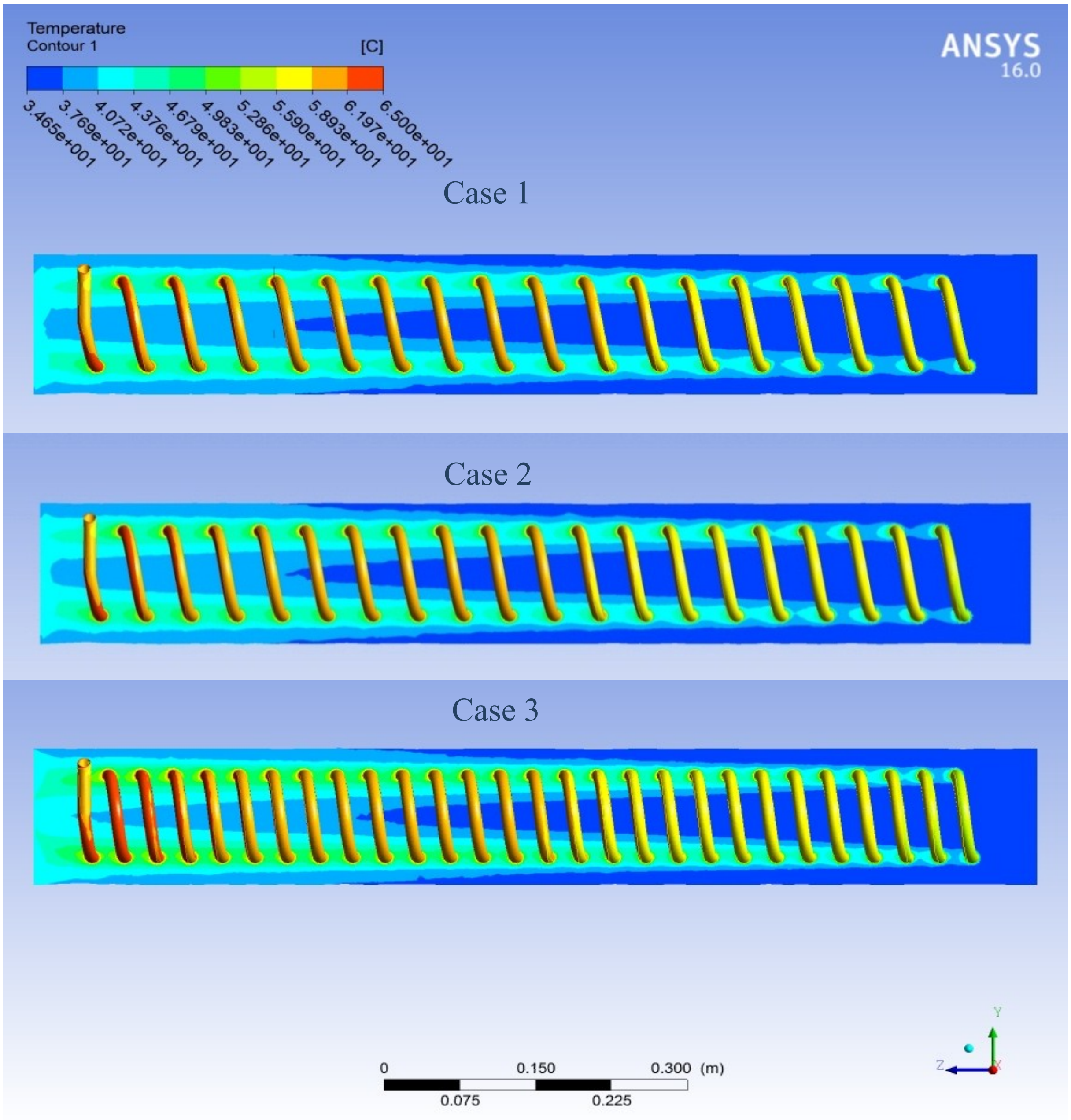

Figure 9. Temperature contours (distribution) at Re_c=898.404, Re_h=21108.98.

