A numerical investigation on heat transfer enhancement and the flow characteristics in a new type plate heat exchanger using helical flow duct

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Abstract: In this paper, a numerical investigation and simulation on heat transfer enhancement and flow characteristics in a new type plate heat exchanger using helical flow duct in a series arrangement in counter flow of water as the test fluid is presented. Computational fluid dynamics package (ANSYS FLUENT 16) is used. For the numerical simulation, the Reynolds number for each case is varied from 20000 to 60000 in steps of 20000 contributing to three cases for each geometric parameter i.e centre distance variation and hence a total of 9 cases are studied and the results are compared. The effects of centre distance on the different parameters such as pressure drop(Δp) Friction factor (f),and heat exchanger effectiveness. It is found that the increase in centre distance between the helical pipe decreases heat transfer rate and increase the pressure drop. The heat exchanger effectiveness is found maximum (0.98) at distance of 50mm having Reynolds number 20000 among the different cases.

Keywords: Helical Coil Heat Exchangers(HCHE), Computational fluid dynamics, Reynolds number, effectiveness, pressure drop, Friction factor.

1. INTRODUCTION

Helical coil heat exchanger is always used in the field of cooling&heating system as immersion heating exchanger tanks and vessels. Tube pipe sprial coils provides a low-cost l and effective method of getting heat transfer surface area. Tube coils are made by rolling lengths of tubing into helixes or double helixes in which the inlet and outlet are located at one side or at two sides. It can have various coils in various metals including titanium coils,copper tubes and duplex stainless coils, all of which can be supplied in segments or fully fabricated and hydrostatically tested.

Helical Coil Heat Exchangers(HCHE) are the important engineering equipments used for transferring heat from one fluid to another. Heat exchangers are widely used in various kinds of application such as power plants, nuclear reactors, refrigeration and air-conditioning systems, heat recovery systems, petrochemical, mechanical, biomedical industries. Helical coil heat exchangers are gaining wide importance now-a-days because it can give high heat transfer coefficient in small footprint of surface area.

Helical tubes are universally used in chemical reactors, ocean engineering, heat exchangers, piping system and many other engineering applications. It has been long recognized that heat transfer characteristic of helical tubes is much better than the straight ones because of the occurrence of secondary fluid flow in planes normal to the main flow inside the helical structure .Helical tubes show great performance in heat transfer enhancement, while the uniform curvature of spiral structure is inconvenient in pipe installation in heat exchangers. It has been widely reported in literature that heat transfer rates in helical coils are higher as compared to those in straight tubes. Due to the compact structure and high heat transfer coefficient, helical coil heat exchangers find extensive use in industrial applications such as power generation, nuclear industry, process plants, heat recovery systems, refrigeration, food industry, etc. They are mainly employed in the field of cryogenics for cryogenic separation and liquefaction of air, natural gas processing and liquefaction, production of petrochemicals and large refrigeration systems. The exchangers that are used for cryogenic air separation and LPG fractionation are the largest and most complex units of the plate fin type and a single unit could be of several meters in length. They are being used mainly in environment control system of the aircraft, avionics and hydraulic oil cooling and fuel heating. In the automobile sector they are used for making the radiators.

2. LITERATURE REVIEW

Mohanty et al. (2020) analysed the effectiveness of the shell and tube heat exchanger (STE) with 50% baffle cuts (Bc) with varying number of baffles. CFD simulations were conducted on a single pass and single tube heat exchanger(HE) using water as working fluid.

Jeong et al. (2020) presented the new pattern of wire wrap spacer, called U-pattern to enhance coolant mixing and reduce pressure drop for liquid metal cooled reactor fuel assembly. It is designed by designating its winding direction and pin arrangement without any additional structures for fuel assembly.

