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Numerical Study of Heat Transfer Enhancement in Shell And Tube Heat Exchanger Using CFD

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Abstract

This paper numerically demonstrates the advantage of using different designs of baffles and semicircular turbulators inserted in the shell and tube heat exchangers. In this work, a shell and tube heat exchanger is considered for heat transfer enhancement studies. This heat exchanger uses kerosene on the shell side and crude oil on the tube side. The heat exchanger is designed using standard design procedure. CFD analysis is carried out for with baffles and without turbulators in the first stage. The design is incorporated with different designs of baffles and semicircular turbulators, and to study the heat transfer enhancement and pressure drop due to the baffles and turbulators is studied by Computational Fluid Dynamics (CFD) analysis in the second stage. And finally the pressure drop, outlet temperatures and heat transfer coefficient are validated against the theoretical results.

Introduction

The purpose of this present study is to predict the heat transfer coefficient, pressure drop and increased outlet temperatures of cold fluid on tube side and decreased temperatures of hot fluid on shell side, and also analysis is carried out for heat transfer coefficient, pressure drop and temperature variation for with inserting the different designs of baffles and semicircular turbulators and without inserting the baffles and semicircular turbulators.

The results are obtained for the five models (cases), first case is inserting only the segmental baffles on the shell side which is the base line results for the validation with the theoretical results.In the second case there are no baffles and turbulators in either shell or tube side i.e. plain shell and plain tube analysis is carried out for the heat exchanger model. In the third case inserting the segmental baffles inside the shell side along with the semicircular turbulators in the tube side and carried out the analysis for the heat exchanger model. In the fourth case inserting without sealer baffles which are considering decreasing the surface area of the baffles of about 32% in the total area of the baffle [13] and without inserting the turbulators and analysis is carried out for the heat exchanger model. In fifth case inserting without sealer baffles with oval shaped holes on the baffles in shell side and there is no turbulators in the tube side. Here we are trying to decrease the surface area of the baffle which restrict the fluid flow by making the eight oval shaped holes on per baffle, these oval shaped holes are decreases the surface area of about 11%. Totally we

get a decreased area of including without sealer baffle and oval shaped holes of about 43%. By decreasing the surface area will have the decreased pressure drop so this is the reason for the decreasing the surface area.

The oval shaped holes have a more heat transfer rate compare to the other designs like circular, cam shaped or square holes etc. this is the reason for inserting the oval shaped holes on the baffles[2].

The analysis is carried out for all the five cases and results obtained for all the five cases for heat transfer coefficient, Pressure drop, surface temperature and turbulent kinetic energy are given below.

