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Experimental and CFD Analysis of Effect of Curvature Ratio on Helical Coil Tube Heat Exchanger

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Abstract: ***The purpose of this study was to investigate the heat transfer characteristics of helical coil tube heat exchanger with different curvature ratio (0.0952, 0.1670, 0.238, and 0.257) versus straight tube heat exchanger. Hot water is used as working fluid in inner tube and cold water surrounded the tube. The three mass flow rates of hot water taken as 0.03 kg/s, 0.04 kg/s and 0.05 kg/s. Effect of curvature ratio on helical coil tube heat exchanger with constant wall temperature condition were studied. This paper deals with commercial CFD tool Ansys Release 14.5 simulation comparison with experimental results. It is found that the CFD simulation results show good agreement with experimental results. It was reported from experimental results pressure drop increases by 14.81 percent as curvature ratio increases from 0.0952 to 0.238. Based on results, it is found that helical coil with curvature ratio 0.0238 is more efficient than straight tube and its overall heat transfer coefficient increases with hot water mass flow rate.***

Keywords: CFD, Helical coiled tube, curvature ratio, Straight tube, Heat transfer Characteristics, Pressure Drop

1. Introduction

Heat transfer in curved and helical circular tubes has been the subject of several studies and it has been widely reported in literature that heat transfer rates in helical coils are higher as compared to a straight tube. In the present days Heat exchangers are the important engineering systems with wide variety of applications including power plants, nuclear reactors, refrigeration and air-conditioning systems, heat recovery systems, chemical processing and food industries. Helical coil configuration is very effective for heat exchangers and chemical reactors because they can accommodate a large heat transfer area in a small space, with high heat transfer coefficients. Fluid flows through a curved tube will experiences a centrifugal force. This centrifugal force induces a secondary flow pattern inside the tube. This secondary flow pattern has significant ability to mixing the fluid which enhances the heat transfer rate. The secondary flow is perpendicular to main direction of fluid motion.

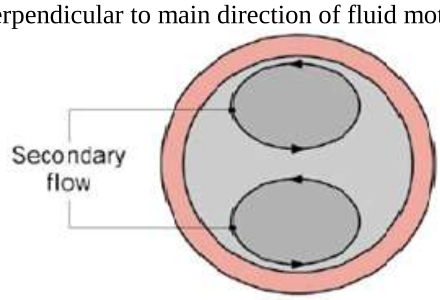

Figure 1: Secondary flow Pattern

2. Literature Survey

First time dean et al.[1] mathematically described flow through curved pipes in which they had made approximation of steady incompressible flow through circular cross section and state that reduction in mass flow rate depends on variable k = 2Re2*(r/R). After that white et al.[2] had extended dean study for different viscosity with laminar flow in cured pipes and they had concluded that in curved pipe flow is more stable as compare to straight pipes.

Sidda reddy et al.[3] had performed parametric analysis of helical tube heat exchanger using water as working fluid. Research study focus on various parameters like number of coil turns, mass flow rate inlet temperature that affect the effectiveness of a heat exchanger. Helical copper tube of 9.5mm internal diameter with 0.187 curvature ratio used for analysis. From the research work it was found that effectiveness and overall heat transfer increases with increase in flow rate. It was also noted that for counter flow the effectiveness of pipes both helical and straight flow is greater in parallel configuration. From the effect of temperature on overall heat transfer coefficient is was observed that overall heat transfer coefficient more in parallel flow than counter flow for helical pipe, but U varies up and down periodically for straight tube. Rogers et al.[4] Effectiveness increases with temperature in helical pipe for both parallel and counter flow configuration but it drops in straight pipe. In counter flow configuration outlet temperature of cold water rises by 70C − 210C, it implies that for the same surrounding area the helical pipe absorbed more heat than that of straight copper tube. Many researchers have reported that a complex flow pattern exists inside a helical pipe which leads to the enhancement in heat transfer. The centrifugal force results in the development of secondary flow and this centrifugal force is governed by the curvature and also affected by the pitch or helix angle of coil.

