CFD simulation of helical shell and tube heat exchanger using optimization techniques

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ABSTRACT

The objective of this study is to simulate the performance of helical tube shell and tube heat exchanger with several optimization techniques using computational fluid dynamics CFD. To check the performance of a designed model of heat exchanger, various techniques are available. In this study, the various possible models of the heat exchanger to enhance the performance of the device have been designed. Firstly, the straight tube is replaced by helical tube in the heat exchanger, and we used 10, 12, and 14 number helical baffles with 50% baffle cut. A total of ten models have been developed. These models are model-I 4-turns without baffle, model-II 4-turns with 10 number baffles, model-III 5-turns without baffle, model-IV 5-turns with 12 number baffles, model-V 6-turns without baffle, model-VI 6-turns with 10 number baffles 0.083m baffle space, model-VII 6-turns with 12 number 0.083m baffle space, model-VIII 6-turns with 14 number baffles 0.064m baffle space, model-IX 7-turns without baffle, model-X 7-turns with 14 number baffles, different number of baffles and baffle spaces with 50% baffle cut, and used CUO nanofluid model-XI 6-turns with 14 number baffle CUO fluid 0.083m baffle space CFD analysis simulation done on ANSYS FLUENT 18. The simulated result shows that the model XI is approximately 40% more optimized as compared to model-I and approximately 24% than model-VIII. It also found that the high heat transfer is obtained with increased number of baffles.

Keywords- STHXs, CUO, CFD, Solid works, ANSYS Fluent

INTRODUCTION

Shell and tube heat exchanger STHXs are one of the most common types of exchangers which is used in the many engineering applications. These heat exchangers consist of a vessel with different sizes tubes inside. Several different methods have been studied to modify the shell and tube heat exchanger to make them more suitable for several applications. Kishan et al. (2020) have designed tube and box heat exchanger with various pattern of tubes to investigate the flow and temperature field in heat exchanger using ANSYS programming tool. Three types of heat exchangers they have been planned in this examination with various structures of cylinders contains of 175 mm breadth and 1000 mm length shell measurement 175 mm. Advancement is done, which tries to distinguish the best parameter combination of heat exchangers to enhance the rate of heat exchange in heat exchanger. The prefix parameter (tube width) is utilized as an info variable and the yield parameter is the most extreme temperature distinction of container and tube heat exchanger.

Perone et al. (2021) showed that the use of a heat exchanger for the conditioning of the olive paste could enhance the olive oil extraction process. Particularly, paste pre-heating could reduce the malaxation time and, most of all, improve the temperature control during this process. A three-dimensional computational fluid dynamics (CFD) analysis of a tubular heat exchanger was carried out to better understand the influence of the inlet conditions of the olive paste on thermal and hydrodynamic behavior within it and predict the heat transfer and pressure drop in paste side of the exchanger. Multiple analyses by varying the mass flow rate and inlet temperature of the paste were carried out, and temperature and pressure drop were estimated. The numerical model has proved very useful in identifying the main factors affecting the optimization of the heat exchanger to improve the extraction process of the olive paste.

Aydin et al. (2020) studied the flow analysis of the optimized heat exchanger that has been carried out to reveal possible flow field and temperature distribution inside the equipment using computational fluid dynamics. The experimental results were compared with computational fluid dynamics analyses results. It has been concluded that the baffles play an important role in the development of the shell side flow field. It has been found that the heat exchanger with the new baffle design gives rise to considerably lower pressure drops in the shell side, which in turn reduces operating cost.