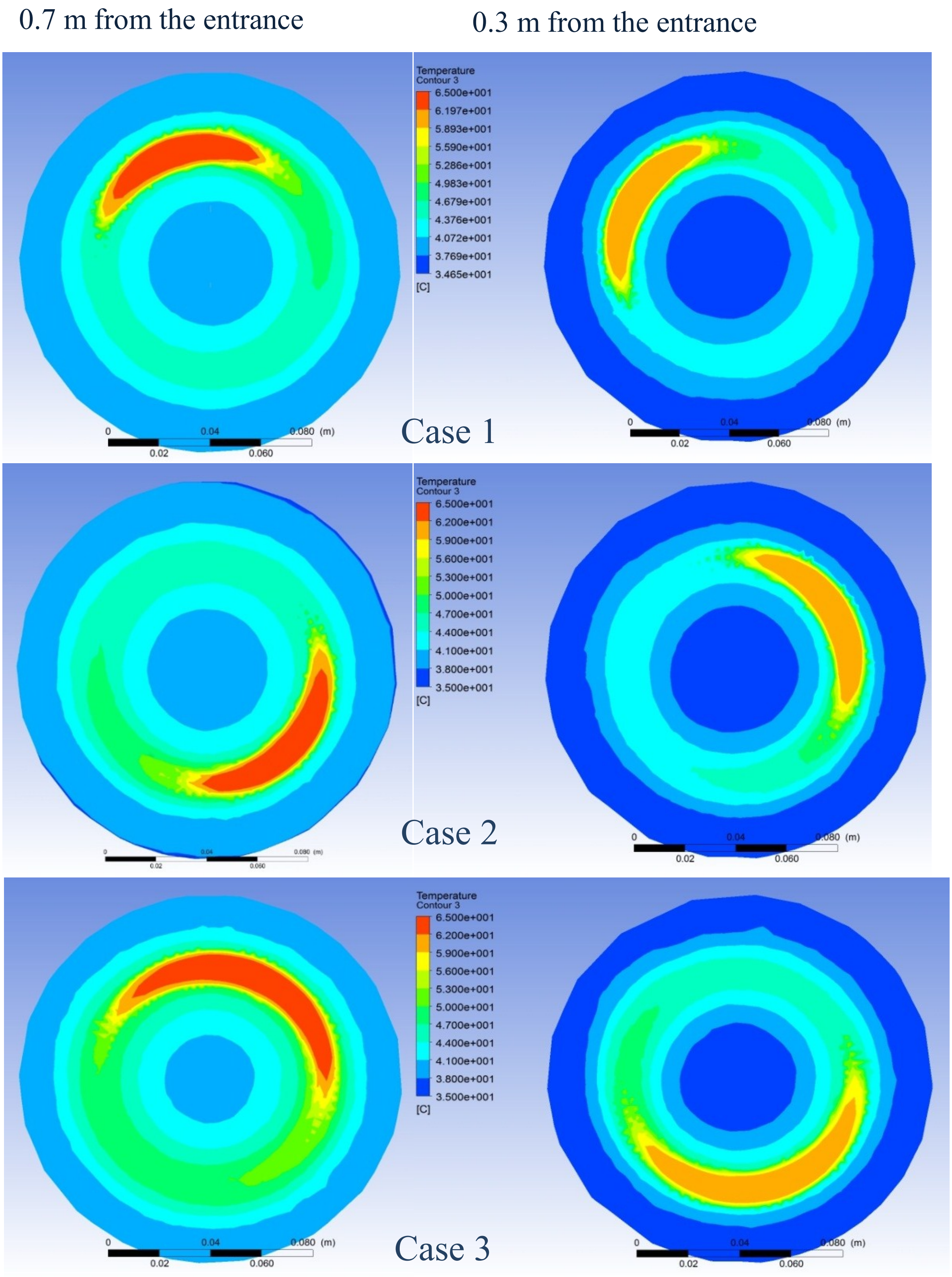

Figure 10. Temperature contours cross section at Rec=898.404, Reh=21108.98.