Kushwaha et al. (2020) heat transfer and fluid flow characteristics for both Newtonian and non-Newtonian fluids in tube-in-tube helical coil (TTHC) heat exchangers have been investigated numerically. The various TTHC heat exchanger configurations studied are (1) parallel and (2) counter flow, with and without baffles. The power law index (n) and Dean

Mozafarie et al. (2020) presented the thermal and flow characteristics of a nanofluid were evaluated numerically in a circular finned double-pipe heat exchanger. A 3D CFD model was employed to study the effects of nanofluid properties and fin configuration on the friction coefficient, Nu number and thermal performance.

Bezbaruaha et al. (2020) presented a unique design of solar air heater with finned absorber plate allowing helical flow of air is considered. The design enhances the heat transfer rate by enhancing the effective heat transfer area as well as by increasing the flow turbulence. The novel design is compared with a conventional single flow single pass design. Computational study of flow dynamics and heat transfer characteristics for both the considered designs is done at different mass flow rates using commercial software ANSYS FLUENT 18.0.

Sharifi et al. (2020) presented a three dimensional numerical simulation of the fluid flow under non-isothermal condition was initially proposed using computational fluid dynamics (CFD) method. After validation of the numerical model, twelve wire coil inserted tubes were tested through the validated model to get their heat transfer and friction coefficients at specific Reynolds ranges.

Chaurasia et al. (2020) presented the experimental analysis is arranged to evaluate thermal hydraulic performance on flow of fluid in the tube with helical screw inserts at numbers of strips and different values of twist ratio at transition flow regime. Single strip helical screw

Arunkumar et al. (2020) presented the performance analysis of solar air heater in which spring shaped fins introduced beneath the absorber plate are investigated. Effects of spring fin wire diameter ratio, spring diameter ratio and helicoidal pitch ratio on the thermal performance for varying flow rates are analyzed. The results for thermo-hydraulic enhancement factor are

Chaurasia et al. (2020) investigate the thermal and friction factor characteristics of fluid flow in a tube with double strip helical screw tape (DS-HST) inserts with different values of twist ratio and compared with single strip helical screw tape inserts and plain tube. Water is used as a working fluid at different flow rates with constant heat flux conditions. CFD analysis is also carried out to visualize thermal and fluid flow characteristics of fluid flow in tube with inserts.

Abushammala et al. (2020) presented CFD simulations are carried out to determine the heat/mass transfer efficiency in helical pipes (particularly highly curved ones) under laminar flow conditions. The packing density (i.e. interfacial area) of these geometries is evaluated using a CAD software.

Lima et al. (2019) presented the results of a numerical analysis of an absorber, one of the main components of absorption refrigeration systems, in terms of the phenomena of heat and mass transfer. The study was carried out using a flat plate configuration with downward fluid to model the absorber and the numerical simulation was performed using ANSYS-CFX software.

Hernández et al. (2019) presented the experimental data of boiling heat transfer coefficients for the ammonia–lithium nitrate mixture in a laminar falling film. The analyzed heat exchanger consists of a shell with an internal helical coil.

Sharma et al. (2019) presented the appropriate selection, from among different types of solar collectors available to meet the demand of capacity and degree of thermal energy required in operating absorption chillers at optimum performance.

Liang et al. (2018) presented an electricity-cooling cogeneration system (ECCS) based on coupling of a steam Rankine cycle (SRC) and an absorption refrigeration system (ARS) proposed to recover the waste heat of marine engine to meet the electricity and cooling demand aboard.

Raut et al. (2018) presented the heat exchanger to transfer the heat from FPC to VARS Through heat exchanger and analyse the different cooling effect at a different mass flow rate of water through a heat exchanger. The heating and cooling load can be achieved with help of this solar VARS. The auxiliary electric heating has done inside the generator of VARS. The

Bounyanite et al. (2018) presented thermodynamic performance simulation and analysis on single-stage vapor absorption refrigeration system for several varied operational parameters. The operating temperature conditions of the generator, condenser and evaporator are ranged respectively from 60 to 90°C, 20 to 40°C and 2.5 to 12.5°C. For the considered operating

Ziegler et al. (2018) presented the influence of the recirculation of the solution on the performance of the system from previous studies and modelled and investigated it more in detail. Ammonia water absorption resorption refrigeration systems do not need a rectification column like conventional absorption refrigeration systems do. In this case such systems need

Oza et al. (2018) presented thermodynamic analysis of ammonia-water combined ejector-absorption refrigeration system. Major components of the combined ejector-absorption system are generator, rectifier, ejector, condenser, expansion device, evaporator, absorber, pump, and solution heat exchanger.

