effect of friction factor on process and design parameters in spiral flow using design of experiment and CFD simulation technique

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Abstract - **Spiral tubes are widely used in various engineering applications like heat transfer among various fluids, refrigeration applications and many more. The optimum spiral tube can improve efficiency of the system. So various research is carried out on spiral tubes design and process parameters in previous decades. In present paper effect of friction factor is studied for spiral tube by chaining its process and design parameters. The present study is based on CFD simulation technique. Experiments are designed using "Taguchi Method". The three process parameters which are identified for this study is wall temperature of surface, fluid inlet temperature and mass flow rate of fluid. Three design parameter which are selected for this study are inner diameter of tube, pitch of tube and curvature ratio of tube. Total six parameters are selected and then experiment table is generated using Taguchi method and 36 experiments are generated which are then simulated using Ansys Fluent (Version 14.5) software. Experiment validation is performed using previous experiment work on spiral tube. Friction factor is response parameter selected for this study and the analysis is performed using Signal to noise ratio parameter. To improve the effect of pressure-drop or decrease the friction factor in spiral tube the most reliable parameter is inner diameter of tube and least parameter is wall temperature of tube. Pitch is another important parameter for friction factor analysis.**

keywords - **Spiral Tube, CFD simulation, Design of Experiment, Taguchi Method, Signal To Noise Ratio, Friction Factor**

INTRODUCTION

Fierce flow and convective heat move in a spirally coiled tube are convoluted as looking at the straight tube. This is on the grounds that the heat moves and flow improvements in the bended tube emphatically rely upon the conduct of auxiliary flow. The optional flow in the bended tube is caused by the radial power. Helical and spiral coils are well known sorts of bended tubes which have been utilized in a wide assortment of utilizations. Be that as it may, most examinations for bended tubes are worried about the helically coiled heat exchanger [1] and [2] tentatively considered on the natural convection heat move from helical coiled tubes in water. The anticipated outlet temperature was analyzed with the deliberate qualities from an exploratory arrangement. [3] thought about impact of tube ebb and flow proportion on the habitation time appropriation of various particles in helical tubes. The majority of the parameters, aside from the transporter liquid thickness affected the flow conduct of particles. [4] gathered the environmental dampness from a nonstop wind stream through a refrigerated coil tube. [5,6] considered entropy age, thermodynamics and Reynolds number improvements of completely created laminar convection in a helical coil with consistent heat transition. In their third and fourth papers, [7,8] broke down the ideal mass flow rate and shape proportion for completely created laminar constrained convection in a helical coiled tube with consistent heat transition in light of negligible entropy age standard. Air and water were utilized as working liquids. [9] tentatively examined impacts of diffusive increasing speed on the flow system map and the spatial and the fleeting flow structure appropriation of air–water two-stage flow in helically coiled tubes. Contrasted with the various examinations in the helically coiled tubes, there are not many specialists on the heat move in the spiral-coil heat exchangers as in open writing. [10,11] utilized the pertinent connections of the tube-side and air-side heat move coefficients in the recreation to decide the warm presentation of the spiral-coil heat exchanger under cooling and dehumidifying conditions. [12] numerically considered the cooling a liquid flowing through a spiral coil submerged in a chilled water compartment. A basic axisymmetric numerical technique was depicted to decide the temperature of the liquid in the spiral coil and that of the coil surface.

Objective of Study

The prime aim of this research is to find the role of friction factor in spiral flow using CFD simulation technique for process and design parameters. The experiments are plan to design using Taguchi method. The selection of parameters is purely on literature review. Signal to Noise ratio is used to identify the ranks among input parameters and nonlinear model equation for friction factor is also in scope of this research study.

Base Design of Spiral Tube and Validation with CFD simulation

The base design is identified from previously available research work of **Paisarn Naphon [01, 02]**. The reason to select this research work is proper availability of geometrical constraints for spiral tube designing and full detailed experiment data which is used for validation of CFD simulation. The experimental validation for pressure drops for selective spiral tube for this research paper. The Experiment validation for pressure drop is present in table 1 and fig. 1.

