A review on Heat transfer & Flow Characteristics in Spiral tubes

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Abstract- *Fluid flows via path curvature pipe can increase the efficiency of transfer of heat. Spiral coils are frequently used for the heat exchangers, electronic cooling, chemical reactors, food industry, health industry and so on. They are compact & their heat transfer rate is much higher as especially in comparison to straight tubes of the very same length.. It is a well-known fact that heat transfer in Spiral coil is higher than in straight pipe. This study summarizes and discusses critically the studies published in the literature about the characteristics of pressure drop & flow in spirally coiled tubes. Consequently, the aim of this analysis is to provide educational and industrial researchers with a realistic overview of the related correlations and supporting Method for measuring the characteristic of pressure drop & flow in Spiral pipe tubes.*
*Keywords – Curved Tubes; Spirally Coiled tube; Curvature ratio; Newtonian fluids*

I. Introduction

Spiral coils are conventionally used curved tubes, which have been utilized in a wide variety of engineering applications such as heating, refrigerating systems, HVAC systems, steam engenderer and condensers in power plants and chemical reactors. In a curved tube, because of the distinctions between the inertial and centrifugal forces, a secondary flow originates in the cross section of the pipe. Developments in the heat transfer and flow in these tubes depend significantly on the output of the secondary flow induced. Heat Transfer describes the exchange rates of heat between cold and hot bodies. Heat Transfer measures temperature distribution and defines the rate at which the heat energy is distributed over a surface selected for analysis due to surface temperature gradients, and the difference in temperature between surfaces. The three ways in which heat transfer occurs are conduction, convection and radiation. The Radiation heat transfer is not included in this investigation because it has a negligible impact in the process since the temperature involved in the process is small. Conduction depends on the chosen material but convection plays a very important role in the heat transfer of a fluid that flows through a heat exchanger. The heat transfer rate and pressure drop in a spiral tube depend on the following parameters: Reynolds numbers, Prandtl number, Graetz number Newtonian or non-Newtonian fluid, thermal boundary state of the wall, ratio of coil to tube radius, section of the tube, ratio of length to diameter, pitch of the coil, number of turns etc. The effect of these parameters on spiral pipe heat transfer and flow friction was defined and investigated. The early investigations on curved tubes in general were fixated on experimental rather than the analytic or theoretical work.   W. R. Dean[4-5] introduced the first empirical evidence that secondary flow occurs in curved coils. W. C. Reynolds investigated the presence of critical velocity for a fluid flowing in the straight circular cross section pipe in 1883. After Reynolds, who analyzed the characteristics of straight coil flow Grindley & Gibson[1] first noticed a difference in straight tube flow & curved coil flow. Kubair and Kuloor experiment with a comparison of the helical coil, straight tube, and spiral coil for heat transfer[9Spiral coil performance was found to be higher than either straight pipe or helical coil performance. The same authors[10] created correlations for friction variables in the spiral coiled tubes for different fluids under laminar, transition, and turbulent flow. Many papers on spiral coils are normally fixed on numeric CFD analysis, simulator on sundry software and then the results obtained are experimentally tested

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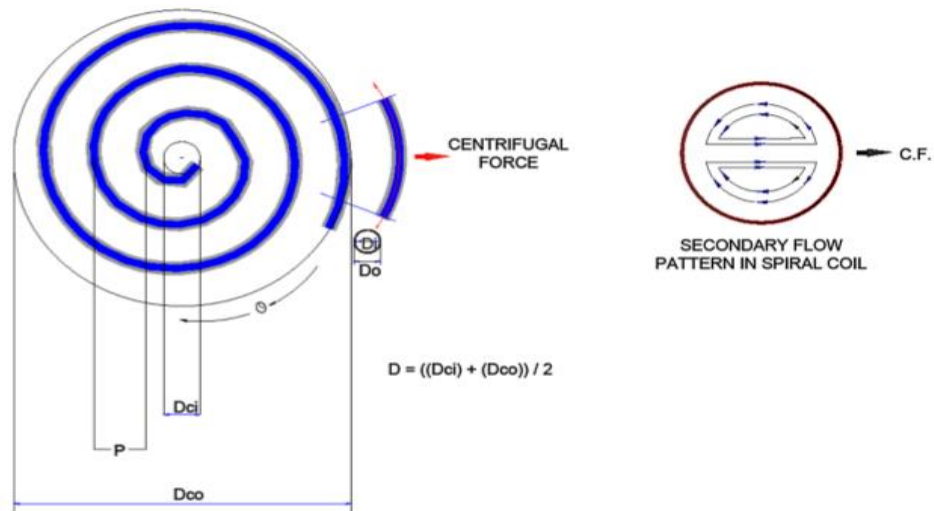
Fig 1: The geometry and the function of the spiral coil secondary flow pattern