Yang et al. (2016) studied about the combined analysis of serial two shell-pass shell-and-tube heat exchanger CSTSP-STHXs with continuous helical baffle and improved the heat transfer performance. Wang et al. (2008) conclude that blocking the gap between the baffle plates and shell by use of sealer which effectively decreases the short-circuit flow in the shell-side and overall heat transfer coefficient heat transfer increased by 15.6–19.7%. Taher et al. (2012) tested the effect of baffle space in different cases on heat transfer of exchanger. Avval and Damangir (1994) investigated optimal baffle spacing for all types of shell and tube exchangers in which they found a high heat transfer coefficient and optimal pressure drop. Wang et al. (2011) investigated experimentally of shell-and-tube heat exchanger with a new type of baffles for improving the heat transfer and pressure drop performance. *Genic et al. 2012* done experiments on the shell-side thermal performances of heat exchangers with helical tube coils and define that shell-side heat transfer coefficients should be based on shell-side hydraulic diameter. *Abd et al. 2018* investigated the effect of shell diameter and tube length on heat transfer coefficient and pressure drop for shell side with both triangular and square pitches and also studied the effect of baffle spacing and cutting space on heat transfer coefficient and pressure drop. *Dong et al. 2015* examined the Flow and heat transfer performances of helical baffle heat exchangers with different baffle configurations and select one of them which has a high heat transfer rate. So, all the study, investigation and experiments represent how to get the highest heat transfer rate and optimal pressure drop with certain parameters and operating conditions which is most beneficial in all industrial processes.

To enhancing the performance of heat exchanger by changing the geometry of tube and shell, use optimal baffles and baffle angles still needs to be investigated. The main objective of this paper is to shows the effect of the increasing number of turns in the helical tube and use of optimal baffles on device performance with nanofluids.3D model of the heat exchanger and helical tube is designed in SOLIDWORKS 2017, and then CFD analysis on ANSYS fluent 18 has been done.

The paper is organized in seven sections including introduction. Section two presents the objective of the study. Section three deals with the methodology adopted for the study. Section four presents modelling of the study. In section fifth analysis of models is done. Section six deals with the results and discussion followed by conclusion of the study in section seven.

Figure 1. Shell and Tube Heat Exchanger

Figure 2. Helical tube of heat exchanger

METHODOLOGY

In this study CAD software, namely SOLIDWORKS and analysis software namely ANSYS 18.0 are used for achieving the objective of the research. So, in this study explanatory type research is used and describes the methodology in stepped flow diagram-

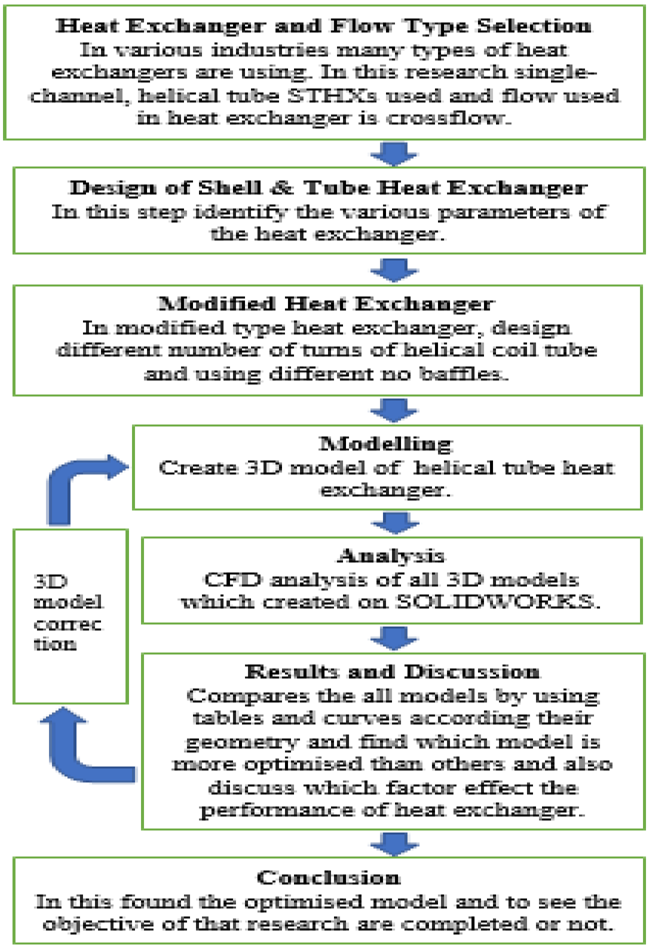

Figure 3. Research methodology of Heat Exchanger

MODELLING

The designed parameters of **modified** type shell and tube heat exchanger without discontinuous segmental baffle and with discontinuous segmental baffle are defined below-