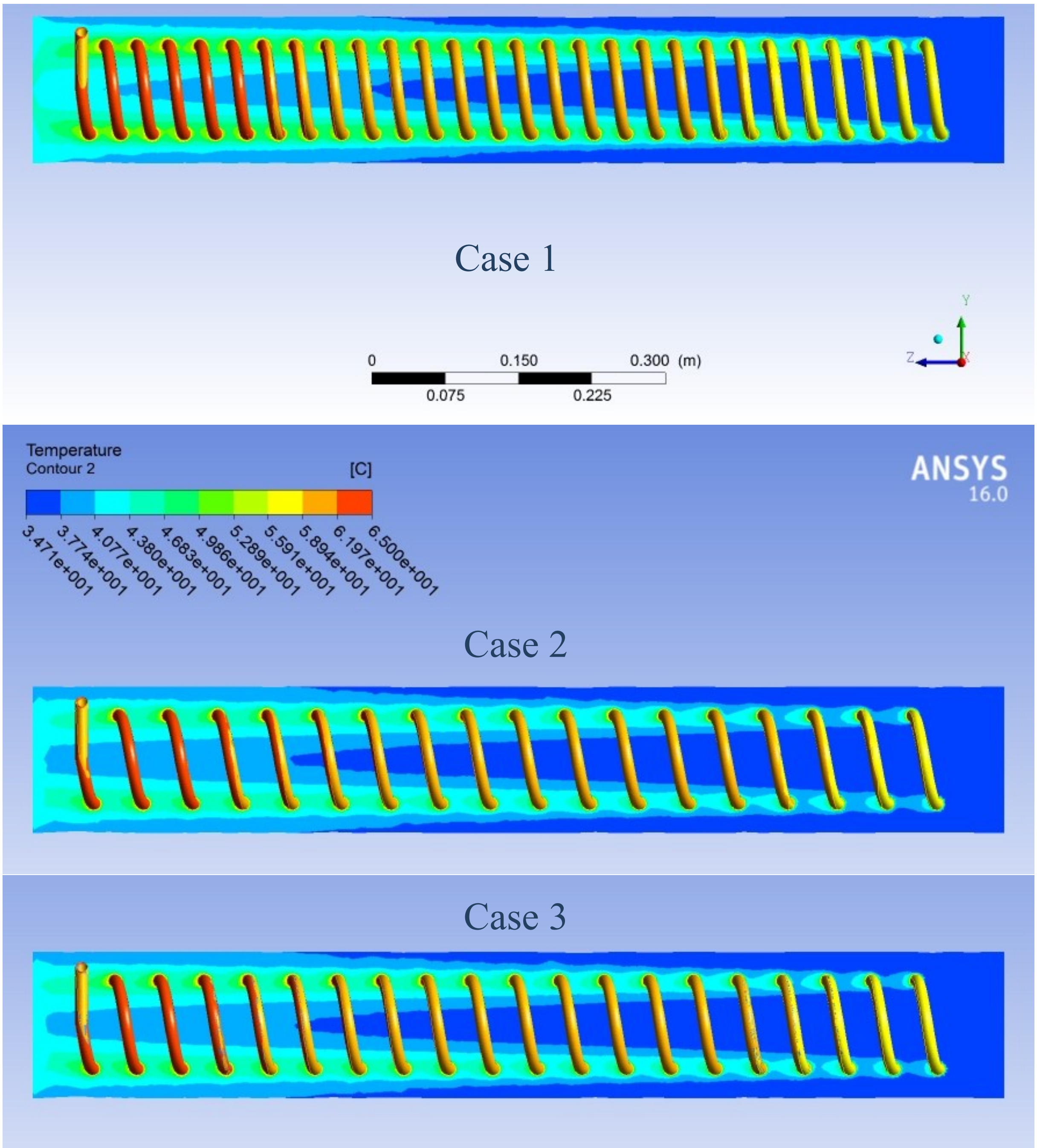

Figure 11. Temperature contours (distribution) at Rec=898.404, Reh=28145.26.