Naphon and Wongwises suggested [17] an average in-tube transfer of heat coefficient in a spirally coiled pipeline. The test part was a spirally coil heat exchanger formed of six layers of concentrated spirally coiled tubing. The experiments were carried out under cooling and dehumidification situations and considering the effects of the inlet parameters of the two working fluids on the heat transfer coefficient in the tubeComparison of the findings obtained from experiments with those derived from other correlations. A new equation for the in-tube heat transfer factor was suggested for the spirally coiled tube as follows:

$$Nu = 27.358 De^{0.287} Pr^{-0.949} \quad \text{for } 300 \leq De \leq 2200, Pr \geq 5$$

A new type of spiral heat exchanger was designed by Dr.Madhukar S. Tandale and Dr. Sandeep M. Joshi [18] for a process industry in which waste heat was recovered from a producer gas and it was used to generate the steam. The design was programmed To do simulation research on a computer in order to access Achievement of a prototype. In their design they had used a new type of flow arrangement for Fluid Warm and cold in which Guiding of the hot fluid was in the axial path while the cold fluid flow was in spiral path. 12% maximum deviations were observed when the calculated values For total transfer of heat & The theoretical system was compared to experimental system. Comparison of the pressure fall value with the known correlations and the actual values observed which Was Discovered within acceptable range.

Pressure drop in Spiral coil was studied by Deshpande, Pramod M., and Dr. Dawande shrikant[19]. They have investigated Spiral coil tube Including laminar flow zone, with tube flow (Re < 2100). From their result it is observed that coil diameter reduces the curvature ratio increases. Due to this higher pressure drop occurs. The experimentally measured pressure drop by CFD due to curvature ratio variation and entrance effect.

A recent development in the field of Anthony Bowman and Hyunjae Park[3], study the pressure drop and heat transfer characteristics in toroidal & spiral coil. CFD Toroidal tube device analysis was conducted to estimate the characteristics of laminar flow and heat transfer, and compared to the existing experiment and numerical data. The analyzes were carried out for non-slip wall situation and are based on the internal wall surface of a coil tube. From their results the inside wall surface of the coiled tube is placed. From their results it is concluded that effectiveness Ratio for heat exchangers with spiral pipeline is Toroidal tube heat exchangers 20-30 percent higher. Because of this desired option the heat exchanger was spiral coil over toroidal.

II.   Research Methods

The thermal transfer and flow characteristics in spirally coil tubes were investigated using experimental and numerical methods. Illustration. 2 Presents a diagram showing of the testing facility developed by Paisarn Naphon[6] to investigate the pressure drop in spiral coiled tubes with different operating process variables such as: pressure, number of nusselt & mass flow rate. It setup is indicative of most experimental research in this field of analysis.
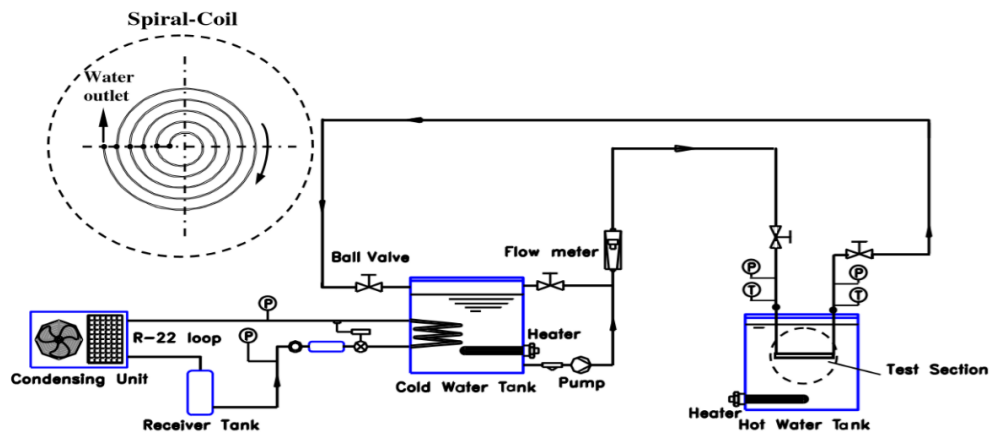
Fig 2: Schematic diagram of Experimental setup (Paisarn Naphon [6], Paisarn Naphon, Jamnean Suwagrai [7])