Ghodeshwar et al. (2018) presented a solar driven Lithium-Bromide absorption cooling system. It was an intermittent system in which water used as a refrigerant and Li-br used as a absorber.

Ustaoğlu et al. (2018) presented energy and exergy analyses of a solar powered absorption refrigeration system carried out by terms of the first and second laws of thermodynamics. NH3-H2O fluid couple is used in the system.

3. RESEARCH METHODOLOGY

The main objective of the current study is to investigate heat transfer enhancement and flow characteristics in a new type plate heat exchanger using helical flow duct. Nine helix turns are constructed in the heat exchanger with changing the centre distance r. The hot fluid flows in the helical channel with the series arrangement in counter with cold fluid. The heat transfer process occurs through a helical copper plate with thickness 1 mm. These plates are repeated in the x-direction, with a pitch P, and height h. Here, the geometric parameter; centre distance,d is used in the numerical study. The hydraulic diameter Dh was used as the characteristic flow channel diameter. The hellical duct heat exchanger using copper is fabricated with overall dimensions of 30mm width, 10 mm length and 9 turns for carrying out the experimental work. The width of the wall (Ww) between the channels is 1mm. For the numerical simulation, the Reynolds number for each case is varied from 20000 to 60000 in steps of 20000 contributing to three cases for each geometric parameter i.e centre distance variation and hence a total of 9 cases are studied and the results are compared.

4. RESULTS AND DISCUSSION

The pressure drop profiles of helical duct heat exchanger are plotted against Reynolds number. It is found that the pressure drop increases as the Reynolds number increased as expected for different geometries of helical duct heat exchanger as shown in Figure below.

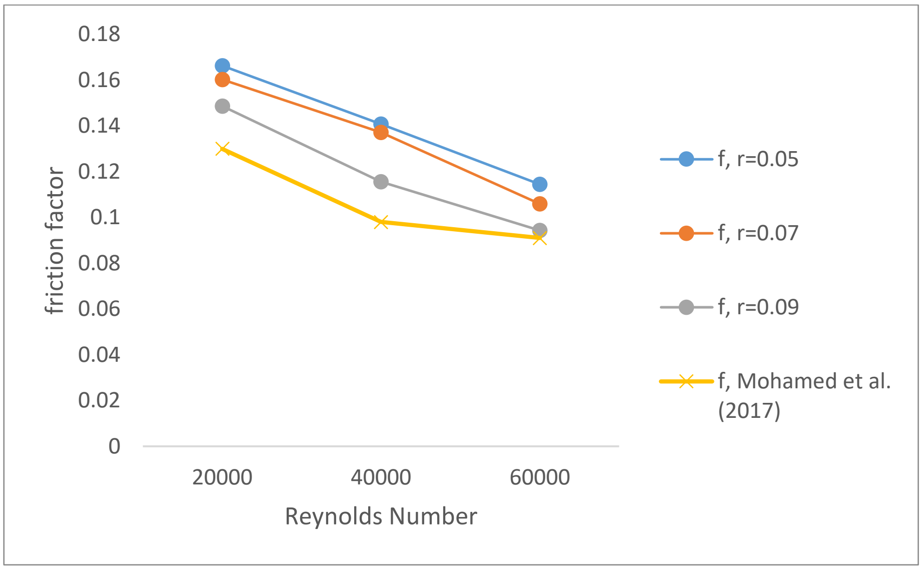

Fig 4. 1 Variation of Reynolds number with friction factor

Theoretically, as pressure drop for a flow increases, it results in a decrease in the friction factor values. According to the pressure loss obtained by CFD, the friction factor f can be calculated using above Equation 4.1. It can be observed from this figure that as the Reynolds number of the flow increases, the friction factor across the fluid flow channel decreases.