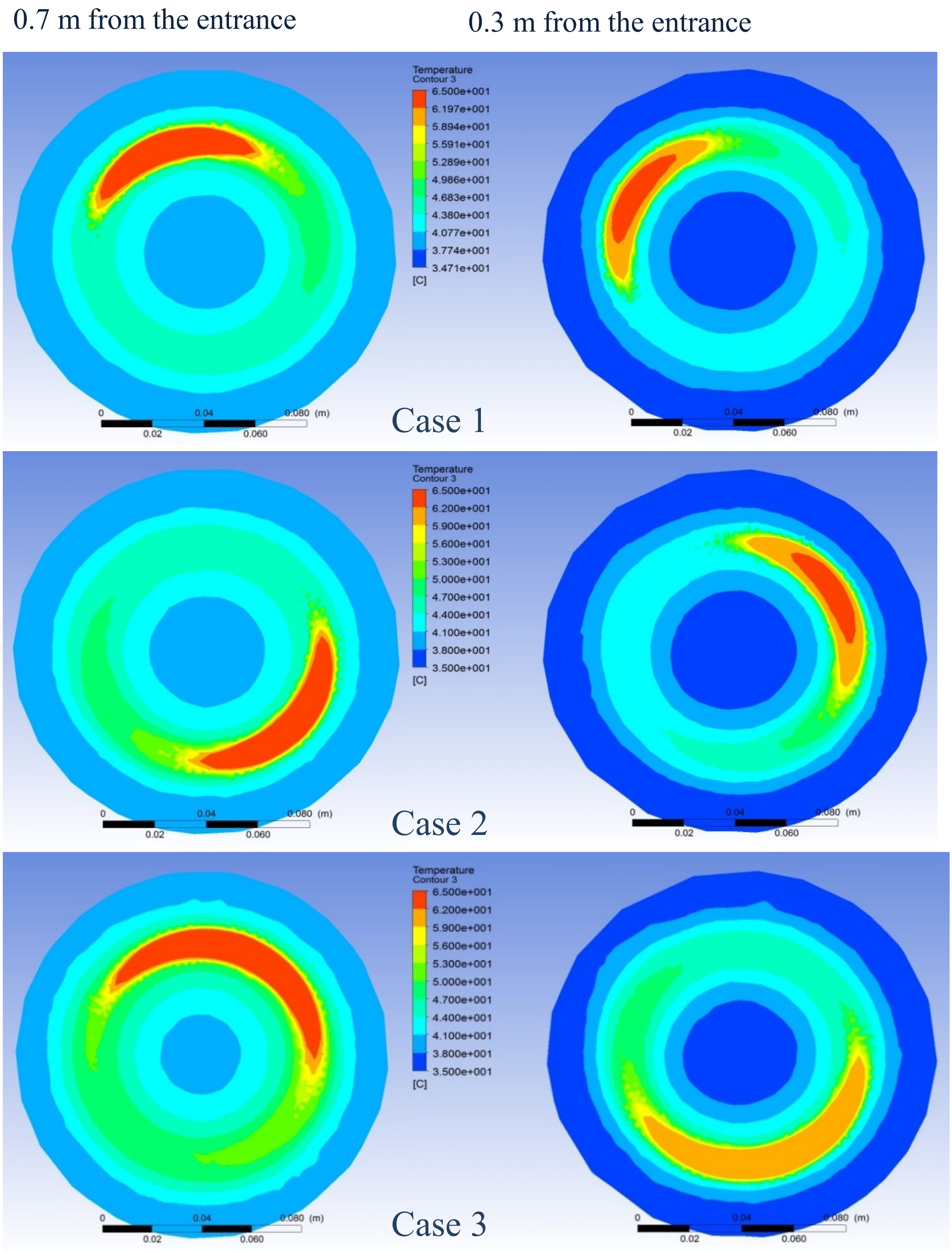

Figure 12. Temperature contours cross section at Re_c=898.404, Re_c=28145.26.