Modified Design Parameters-

Table 1. Design parameters of modified heat exchanger

S.No	Parameter	Dimension
1	Shell diameter	0.091m
2	Shell length	0.52m
3	Shell thickness	0.003m
4	Tube diameter	0.013m
5	Tube length	0.52m
6	Tube thickness	0.001m
7	Tube pitch type	Rectangular

8	Number of tubes required	4
9	Number of baffles required 4-Turns	10
10	10 Baffle spacing 4-Turns	0.094m
11	Number of baffles required 5-Turns	12
12	12 Baffle spacing 5-Turns	0.076m
13	Number of baffles required 6-Turns	14
14	14 Baffle spacing 6-Turns	0.063m
15	Number of baffles required 6-Turns	12
16	12 Baffle spacing 6-Turns	0.083m
17	Number of baffles required 6-Turns	10
18	10 Baffle spacing 6-Turns	0.083m
19	Number of baffles required 7-Turns	14
20	Baffle spacing 7-Turns	0.063m
21	Shell inlet diameter	0.02m
22	Shell outlet diameter	0.02m

Model-I

Modified type 4-Turns helical tube shell and tube heat exchanger without baffle-

Isometric view-

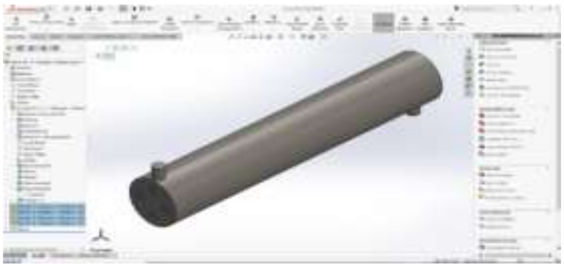

Figure 1. Isometric view of 4-Turns of helical tube STHXs

Internal view-

Figure 2 Internal view of 4-Turns of helical tube STHXs

Model-II

Modified type 4-Turns helical tube shell and tube heat exchanger with baffle-

Internal view-

Figure 3. Internal view of 4-Turns with 10 number baffles of helical tube STHXs

Isometric view-

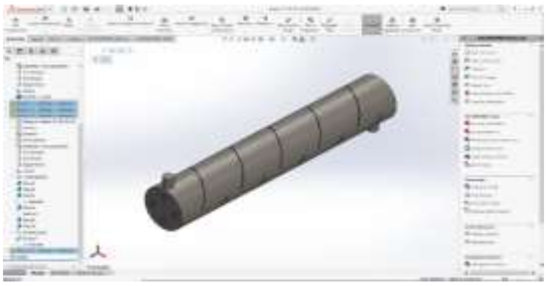

Figure 4. Isometric view of 4-Turns with 10 number baffles of helical tube STHXs

Model-III

Modified type 5-Turns helical tube shell and tube heat exchanger without baffle-

Isometric view-

Figure 5. Isometric view of 5-Turns of helical tube STHXs

Internal view-

Figure 6. Internal view of 5-Turns of helical tube STHXs

Model-IV

Modified type 5-Turns helical tube shell and tube heat exchanger with 12 baffle-

Isometric view-

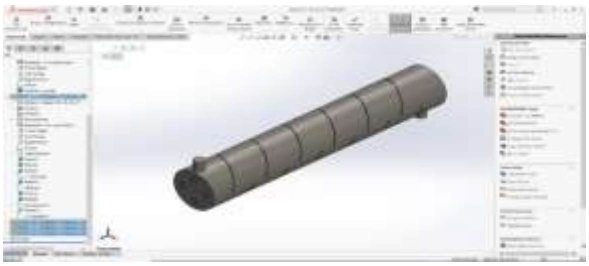

Figure 7. Isometric view of 5-Turns with 12 number baffles of helical tube STHXs

Internal view-

Figure 8. Internal view of 5-Turns with 12 number baffles of helical tube STHXs