Table 3.9

Table1 Experimental validation with previous research work [01, 02] for Pressure Drop

MFR	Experiment (Tin=20 C and THS=35 C)				Simulation (Tin=20 C and THS=36 C)			
	Straight	CR-0.02	CR-0.04	CR-0.05	Straight-S	CR-0.02-S	CR-0.04-S	CR-0.05-S
0.050	0.99	1.90	1.53	1.51	1.11	2.09	1.76	1.81
0.066	1.92	2.83	2.83	2.73	2.08	3.14	3.04	3.24
0.085	3.20	4.34	4.34	4.26	3.45	4.82	5.00	4.80
0.100	4.71	6.24	6.24	5.84	4.80	7.12	6.77	6.24
0.117	6.39	8.02	8.02	7.82	6.86	9.05	8.94	8.32

Table 2 Error in experimental validation Pressure Drop [01, 02]

Error (Tin=20 C and THS=36 C)			
Straight-S	Cr-0.02-S	Cr-0.04-S	Cr-0.05-S
12.1	10.0	15.0	19.9
8.4	10.8	7.3	18.5
7.7	11.1	15.3	12.7
2.0	14.1	8.5	6.8
7.3	12.8	11.5	6.4

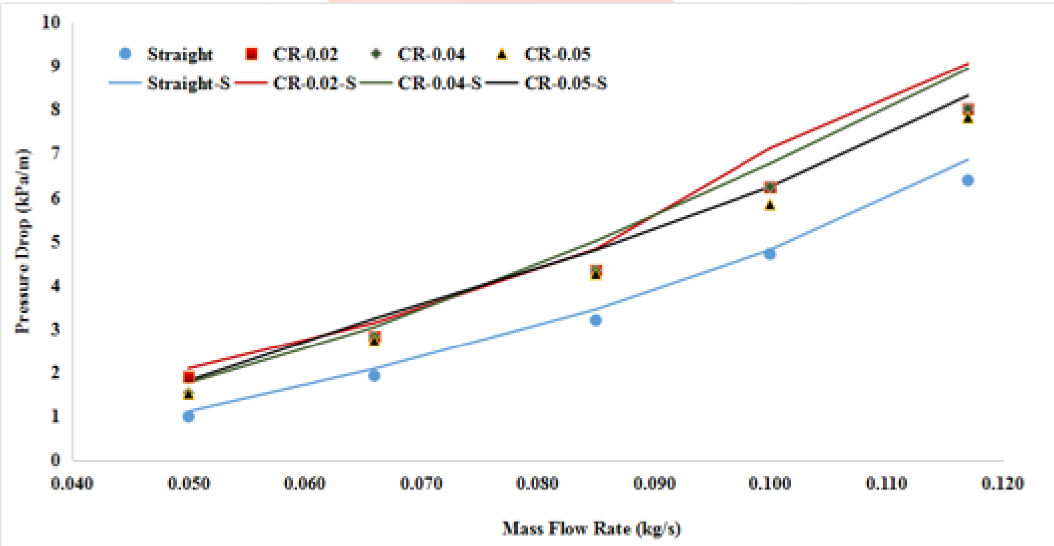


Figure 1 Experiment Validation for Pressure Drop [01, 02]

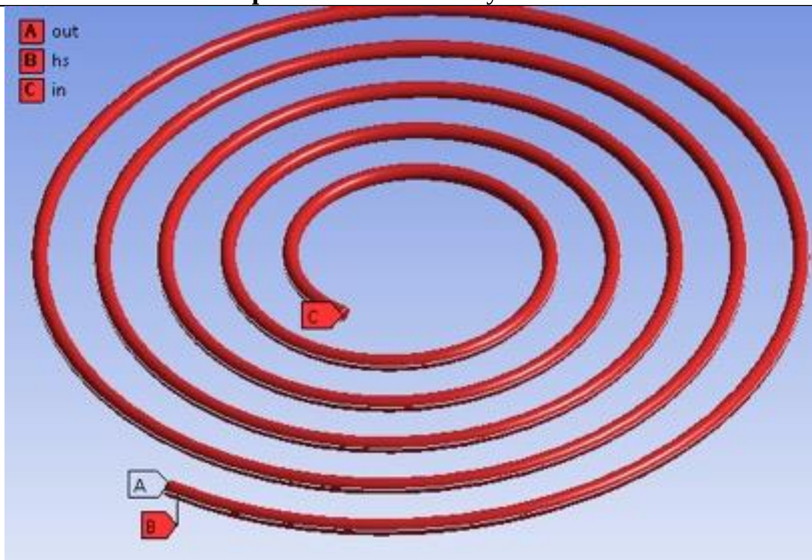
CFD Simulation Modeling Steps

As show in figure 1, the proper experiment validation is performed for this selective research paper. After validation of spiral tube, the proper modeling steps used for this research study is present in this section and detailed steps are present in table 2 for CFD simulation using Ansys Fluent Software (Version 14.5)