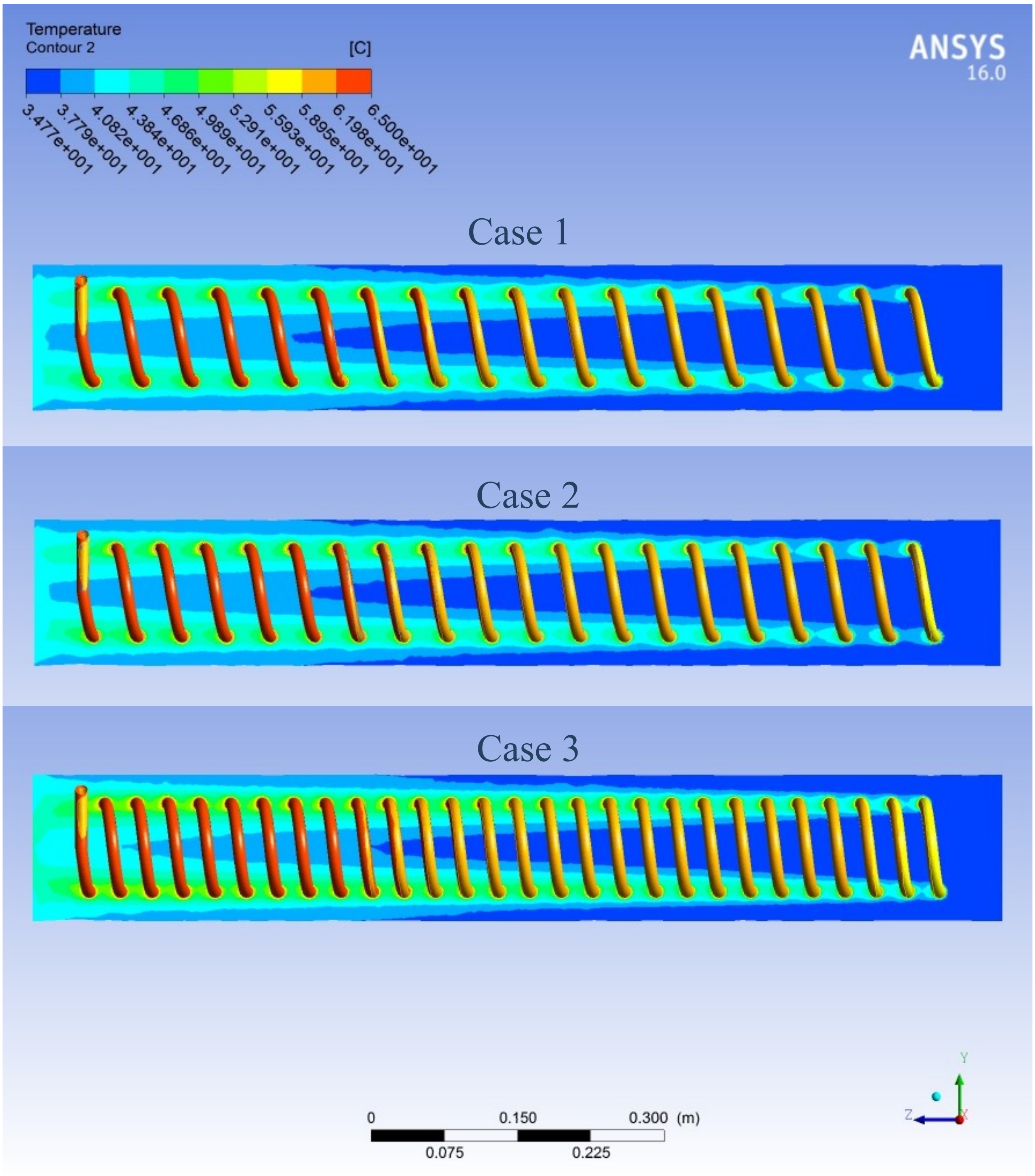

Figure 13. Temperature contours (distribution) at Re_c=898.404, Re_h=35181.58.