As shown on Fig. 2, Standard setup for the experiment. The test loop contains a sample section, a refrigerant loop, a cool water loop and a process for data acquisition. The testing section and piping device connections are constructed in such a way that parts can be easily modified or repaired. The hot and cold water is regulated to the level desired and monitored by the temperature sensor. After adjustment of the water temperatures to reach the desired amount, the cold water is pumped out of the storage tank and passed through a flow meter, test portion, and returned to the storage tank for cold water. The experimental portion is the horizontal spiral-coil tube that submerged itself in the hot water tank. The near cold water loop consists of a 0.5 m3 reservoir, an electric heater operated by voltage change, and a cooling coil submerged in a storage tank. Check portion and returned to storage tank for cold water. By changing the valve, the flow rate of the cold water was regulated and measured by the flow meter with a full scale accuracy of ±0.2 percent. The examination portion is constructed of the innermost and outermost 270.00 and 406.00 mm diameters, respectively, from the straight copper wire. Studies were performed with different cold and hot water inlet temperatures, and cool water flow rate joining the test area. In the analyses, the cool-water flow rate rise in small increments while cold water and warm water temps was keeps constant. The temperatures for inlet hot and cold water were modified to achieve the desired level using temperature controlled electric heaters. The device had been enabled to reach the steady state before any data were collected. All type T-thermocouples are pre-calibrated with a calibrator thermo-well. To measure the pressure drop through the test area, the differential pressure transducer with an accuracy of ±0.02 per cent of the full scale is used. Taking into account the findings derived from the Numerical analysis and those from the data measured. It is found from their findings that the Nussult number and the pressure decrease derived from spiral coil tube is 1.49 around 1.50 times greater than straight tube.

Paisarn Naphon, Jamnean Suwagrai [7] discussed the impact of curvature ratios in Horizontal Spirally Coiled Tubes on Transfer of heat and Flow growth. Using same experimental setup they developed mathematical and numerical models. Revolutionary new data of convective transfer of heat in spiral coiled tube are presented below steady wall temperatures and results obtained from the mathematical and numerical model must be validated by comparing with experimental data. The conclusion was same as above given. For Numerical simulation K-Ɛ Turbulence method was used.