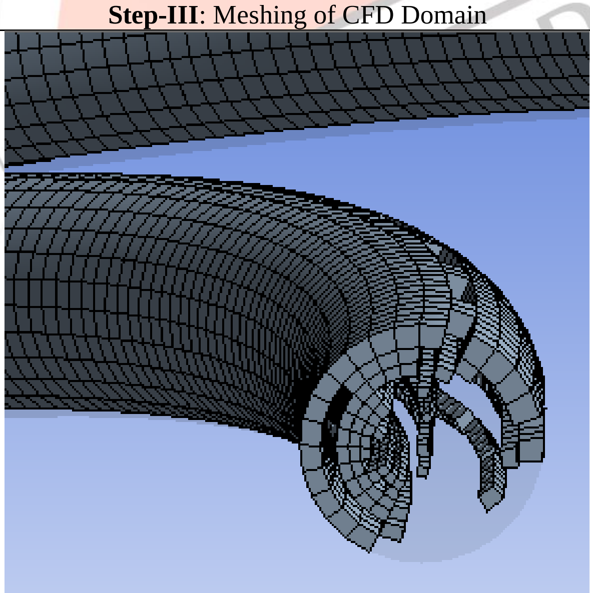
Table 2 CFD Modeling Steps

Step-I: CFD Domain Making

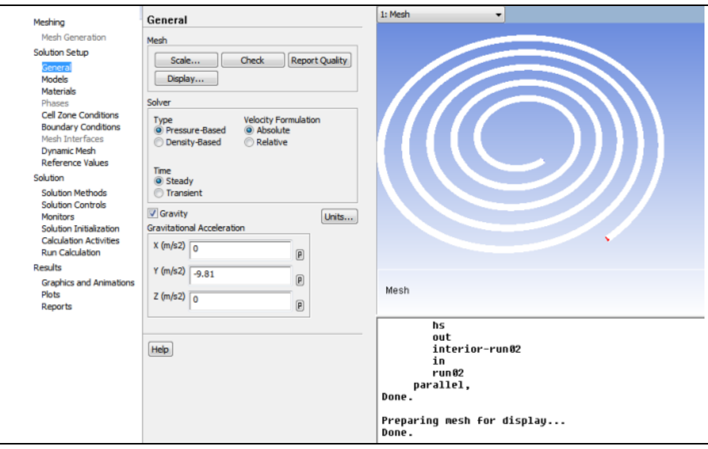
Step-II: Named Boundary Selection



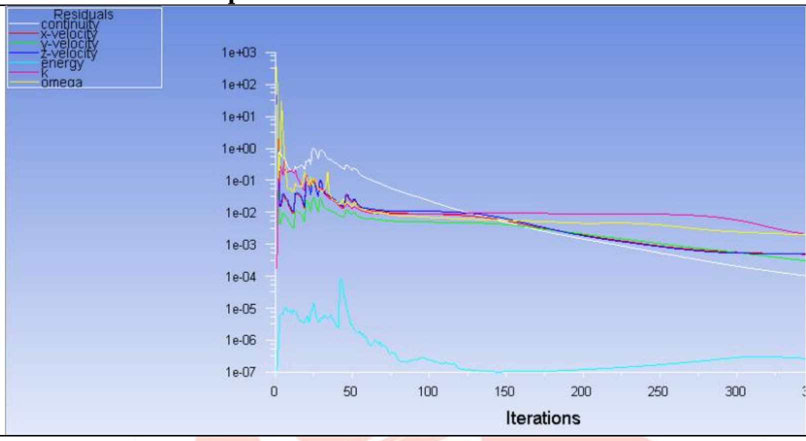
Step-III: Meshing of CFD Domain



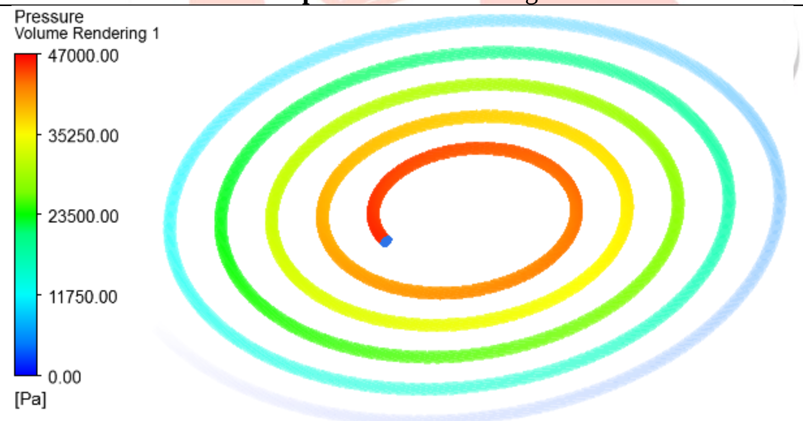
Step-IV: CFD Simulation Solver



Step-V: Solution method and Residuals



Step-VI: Post Processing



Factor and Levels

As present in objective of the research work, the selective process and design parameters for spiral flow study is present in table 3 and table 4 with proper levels. The selection of levels is done with help of previous published research work.

Table 3 Process parameter and their levels

Factors	Short Discription	Level-I	Level-II	Level-III	Unit
Inner Diameter	ID	8	9	NA	mm
Mass Flow Rate	MFR	0.1	0.12	0.14	kg/sec
Heat Flux (Twall)	HF	30	33	36	C

Table 4 Design parameter and their levels

Factors	Short Discription	Level-I	Level-II	Level-III	Unit
Fluid Temperature	FT	15	17	19	C
Pitch	Pitch	25	30	35	mm
Curvature Ratio	CR	0.018	0.020	0.024	NA

Mixed Orthogonal Array

Taguchi method is selected for the present study using Minitab software for making this experiment table. The experiments are then numerically solved by using CFD simulation software. Total 36 cases are designed for this research work. The primary parameter pressure is simulated using Ansys Fluent software. The experiment table is present in table 5.