0.7 m from the entrance 0.3 m from the entrance

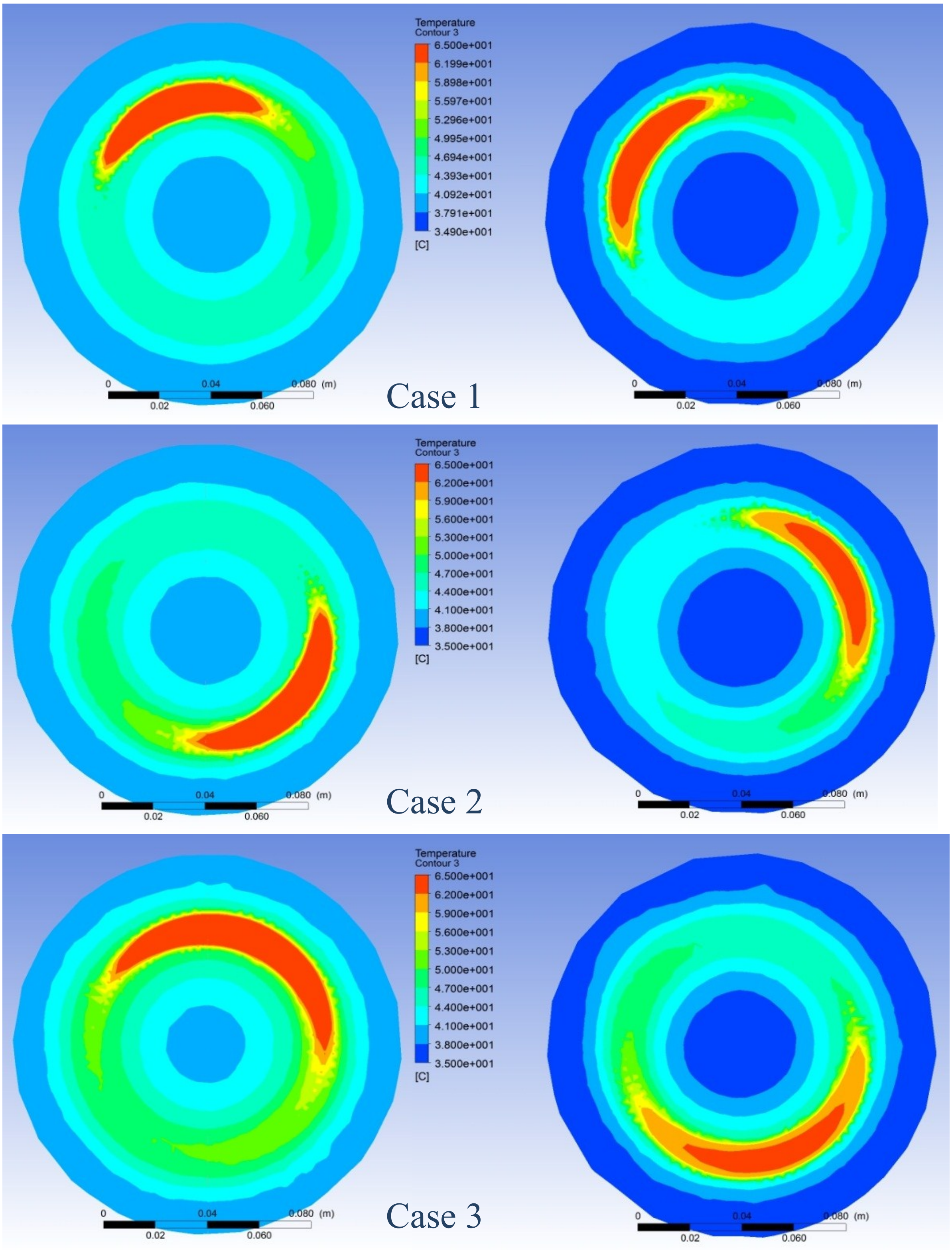

Figure 14. Temperature contours cross section at Rec=898.404, Reh=35181.58.