Experimental methodology has been used to determine the flow of petroleum base oils SN70, SN150 and SN300 under isothermal stable state and a combination of isothermal steady state & non-isothermal unstable state conditions for "Graetz issue.". Fig. 3 represented the experimental setup which developed by Rahul Patil [11], Mariappan Nadar, Rashed Ali [12]. A current dimensionless number is added which is proved by the analyzation method without dimensions. The Nusselt number is associated with the Newtonian fluid number, depending on the experimental evidence. A variety of correlations are established of Newtonian fluids in isothermal stable state (total of 130 trials) and a mixture of isothermal stable state & non-isothermal unstable state cases (total 154 trials). The correlations established are compared with the correlations formed by prior researchers, but are still reported to be in good agreement.
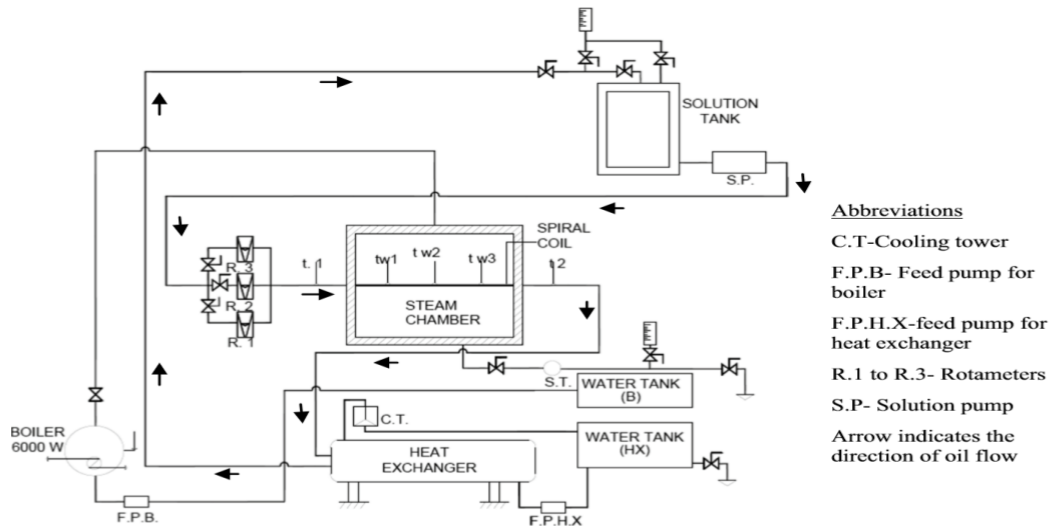
Fig 3: Experimental setup (Rahul Patil[11], Nadar, Rashed Ali [12])

The revolutionary set-up involves a helical coil heat exchanger, a water boiler, water reservoirs, oil tank, gear pump, water pump, and fittings and tube fittings for stainless steel. The steam piping is 16 mm long and even the oil loop piping is 12 mm long. The equipment used for the test are three range rotameters, 0.5 to 5 LPH, 5 to 50 LPH, and 50 to 500 LPH, that are used as flow indicators. The RTD's used to calculate the temperature of the wall surface are mounted on the coil at the inlet, middle and outlet location. An RTD senses the temperature in the steam chamber, and two RTD's are used for calculating the test fluid's inlet and outlet temperature. The RTDs used are calibrated; their exactness is ±0.1. The spiral coil is first put into the steam chamber and installed. The outside wall of the spiral coil is held at a constant temperature by pumping steam within the steam chamber with the aid of a boiler for reading isothermic steady state. The vapor temperature within the steam chamber varies between 99 and 101. The fluid that reaches the spiral coil passes first through the isothermal relaxing section and through the spiral coiled tube heating segment. Hence the velocity profiles develops completely, and the temperature profile starts to evolve at the spiral coil entrance. This is the issue of 'Graetz.' The fluid moves through the spiral coil to the heat exchanger, where it is cooled to the oil temp throughout the oil storage tank. The tests are obtained by inserting one coil at a time in the fluid chamber, for various flow speeds. It records between 13-15 readings per coil. First reading at 60 and further readings at 70, 80, and 90 are taken. With isothermal stable equilibrium, after the first testing, second flow rate is selected and second reading is obtained, so that all readings are obtained.


Fig. 4: Actual Experimental setup (Rahul Patil [11], Nadar, Rashed Ali [12])

Their correlations concerning R 'numbers, built on basis of experimental evidence for spiral coiled tubes, are verified with the works of prior authors and the expected results are considered satisfactory.

Rahul Patil, Mariappan Nadar, Rashed Ali [12] are the only authors who investigated the effect of Dean Number on heat transfer to petroleum base oils flowing through spiral coils using the same experimental setup and it was reported that a rise in the curvature ratios also increases the heat transfer to oil. An overall consequence of the rise in Dean number across all coils is to rise the transfer of heat, but as the average radius of the spiral coil increases the transfer of heat and decreases due to the resulting decrease in centrifugal force. Wall temp is held constant throughout the present study. At fluid bulk temperature, the properties are determined. The within heat transfer coefficient is determined as above represented orally, calculating assorted non-dimensional numbers such as Nusselt Number, Reynold Number, Graetz Number, Prandtl Number and Dean Number. Dimensional analytics methodology is used to identify the specific type of the appropriate correlation. This gets the following correlation.