Table 5 Mixed orthogonal Array

Run	ID	MFR	HS	FT	PITCH	CR
1	8	0.1	25	15	25	0.018
2	8	0.12	28	17	30	0.020
3	8	0.14	31	19	35	0.024
4	8	0.1	25	15	25	0.020
5	8	0.12	28	17	30	0.024
6	8	0.14	31	19	35	0.018
7	8	0.1	25	17	35	0.018
8	8	0.12	28	19	25	0.020
9	8	0.14	31	15	30	0.024
10	8	0.1	25	19	30	0.018
11	8	0.12	28	15	35	0.020
12	8	0.14	31	17	25	0.024
13	8	0.1	28	19	25	0.024
14	8	0.12	31	15	30	0.018
15	8	0.14	25	17	35	0.020
16	8	0.1	28	19	30	0.018
17	8	0.12	31	15	35	0.020
18	8	0.14	25	17	25	0.024
19	9	0.1	28	15	35	0.024
20	9	0.12	31	17	25	0.018
21	9	0.14	25	19	30	0.020
22	9	0.1	28	17	35	0.024
23	9	0.12	31	19	25	0.018
24	9	0.14	25	15	30	0.020
25	9	0.1	31	17	25	0.020
26	9	0.12	25	19	30	0.024
27	9	0.14	28	15	35	0.018
28	9	0.1	31	17	30	0.020
29	9	0.12	25	19	35	0.024
30	9	0.14	28	15	25	0.018
31	9	0.1	31	19	35	0.020
32	9	0.12	25	15	25	0.024
33	9	0.14	28	17	30	0.018
34	9	0.1	31	15	30	0.024
35	9	0.12	25	17	35	0.018
36	9	0.14	28	19	25	0.020

The CAD design of spiral tube is present in fig. 2. CAD file is make using Autodesk Inventor software for all 36 cases. Final selection of design parameters is conduct by research papers of [01] and [02].