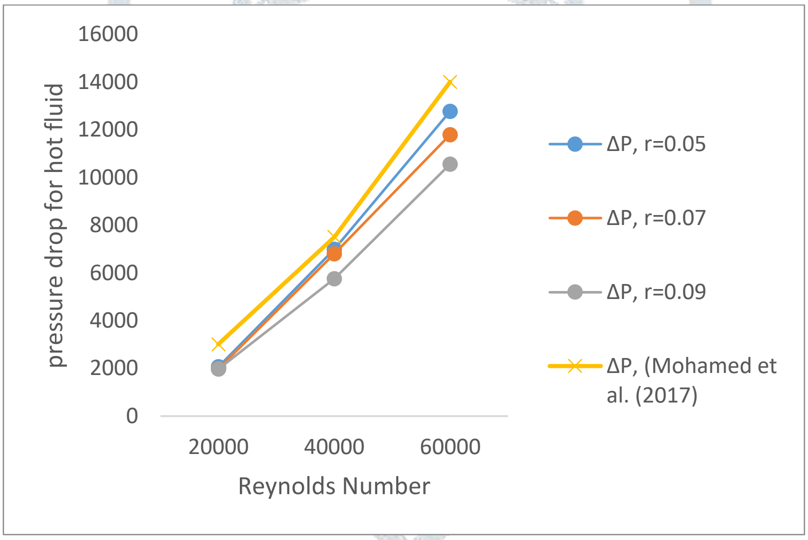

Fig 4. 2 Variation of Reynolds number with pressure drop for hot fluid

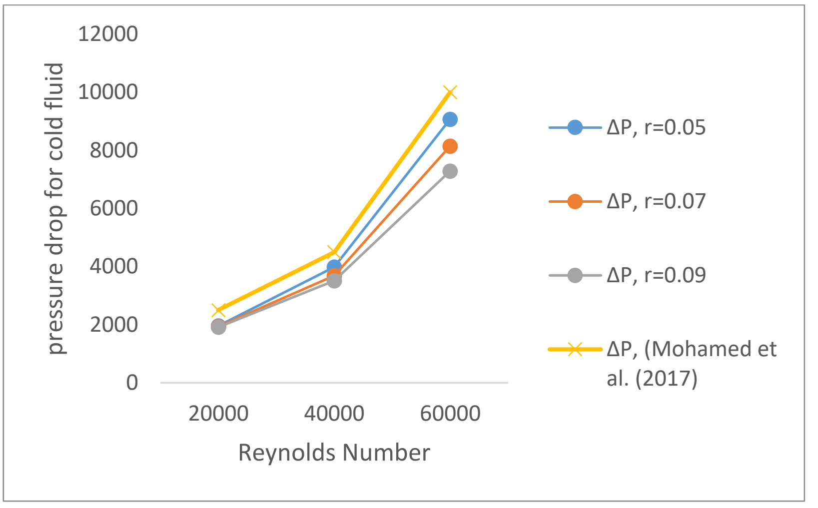

Fig 4. 3 Variation of Reynolds number with pressure drop for cold fluid

It can be observed from these figures that as the Reynolds number of the flow increases, the pressure drop across the fluid flow channel also increases for all centre distance values.