(1) $\quad Nu = 2.251 De^{0.575}$

(2) $\quad Nu = 7.548 De^{0.575} (Di/D)^{0.315}$

(3) $\quad Nu = 0.197 De^{0.671} Pr^{0.4}$

(4) $\quad Nu = 0.771 De^{0.671} Pr0.4 (Di/D)^{0.357}$
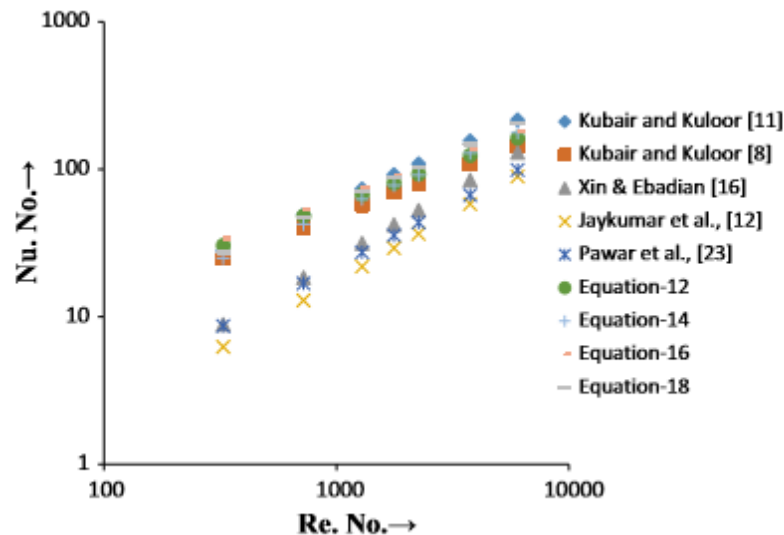
(3)

Fig 5: logarithmic plot of Reynold's Number versus Nusselt Number to compare the developed correlations based on the present experimental data with range; (Re = 326 to 6013; Pr = 102 and (Di/D) = 0.03011) with the works of earlier investigators.

The correlation not available in Literature. The correlations formed should allow use of literature in filling the space. The associations established are checked with advanced investigators' details and investigations, and they are considered to be within reasonable limits. The correlations (1,2,3,4) can therefore be used to design the thermal systems, with requirements as defined, where spiral coils are used for the process of heat transfer.

III.CONCLUSION

The above paper produced a study of all available investigations in the related heat transfer and flow characteristics literature in spiral tubes. It has been concluded that the amount of Nusselt and that the pressure drop generated from the spiral coil tube was 1.49 to 1.50 times greater than the straight tube according to other researchers' study. From the information obtained from experiment, this is discovered that the dean vortices directly caused by centrifugal force throughout the spiral tubes play an important role in the enhancement of transfer of heat and analysis shows that both Nusselt number & pressure drop rise with dean numbers. As per verified correlations (1, 2, 3, 4) it is possible to use spiral coils for the heat transfer process when designing the thermal systems, with the conditions as defined.

List of symbols

a2′, b2′, c2′, a3′, b3′ Correlation constants

Cp Specific heat at constant pressure

D Average diameter of curvature for a spiral

Dco Maximum diameter of coil

Dci Minimum diameter of coil

Di Inside diameter of spiral coil tube

Do Outside diameter of Spiral Coil tube

De Dean Number

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(Di/D) Variable curvature ratio

Gz Graetz number

H Heat transfer coefficient

K Fluid thermal conductivity

L Tube length

m Mass of the fluid

ṁ Mass flow rate

n Number of spiral coil turns

Nu Nusselt number

P Pitch of Coil

Pr Prandtl number

Q Heat transfer rate,

q Heat Flux,

Re Reynolds number

R Average radius of curvature of spiral

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