Kang et al. [5] investigated the heat transfer characteristics of a helically baffled heat exchanger combined with a finned tube experimentally and theoretically. Commercial Fluent 6.0 CFD code was used for predicting its fluid flow and heat transfer performances. The authors reported a good agreement between the modeling and experimental results. Timothy et al. [6] a computational fluid dynamics package (PHOE-NICS 3.3) was used to numerically study the heat transfer characteristics of a double-pipe helical heat exchanger for both parallel flow and counter flow. The results of these simulations were well within the range of result from the literature for helical coils. It was noted that very little difference in overall heat transfer coefficient in parallel and counter flow configuration, but heat transfer rate is higher in counter flow due to higher log mean temperature difference.

3. Methodology

3.1 Geometrical Parameter of Helical Coil Tube

Copper tubes of 9.52 mm outer diameter and 1257 mm length are used for analysis as it higher thermal conductivity than steel, aluminum etc. First straight tube analysis is done then helical coil of same length is going to analyze. Analysis made by different curvature ratio of helical coil done by varying PCD of coil, details given below table.

Table 3.1: Geometrical Parameters

Sr. No	Curvature Ratio	PCD	Tube Length	Pitch	No. of
	δ	mm	mm	mm	Turns
1	0	0	1256	-	0
2	0.0952	100	1256	25	4
3	0.1641	58	1256	25	6.89
4	0.238	40	1256	25	9.99
5	0.257	37	1256	25	10.81

3.2 Curvature Ratio

The pipe diameter to coil diameter is called curvature ratio (δ) where d is the diameter of the coiled tube, D is the coil diameter.

$$\delta = d / D \quad (1)$$

3.3 Formulation

In this experimental work heat transfer coefficients and heat transfer rate depends on the measured temperature data.

Reynolds number

$$Re = (\rho * V * d) / \mu \quad (2)$$

Dean number

$$De = (Re) * \sqrt{\delta} \quad (3)$$

Nusselt number

$$Nu = 0.023 *(Re0.85 * Pr0.4 * \delta 0.1) \quad (4)$$

Heat transfer coefficient

$$h = (Nu*k) / D \quad W/m2K \quad (5)$$

Heat flux

$$q = h*A*(Thi - Twi) \quad W/m2 \quad (6)$$

Pressure drop

$$dp = (Phi - Pho) \quad (7)$$

Friction factor

$$f = (hf *d * 2 * g) / (L*V2) \quad (8)$$

Prandtl Number

$$Pr = (\mu * Cp) / K \; [2] \quad (9)$$

3.4 Experimental Setup and Description

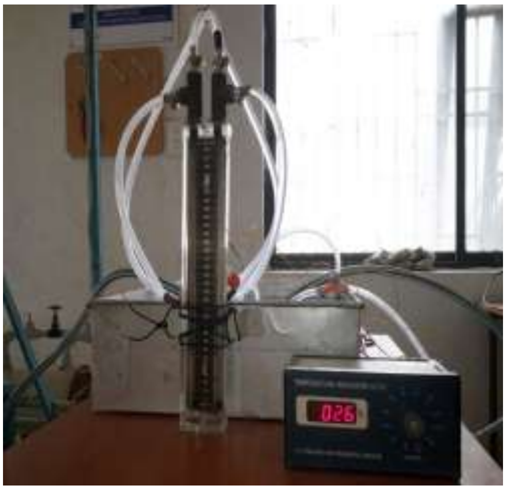

Figure 3.1: Experimental Setup

Experiments were conducted under steady state conditions with hot water used as working fluid. The fluid flow rate was varied a range 0.03 to 0.05 kg/s. Helical coil tube made of copper is completely immersed in sheet duct which act as shell which contains cold water at constant temperature of 303 k. Water is heated in hot water tank with the help of electric heater up to 333 k and then flow through PVC pipe from hot tank to inlet of heat exchanger. In order to measure various parameters various devices fitted to control panel i.e. the tube side hot water flow rate was measured using rotameter, inlet and out let temperature of hot water were recorded using k type thermocouple, Pressure P1, P2 measure using U tube manometer. By varying flow rate for single tube then number of readings is taken and then again reading are taken similar procedures repeated for other helical tube configuration.