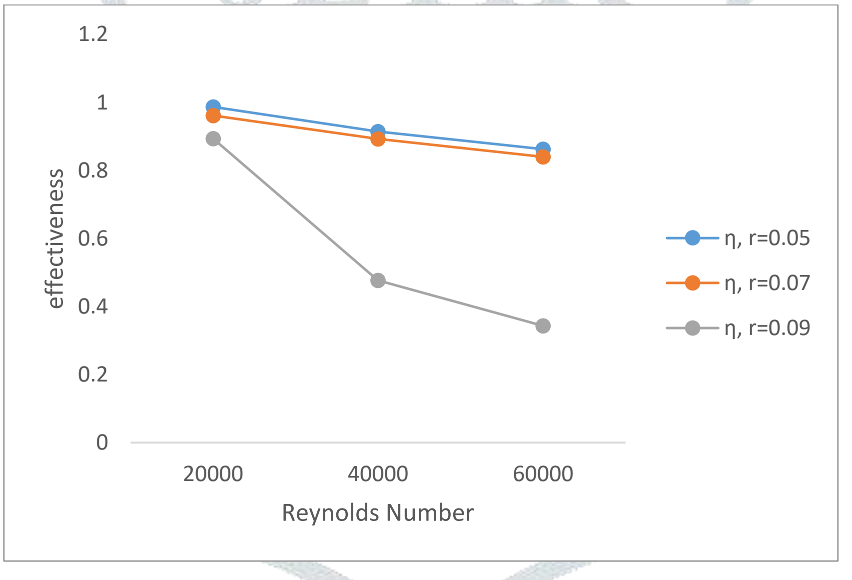

Fig 4. 4 heat exchanger effectiveness with Reynolds number

It can be observed from these figures that as the Reynolds number of the flow increases, the **heat exchanger effectiveness** decreases for all centre distance values.

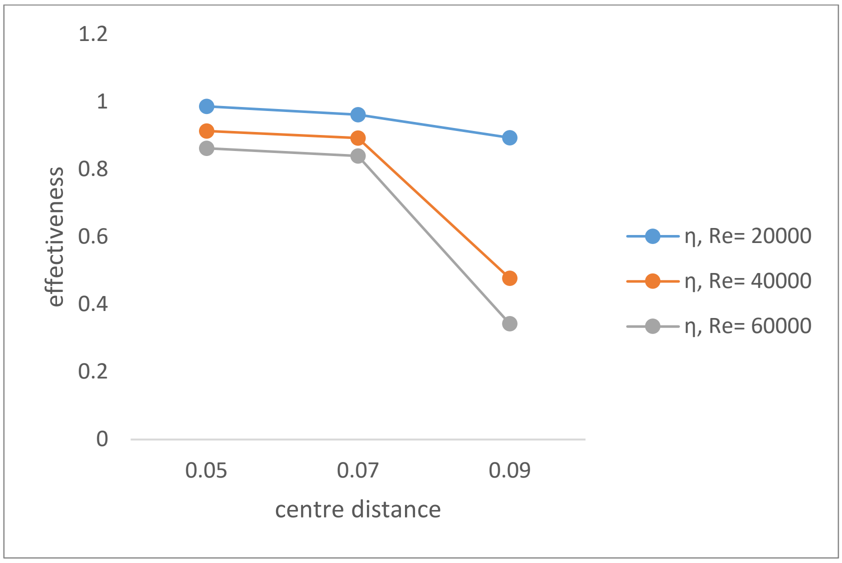

Fig 4. 5 heat exchanger effectiveness with centre distance

It can be observed from these figures that as the distance between the pipe is increased, the **heat exchanger effectiveness is** decreased for all Reynolds number values. hence among the three geometries, the first geometry with pipe at distance of 50 mm has the best effectiveness.