Model-V

Modified type 6-Turns helical tube shell and tube heat exchanger without baffle

Isometric view-

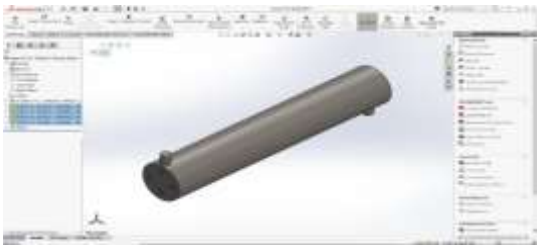

Figure 9. Isometric view of 6-Turns of helical tube STHXs

Internal view-

Figure 10. Internal view of 6-Turns of helical tube STHXs

Model-VI

Modified type 6-Turns helical tube shell and tube heat exchanger with 10 baffle-

Isometric view-

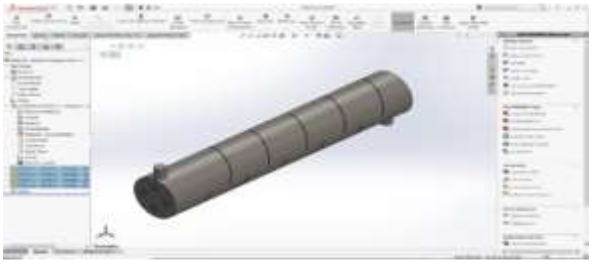

Figure 11. Isometric view of 6-Turns with 10 number baffles of helical tube STHXs

Internal view-

Figure 12. Internal view of 6-Turns with 10 number baffles of helical tube STHXs

Model-VII

Modified type 6-Turns helical tube shell and tube heat exchanger with 12 baffle-

Isometric view-

Figure 13. Isometric view of 6-Turns with 12 number baffles of helical tube STHXs

Internal view-

Figure 14 Internal view of 6-Turns with 12 number baffles of helical tube STHXs

Model-VIII

Modified type 6-Turns helical tube shell and tube heat exchanger with 14 baffle-

Isometric view-

Figure 15. Isometric view of 6-Turns with 14 number baffles of helical tube STHXs

Internal view-

Figure 16. Internal view of 6-Turns with 14 number baffles of helical tube STHXs

Model-IX

Modified type 7-Turns helical tube shell and tube heat exchanger without baffle-

Isometric view-	Internal view-
	
Figure 17. Isometric view of 7-Turns of helical tube STHXs	**Figure 18.** Internal view of 7-Turns of helical tube STHXs

Model-X

Modified type 7-Turns helical tube shell and tube heat exchanger with 14 baffle-

Isometric view-

Figure 19. Isometric view of 7-Turns with 14 number baffles of helical tube STHXs

Internal view-

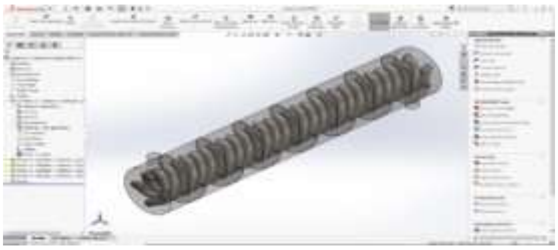

Figure 20. Isometric view of 7-Turns with 14 number baffles of helical tube STHXs

ANALYSIS

The analysis data input for modified type shell and tube heat exchanger without discontinuous segmental baffle and with discontinuous segmental baffle are defined below-