4. Results

4.1 Experimental Results

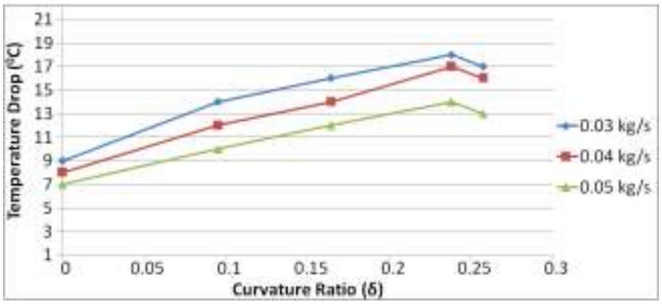

Figure 4.1: Temperature Drop Vs Curvature Ratio

Figure 4.1 show that temperature curve goes on increasing up to 0.23 after words decreases due to decrease in pressure drop. Output temperature drop corresponding to the helical coils are higher than straight Tube for all mass flow rate. i.e. temperature drop increases by 28.57 percent on increasing curvature ratio from 0.095 to 0.23.

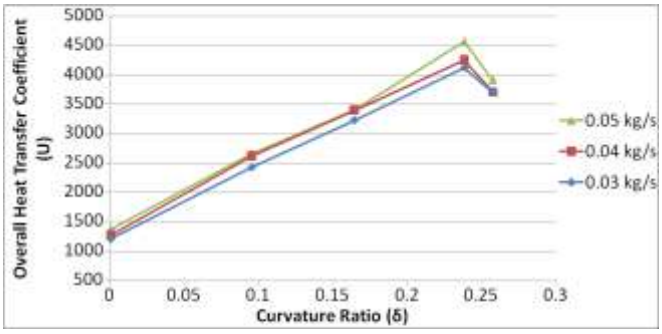

Figure 4.2: Overall Heat Transfer Coefficient Vs Curvature Ratio

Figure 5.2 was noted that Overall heat transfer coefficient increases with increase in curvature ratio of helical tubes up to 0.23 afterwards decreases due to decrease in heat transfer rate. Result shows that helical tube gives 52.60 percent higher value of Overall heat transfer coefficient over straight tube.

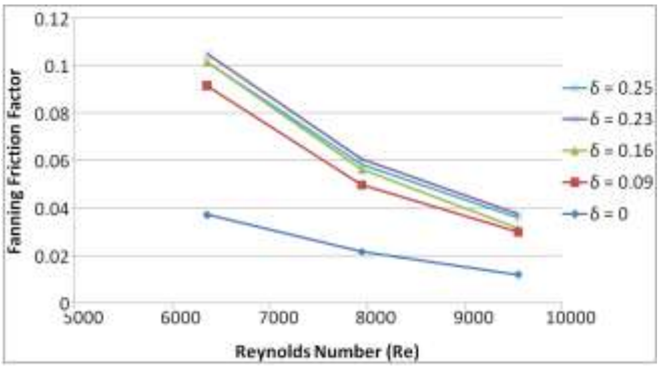

Figure 4.3: Fanning Friction Factor Vs Reynolds Number

Figure 4.3 show that as friction factor decreases with increase in Reynolds number due to relative roughness of surface, and velocity of flowing fluid

4.2 CFD Results

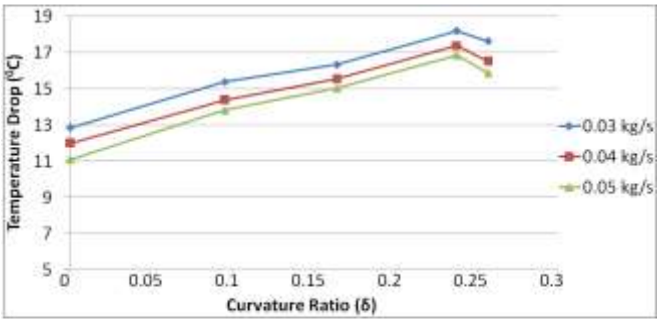

Figure 4.4: Temperature Drop Vs Curvature Ratio

Figure 4.4 shows that output temperature drop corresponding to the helical coils are higher than straight Tube for all mass flow rates. *i.e.* temperature drop increases by 9.30 percent on increasing curvature ratio from 0.095 to 0.23.