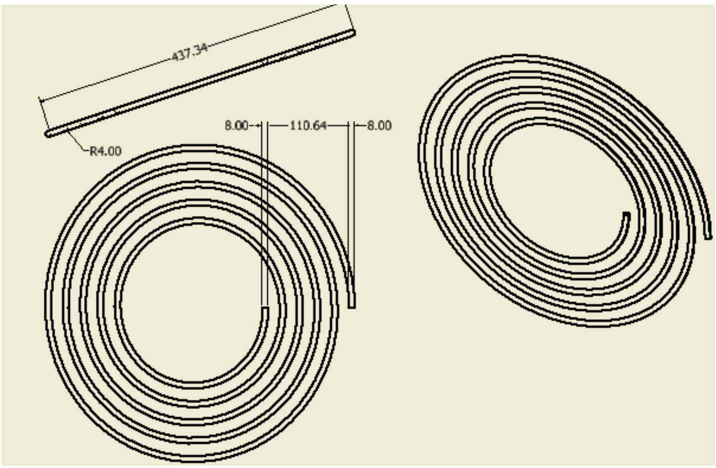


Figure 2 Dimension of spiral tube used in present research study

Result and Discussion

The final table of friction factor for 36 cases are present in table 6 with friction factor and S/N ratio calculation for each experiment using S/N ratio log formula.

Table 6 S/N ratio calculation for friction factor

Run	ID	MFR	HS	FT	PITCH	CR	ff	S/N Ratio
1	8	0.1	25	15	25	0.018	0.0519	25.69
2	8	0.12	28	17	30	0.020	0.0400	27.96
3	8	0.14	31	19	35	0.024	0.0387	28.24
4	8	0.1	25	15	25	0.020	0.0492	26.16
5	8	0.12	28	17	30	0.024	0.0366	28.74
6	8	0.14	31	19	35	0.018	0.0375	28.52
7	8	0.1	25	17	35	0.018	0.0421	27.52
8	8	0.12	28	19	25	0.020	0.0451	26.91
9	8	0.14	31	15	30	0.024	0.0403	27.90
10	8	0.1	25	19	30	0.018	0.0463	26.69
11	8	0.12	28	15	35	0.020	0.0342	29.32
12	8	0.14	31	17	25	0.024	0.0402	27.92
13	8	0.1	28	19	25	0.024	0.0473	26.50
14	8	0.12	31	15	30	0.018	0.0421	27.52
15	8	0.14	25	17	35	0.020	0.0329	29.65
16	8	0.1	28	19	30	0.018	0.0468	26.60
17	8	0.12	31	15	35	0.020	0.0367	28.72
18	8	0.14	25	17	25	0.024	0.0400	27.97
19	9	0.1	28	15	35	0.024	0.0438	27.16
20	9	0.12	31	17	25	0.018	0.0572	24.86
21	9	0.14	25	19	30	0.020	0.0471	26.54
22	9	0.1	28	17	35	0.024	0.0488	26.23
23	9	0.12	31	19	25	0.018	0.0572	24.86
24	9	0.14	25	15	30	0.020	0.0483	26.33
25	9	0.1	31	17	25	0.020	0.0583	24.68
26	9	0.12	25	19	30	0.024	0.0445	27.03
27	9	0.14	28	15	35	0.018	0.0458	26.79
28	9	0.1	31	17	30	0.020	0.0512	25.81
29	9	0.12	25	19	35	0.024	0.0479	26.39
30	9	0.14	28	15	25	0.018	0.0582	24.70

Run	ID	MFR	HS	FT	PITCH	CR	ff	S/N Ratio
31	9	0.1	31	19	35	0.020	0.0466	26.64
32	9	0.12	25	15	25	0.024	0.0469	26.57
33	9	0.14	28	17	30	0.018	0.0521	25.66
34	9	0.1	31	15	30	0.024	0.0460	26.75
35	9	0.12	25	17	35	0.018	0.0475	26.47
36	9	0.14	28	19	25	0.020	0.0542	25.31

Rank Identification of friction factor for Spiral Flow

S/N ratio present in table 6 is used to find the rank among all factors for friction factor response and the final results for ff is present in table 7 with all ranks among factors. It is also show in fig. 3 for S/N ratio of ff response variable.

Table7 Rank identification for friction factor

Level	ID	MFR	HS	FT	PITCH	CR
1	27.7	26.37	26.92	26.97	26.01	26.32
2	26.04	27.11	26.82	26.96	26.96	27
3		27.13	26.87	26.68	27.64	27.28
Delta	1.65	0.76	0.09	0.28	1.62	0.96
Rank	**1**	**4**	**6**	**5**	**2**	**3**