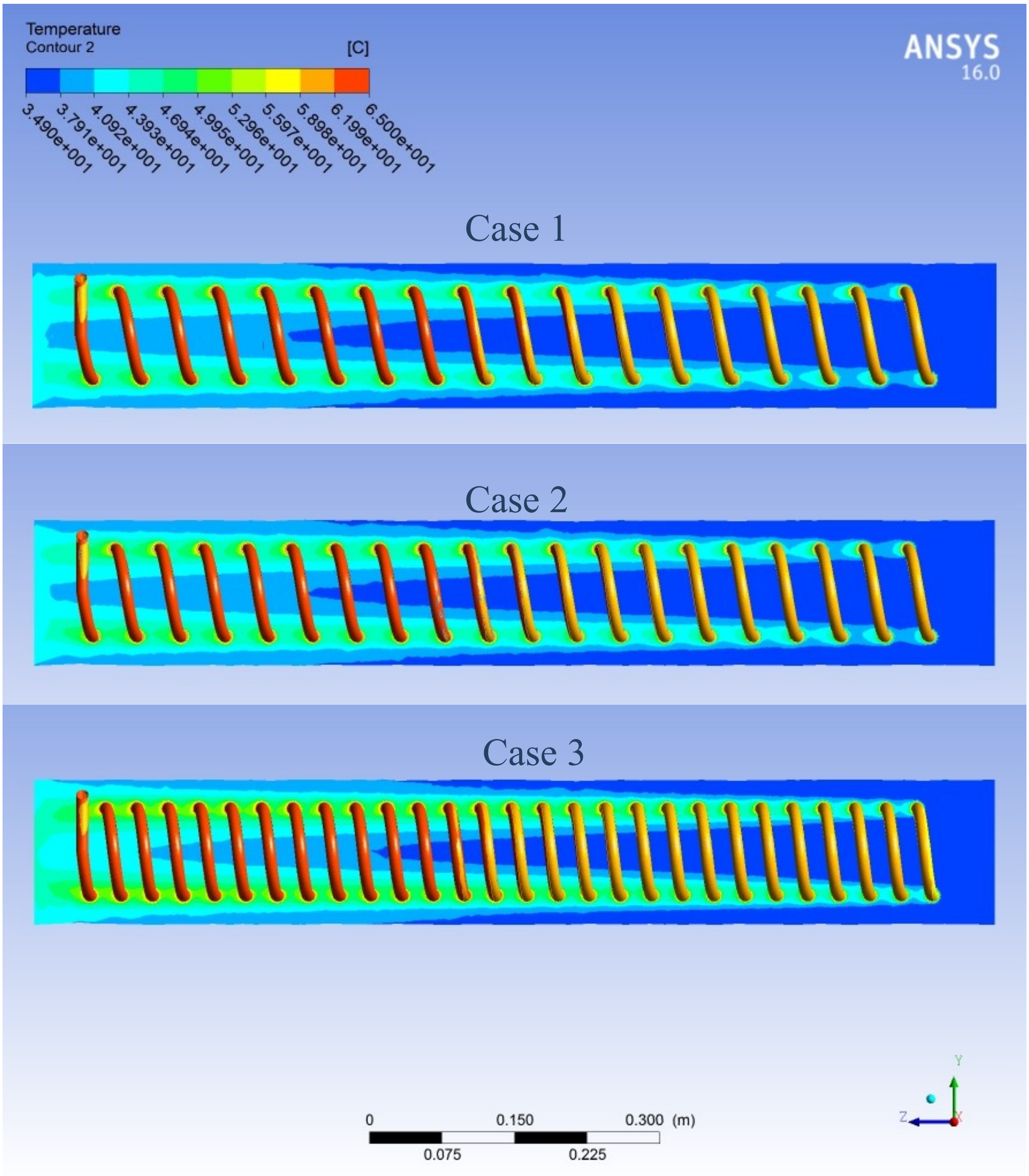

Figure 15. Temperature contours (distribution) at Re_c=898.404, Re_h=42217.89.