4.2 CONTOUR DIAGRAMS

The temperature, pressure and velocity contour diagrams of the helical duct heat exchanger are shown below

FOR d= 0.05m

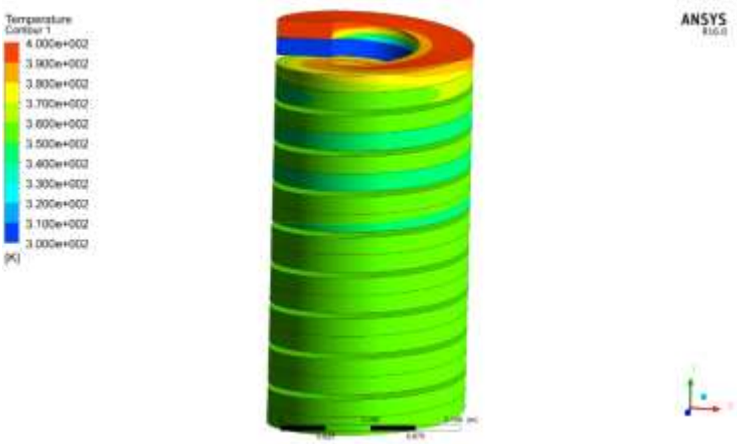

Fig 4. 6 temperature contour diagram (front view) for d= 0.05m

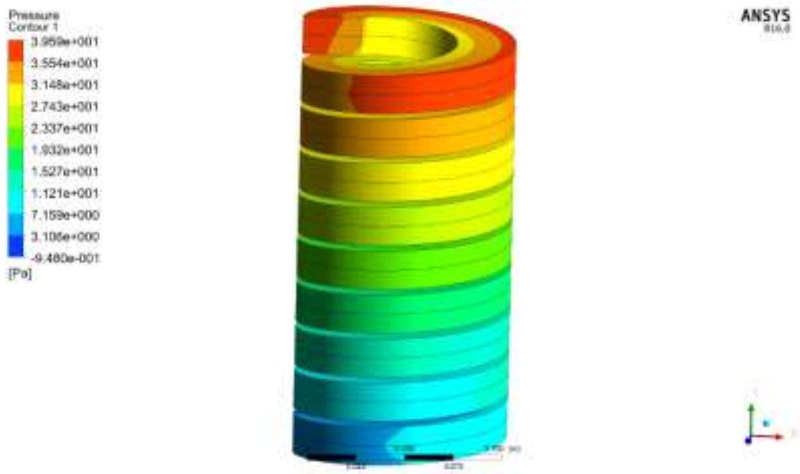

Fig 4. 7 pressure contour diagram (front view) for d= 0.05m

Fig 4. 8 velocity contour diagram (front view) for d= 0.05m

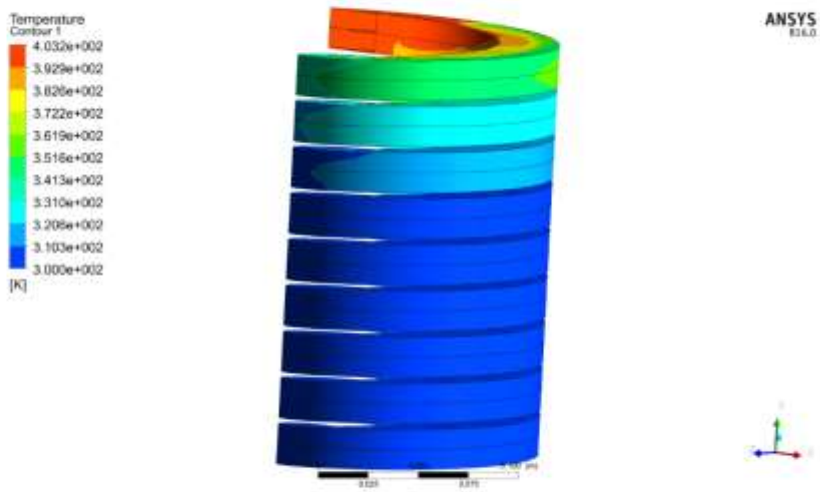

Fig 4. 9 temperature contour diagram (front view) for d= 0.07 m

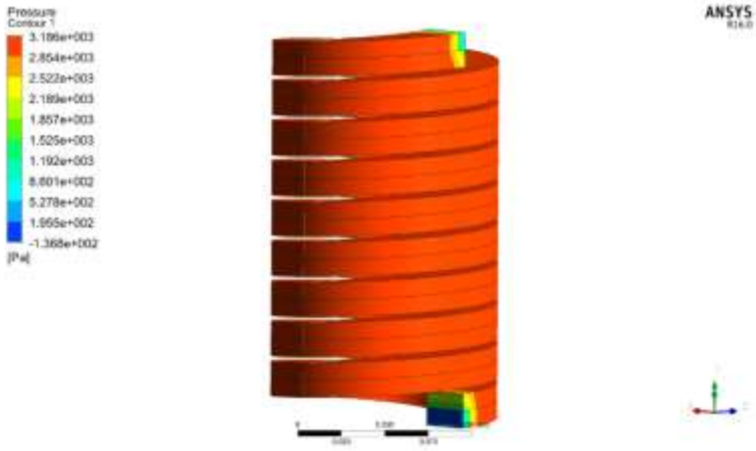

Fig 4. 10 pressure contour diagram (front view) for d= 0.07 m