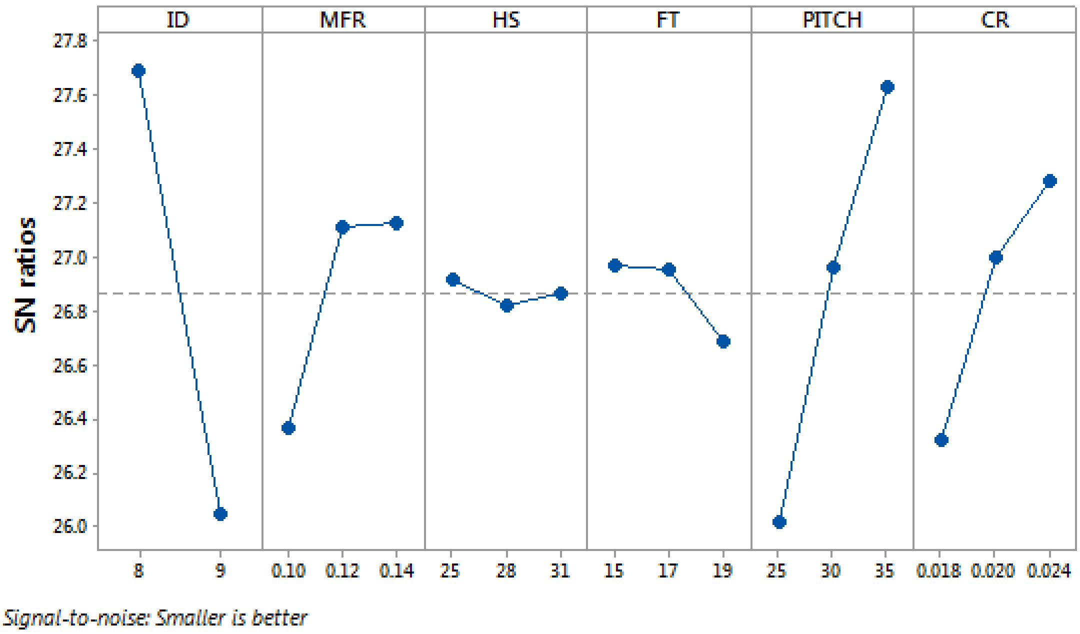


Figure 3 S/N ratio for friction factor (ff)

As seen in table 7, the first rank of factor is inner diameter of tube, second rank is for Pitch, third rank is set for curvature ratio (CR), fourth and fifth ranks are set for mass flow rate and inlet temperature of fluid and last rank is set for wall temperature of surface of spiral tube.

Optimal Solution Calculation for ff

The single response optimization is present in table 8 for friction factor and full detailed calculation is also present in this section for this response variable.

Table 8 Optimal Solution for friction factor (ff)

Response	ID	MFR	HS	FT	PITCH	CR	ff
ff	8	0.14	25	15	35	0.024	0.0267

The formula is following:

$$\mu_{response} = \overline{A}_{Ln} + \overline{B}_{Ln} + \overline{C}_{Ln} + \overline{D}_{Ln} - (F-1)\overline{R}$$

Here Ln represent Level number, F represent number of factors.

Predicted value for Friction Factor (ff)

$$\mu_{ff} = \overline{ID}_8 + \overline{MFR}_{0.14} + \overline{HS}_{25} + \overline{FT}_{15} + \overline{PITCH}_{35} + \overline{CR}_{0.024} - 5 * \overline{ff}$$

Where **ff** is average of friction factor = 0.0458
ID is average value of factor ID for 8 mm = 0.0415
MFR is average value of factor MFR for 0.14 kg/s= 0.0383
HS is average value of factor HS for 25 C is = 0.0452
FT is average value of factor FT for 15 C is = 0.0453
PITCH is average value of factor PITCH for value 35 mm=0.0419
CR is average value of factor CR for value 0.024 mm=0.0434
Substituting the values of various terms in the above equation,

$$\mu_{ff} = \overline{ID}_8 + \overline{MFR}_{0.14} + \overline{HS}_{25} + \overline{FT}_{15} + \overline{PITCH}_{35} + \overline{CR}_{0.024} - 5 * \overline{ff}$$

$$\mu_{ff} = 0.0415 + 0.0383 + 0.0452 + 0.0453 + 0.0419 + 0.0434 - 5 * 0.0458$$

$$\mu_{ff} = 0.0267$$

Non-Linear Model Equation for ff

$$\mathbf{ff} = 0.00097 * ID^{1.58} * MFR^{-0.26} * HS^{-0.017} * FT^{0.101} * PITCH^{-0.55} * CR^{-0.400}$$