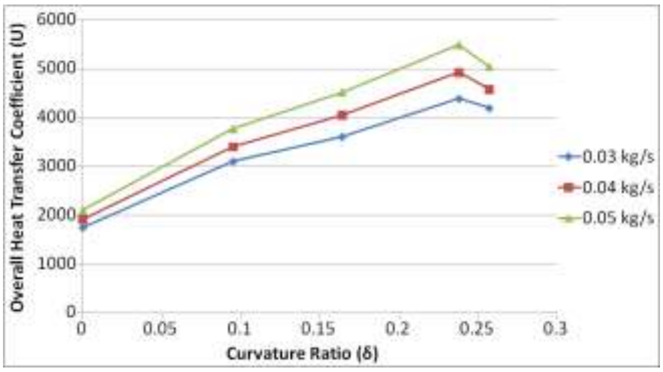

Figure 4.5: Overall Heat Transfer Coefficient Vs Curvature Ratio

Figure 5.5 indicates that as the mass flow rate of hot water increase inside the tube the overall heat transfer coefficient increases for each corresponding mass flow rate.

4.3 Comparison between Experimental and CFD Results

Figure 4.6 gives variation of heat transfer rate against mass flow rate. It is noted that CFD methodology gives 20.36 percent higher of heat transfer rate for 0.23 curvature ratio tube at 0.05 kg/s mass flow rate and such variation is may be due to assumption and practical errors.

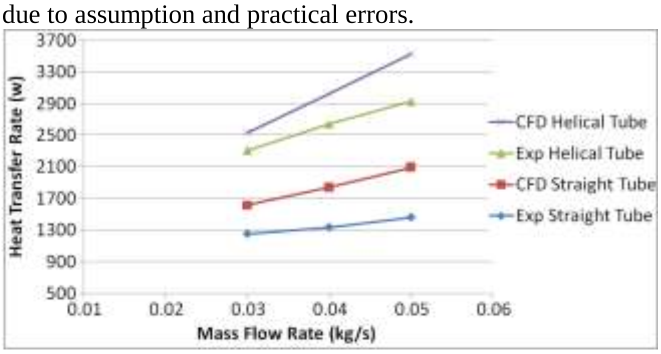

Figure 4.6: Heat Transfer Rate Vs Mass Flow Rate

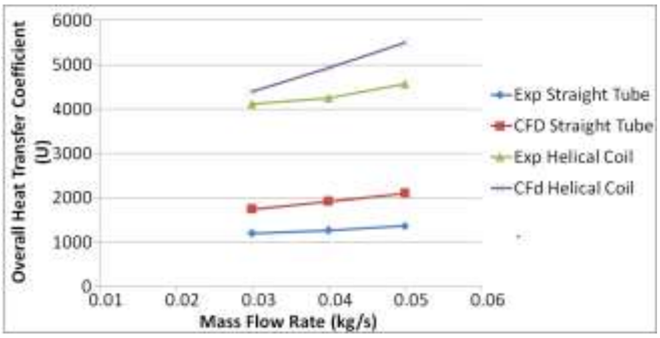

Figure 4.7: Overall Heat Transfer Coefficient Vs Mass Flow Rate

Figure 4.7 gives overall heat transfer coefficient against mass flow rate, it was reported 20.31 percent higher result of overall heat transfer coefficient by CFD methodology as compare to experimental methodology.

5. Conclusion

In this work the different helical tube models have been designed, generated in modeling software and manufactured, in order to investigate the effects of curvature ratios on convective fluid flow and heat transfer characteristics two methods. Using variation in mass flow rates, different parameters have been analyzed experimentally and CFD Modeling methodology. After results analysis and comparison several conclusions have been raised as given blow:

1) Experimental study shows increments in various parameters i.e. Nusselt Number, Heat transfer coefficient, Dean Number and heat transfer rate if curvature ratio increases from 0.0952 to 0.238. In experimental comparison of helical tube against straight tube, it was also noted that these parameter increase by double percentage and hence again it has been proved that helical coil tube is superior to straight tube.

2) CDF modeling for same objectives followed by experimental study shows that all heat transfer characteristics increases with increase in curvature ratio up to 0.238. The curvature ratio 0.238 is optimizing condition where heat transfer rate will maximum.

3) CFD modeling for same objectives followed by experimental study shows that all heat transfer characteristics increases with increase in curvature ratio but at expense of pressure drop. It was also conclude here CFD results partially match with experimental results i.e. Nusselt number and heat transfer coefficient are show larger deviation whereas percentage variation in friction coefficient are smaller and increase in pressure drop is double. Justifications for such variations in results are already given in previous parag

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