Analysis Parameters-

Table 2. Data input for analysis of heat exchanger

Fluid type	water fluid and CUO-water nano fluid
Nano fluid property	Specific heat 540 J/kg K, Density 6510 Kg/m3, Thermal conductivity 18 W/mK.
Flow type	Counter flow
Inlet temperature of hot fluid	90 °C
Inlet velocity of hot fluid	0.4m/s
Inlet temperature of cold fluid	26 °C
Inlet velocity of cold fluid	0.5m/s
Initialisation	Standard
Environmental Condition	27 °C, 1 atm

Model-I

Modified 4-Turns Helical Tube shell and tube heat exchanger without baffles-

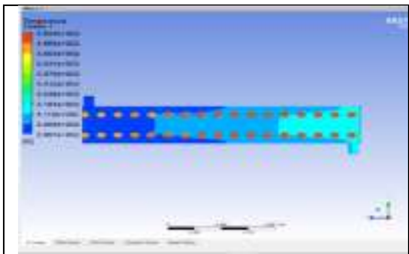

Figure 21. Temperature view of 4-Turns of helical tube STHXs

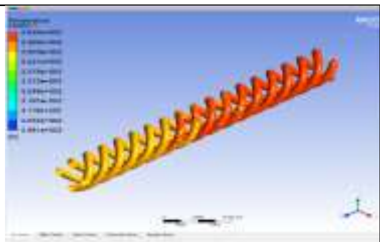

Figure 22. Tube view of 4-Turns of helical tube STHXs Shell side-

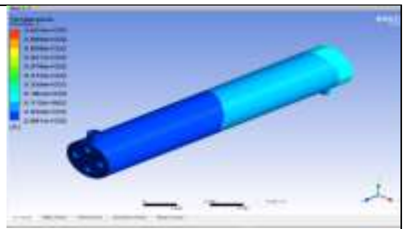

Figure 23. Shell view of 4-Turns of helical tube STHXs

Shell side-

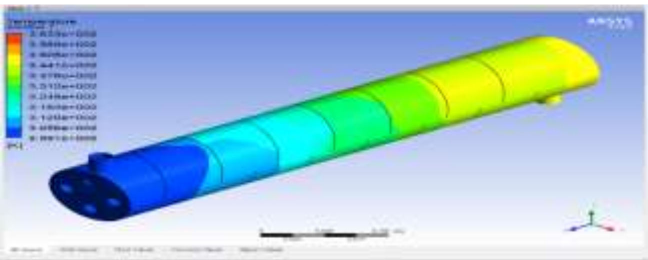

Figure 24. Shell view of 6-Turns CUO model with 14 number baffles of helical tube STHXs

Mesh model-

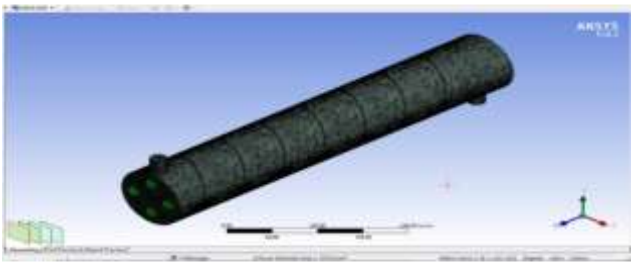

Figure 25. Mesh model of 6-Turns CUO model with 14 number baffles of helical tube STHXs