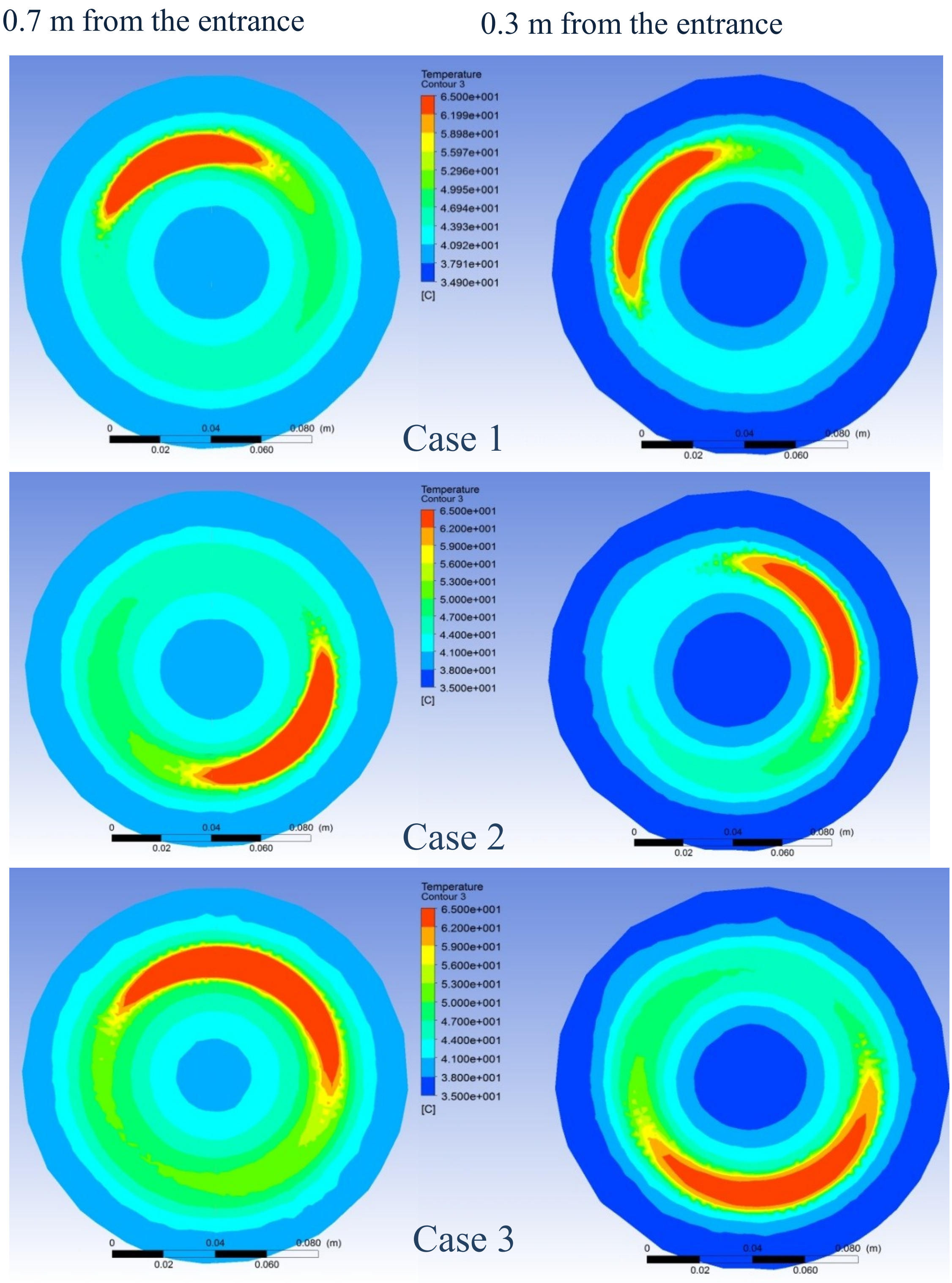

Figure 16. Temperature contours cross section at Rec=898.404, Reh=42217.89.

6. Conclusions

Since the efficiency of energy resources push the researchers to develop more effective equipment and heat exchangers. Helical heat exchanger has the ability to increase the contact time and increasing the turbulence for flowing fluids rather than the traditional type one. Experimental and numerical studies are applied on the same test rig. This study has reached the following conclusions:

1- Decreasing the flow rate in tube side tend to increase the heat transfer in the heat exchanger.
2- Increasing the pitch distance tends to reduce turbulence in flow and then decreases the heat transfer.
3- Decreasing the flow rate in shell side tends to increase the heat transfer in the heat exchanger.

4- Coiled tube heat exchanger effectiveness is increased with pitch decrease.
5- The effectiveness of heat exchanger with helical coil is better than straight tube.

Nomenclature

q	Amount of heat transfer W	T	Temperature °C
Nu	Nusselt number (h d / k)	T_{co}	Outlet temperature of cold fluid °C
Re	Reynolds number	T_{ci}	Inlet temperature of cold fluid °C
f	Friction factor	T_{ho}	Outlet temperature of hot fluid °C
b	Pitch length mm	T_{hi}	Inlet temperature of hot fluid °C
P	Pressure Pa	$\mathcal{E}$	Effectiveness
Q	Mass flow rate L/min	*CFD*	Computational fluid dynamics

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