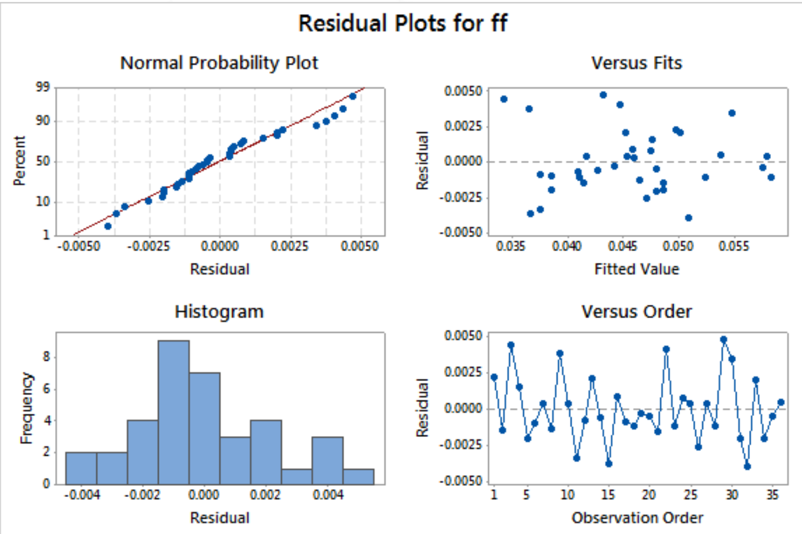


Figure 4 Residual plot for friction factor (ff)

Conclusion

Three process and three design parameters are used for spiral tube flow analysis using CFD simulation and DOE technique. Total 36 cases are designed for this present research study. The final conclusion of the study is that the both type of parameters effect on the friction factor of spiral tube but most effective parameter is inner diameter of spiral tube and least important parameter is wall temperature of spiral tube. Pitch and CR are also play important role on this spiral tube flow for friction factor.

References

[1] NAPHON P., SUWAGRAI J. Effect of curvature ratios on the heat transfer and flow developments in the horizontal spirally coiled tubes[J]. International Journal of Heat and Mass Transfer, 2007, 50(3-4): 444-451.
[2] NAPHON P. Study on the heat transfer and flow characte- ristics in a spiral-coil tube[J]. International Communica- tions in Heat and Mass Transfer, 2011, 38(1): 67-74.
[3] A. Cioncolini, L. Santini, An experimental investigation regarding the laminar to turbulent flow transition in helically coiled pipes, Exp. Ther. Fluid Sci. 30 (2006) 367–380.
[4] WONGWISES S., NAPHON P. Heat transfer characteri- stics of a spirally coiled, finned-tube heat exchanger under dry-surface conditions[J]. Heat Transfer Engineering, 2006, 27(1): 25-34.
[5] JI Jia-dong, GE Pei-qi and BI Wen-bo. Numerical analysis on flow-induced vibration responses of elastic tube bundle[J]. Journal of Vibration and Shock, 2016, 35(6): 80-84(in chinese).
[6] LI Cheng-guang, XUE Wan-yun and HUAI Wen-xin. Effect of vegetation on flow structure and dispersion in strongly curved channels[J]. Journal of Hydrodynamics, 2015, 27(2): 286-291.
[7] ZACHÁR A. Analysis of coiled-tube heat exchangers to improve heat transfer rate with spirally corrugated wall[J]. International Journal of Heat and Mass Transfer, 2010, 53(19-20): 3928-3939.
[8] NAPHON P., WONGWISES S. A review of flow and heat transfer characteristics in curved tubes[J]. Renewable and Sustainable Energy Reviews, 2006, 10(5): 463- 490.

[9] YAN Ke, GE Pei-qi and BI Wen-bo et al. Characteristics of fluid-structure interaction of conical spiral tube bundle with FEM[J]. Journal of Hydrodynamics, 2010, 22(1): 121-128.
[10] Vijiapurapu, S., Cui, J., Simulation of Turbulent Flow in a Ribbed Pipe Using Large Eddy Simulation, Numerical Heat Transfer, Part A, 51 (2007), 12, pp. 1137–1165.
[11] Bernhard, D., Hsieh, C., Pressure Drop in Corrugated Pipes, Journal of Fluids Engineering, 118 (1996), 2, pp. 409–410.
[12] Taylor, J. et al., Characterization of the Effect of Surface Roughness and Texture on Fluid Flow - Past, Present and Future, International Journal of Thermal Sciences, 45 (2006), 10, pp. 962–968.

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