Temperature curve of both fluids-

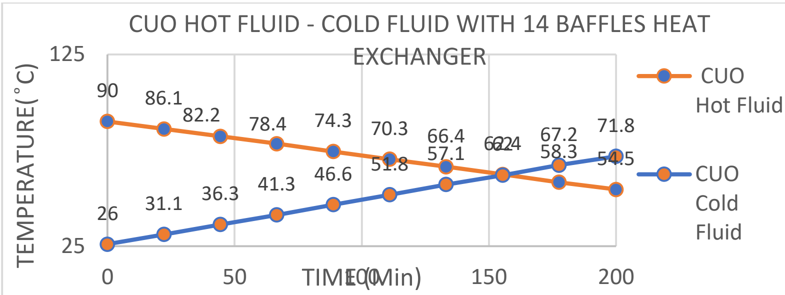

Figure 26. CUO hot fluid – cold fluid with 14 baffles heat exchanger curve

RESULTS AND DISCUSSION

Analysis done on both type heat exchangers where cold inlet temperature of fluid in shell side is 26 °C 299.15K and hot inlet temperature of fluid in tube side is 90 °C 363.15K.

Comparison of Model with and Without Baffle-

Table 3. For Hot Fluid

S. NO.	Model Number	Static Temperature *C		
		Hot Inlet	Hot Outlet	Temperature Difference
1	I	90	81.2	8.8
2	II	90	79.8	10.2
3	III	90	78.7	11.3
4	IV	90	77.5	12.5
5	V	90	74.1	15.9
6	VI	90	70.8	19.2
7	VII	90	84.6	5.4

8	VIII	90	82.4	7.6
9	IX	90	84.45	5.55
10	X	90	82.43	7.57
11	XI	90	54.54	35.46

Table 3. For Cold Fluid-

S. No.	**Model Number**	**Static Temperature *C**		
		Cold Inlet	**Cold Outlet**	**Temperature Difference**
1	I	26	39.9	13.9
2	II	26	37.9	11.9
3	III	26	38.4	12.4
4	IV	26	41.3	15.3
5	V	26	40.3	14.3
6	VI	26	44.9	18.9
7	VII	26	64.7	38.7
8	VIII	26	65.7	39.7
9	IX	26	64.7	38.7
10	X	26	65.6	39.6
11	XI	26	71.8	45.8

In this research, the 6 turn helical tube shell and tube heat exchanger model is more optimised than others. So used different number of baffles in 6 turns helical model. In this model different number of baffle 10 number baffles, 12 number baffles and 14 number baffles used with different pitch and to find which number of baffles is more optimised than others.