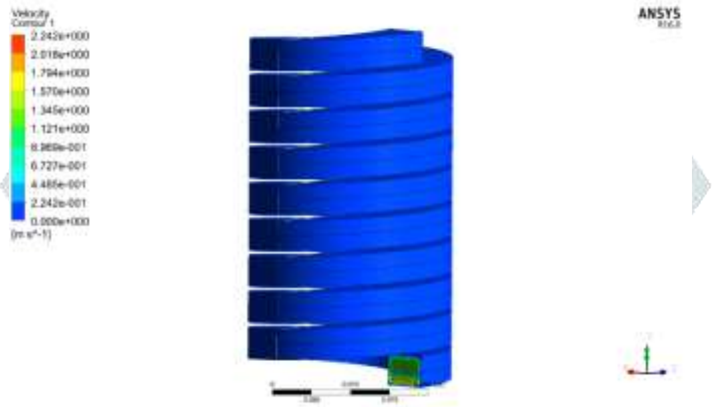

Fig 4. 11 velocity contour diagram (front view) for d= 0.07 m

FOR d=0.09 m

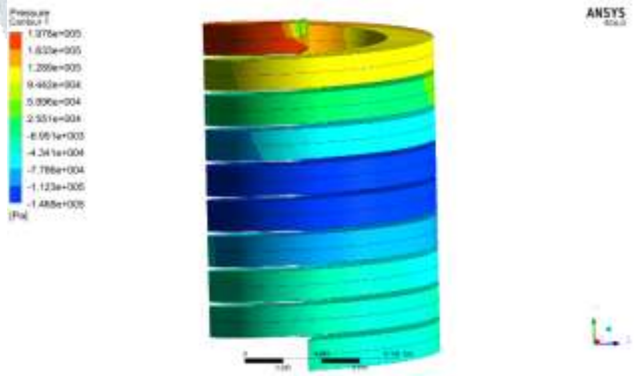

Fig 4. 12 pressure contour diagram (front view) for d = 0.09 m

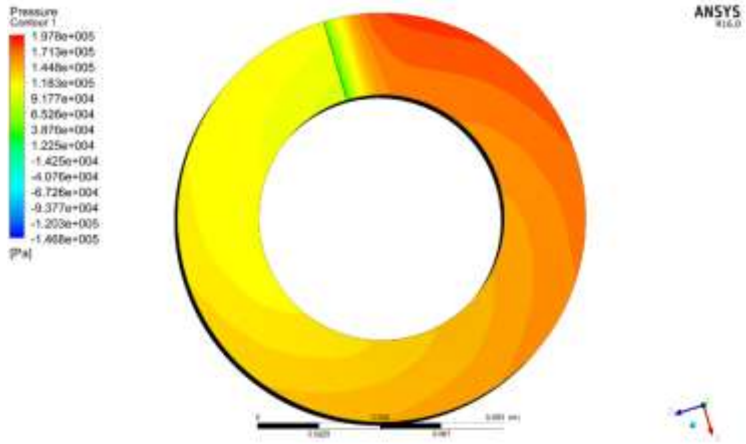

Fig 4. 13 pressure contour diagram (top view) for d = 0.09 m

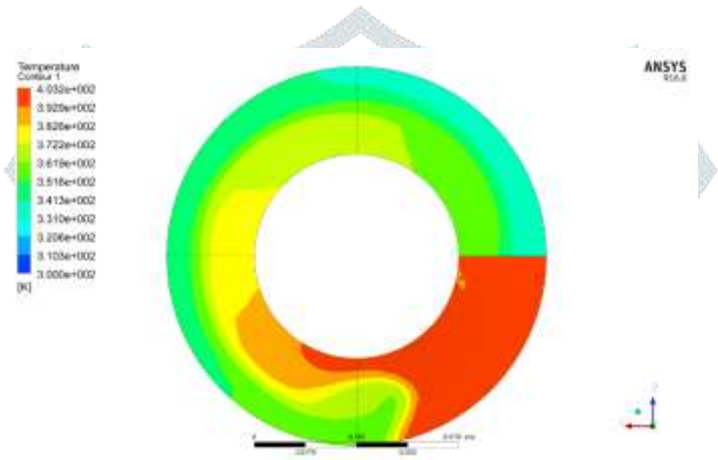

Fig 4. 14 temperature contour diagram (top view) for d = 0.09 m

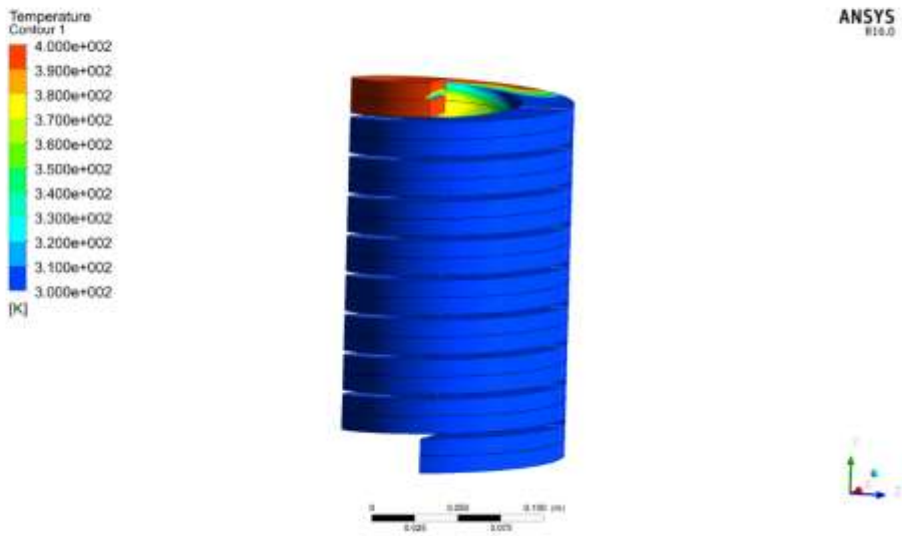

Fig 4. 15 temperature contour diagram (front view) for d = 0.09 m

Fig 4. 16 velocity contour diagram (front view) for d = 0.09 m

3. CONCLUSION

The main conclusions are summarized:

1. The present numerical simulation had been compared and a good agreement with published work of Mohamed et al. (2017)).
2. The increase in centre distance between the helical pipe decreases heat transfer rate and increase the pressure drop.
3. The heat exchanger effectiveness is maximum (0.98) at distance of 50mm having Reynolds number 20000.
4. The present work is expected to provide some insights to the understanding and optimization of flow and convective heat transfer mechanisms of the helical heat exchanger.

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