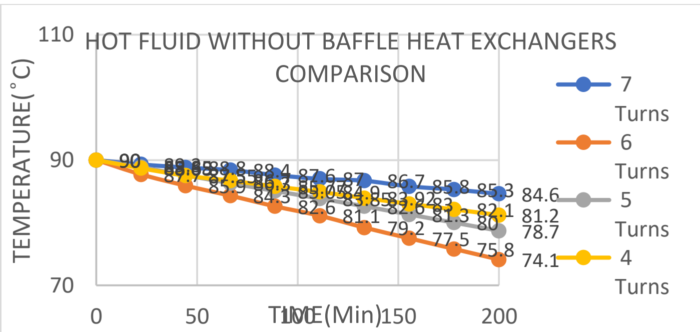

Figure 27. Hot fluid without baffle heat exchanger comparisons

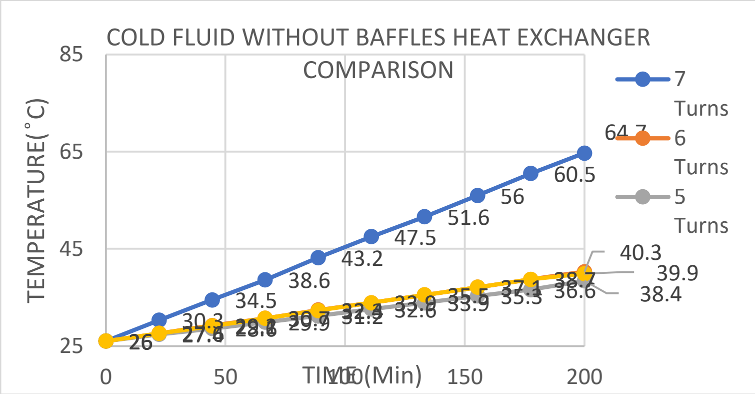

Figure 28. Cold fluid without baffles heat exchanger comparison curve

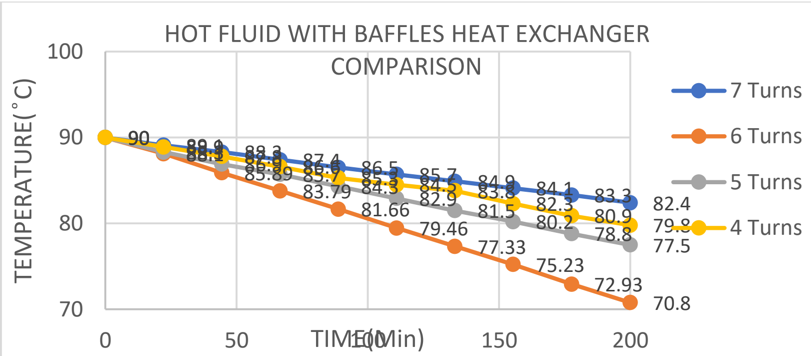

Figure 29. Hot fluid with baffles heat exchanger comparison curve

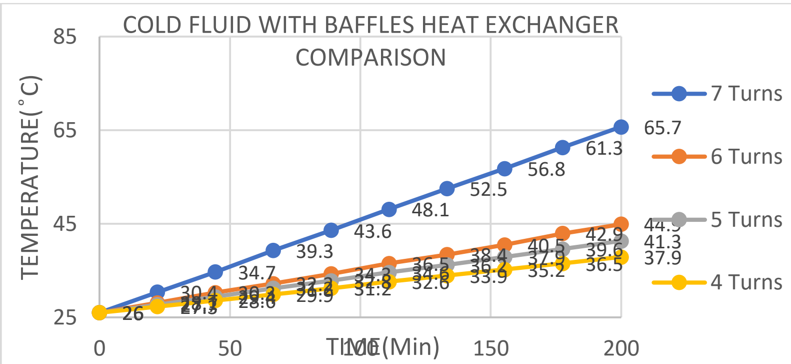

Figure 30. Cold fluid with baffles heat exchanger comparison curve

Table 4. 6 Turns Helical Tube Heat Exchanger

[MODEL-VI]-[MODEL-VII]-[MODEL-VIII] **6 Turns Helical Tube Heat Exchanger** all values in temperature °c			
Position	10 Baffles hot fluid tube	12 Baffles hot fluid tube	14 Baffles hot fluid tube

Inlet temp	90	90	90
Outlet temp	75.3	73.2	70.8
Temperature Difference	14.7	16.8	**19.2**

CONCLUSION

The objective of the study is to enhance the performance of shell and tube heat exchanger without baffle by using optimum baffle condition. The CAD software namely SOLIDWORKS 2017 and analysis software namely ANSYS FLUENT 18 are used for achieving the objective of the research.

- In this research found that with increasing the number of turns the hot fluid temperature difference increase till 6-Turns and in 7-Turns the temperature difference in hot fluid again decrease. Model-VIII is 18% more optimum than model model-X So, it shows that the quantity of cold fluid present between turns is should be in right amount.
- In 6-Turn more temperature difference see, so this is more optimised model. In this model applied 10, 12, 14 number of discontinuous helical baffles with 50% baffle cut and found that the 14-number baffle of model have more temperature difference in hot fluid with 0.063m baffle spacing.
- In last objective model-XI 6-Turn 14 baffles optimised model the water fluid is replace by the CUO nano fluids and find more temperature difference in hot fluid than model-VIII water fluid 6-Turn 14 baffle heat exchanger model. The model-XI is approx. 25% more efficient than model-VIII.

The helical baffle can design in a more optimum way to enhance the performance of the heat exchanger device. In future work use different technique and smart material which forcefully extract heat from hot fluid to cold fluid.

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