Models

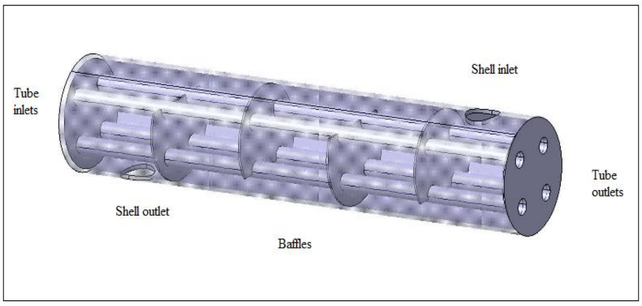

Fig 1. Shell and tube heat exchanger with baffles

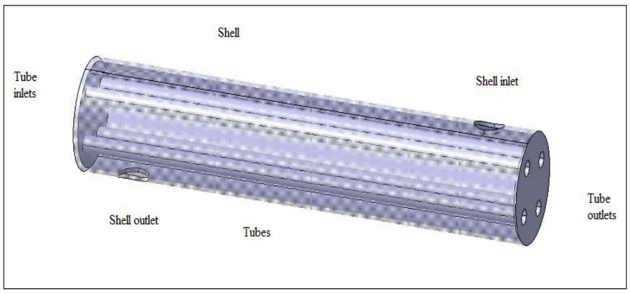

Fig 2. Shell and tube heat exchanger without baffles

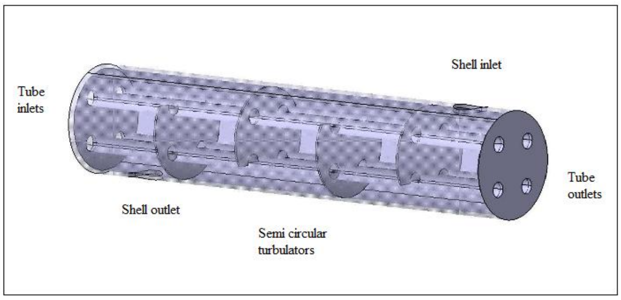

Fig 3. Shell and tube heat exchanger with baffles and semicircular turbulators

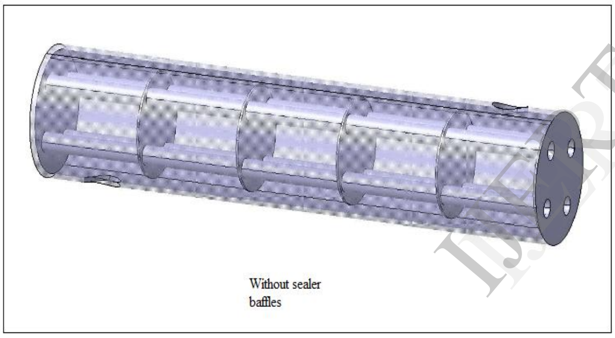

Fig 4. Shell and tube heat exchanger without sealer baffles and without turbulators

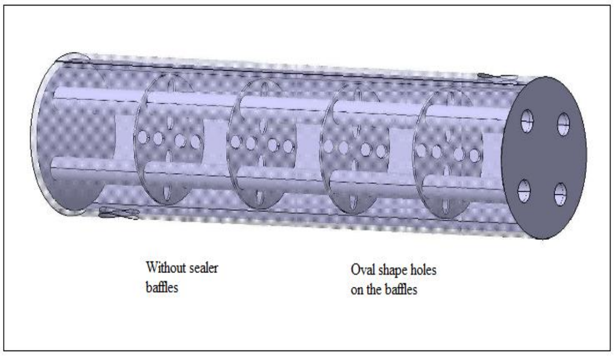

Fig 5. Shell and tube heat exchanger without sealer baffles with oval shaped holes on the baffles and without turbulators

CFD Meshing

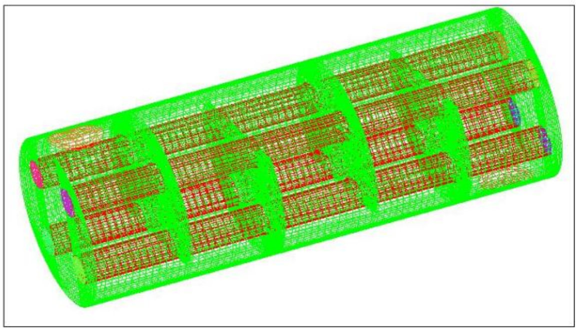

Fig 6. Mesh generated for the heat exchanger with baffles

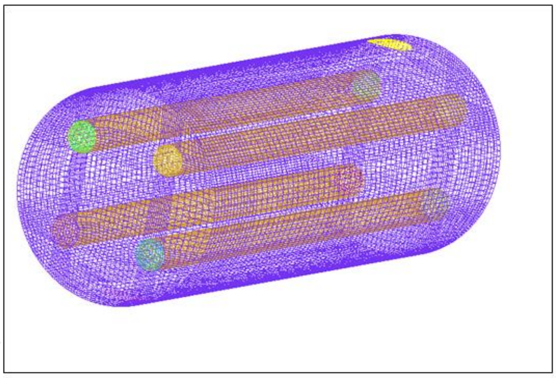

Fig 7. Mesh generated for the heat exchanger without baffles

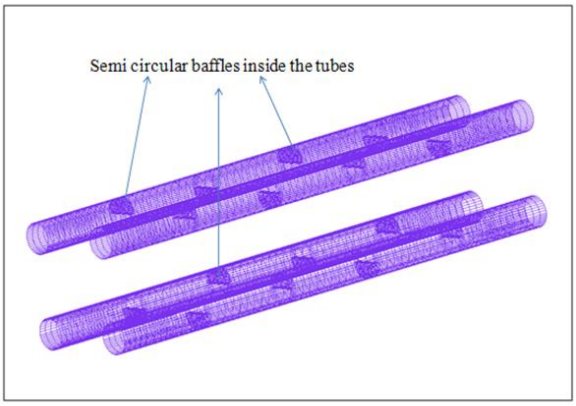

Fig 8. Mesh generated for the semicircular turbulators inside the tubes

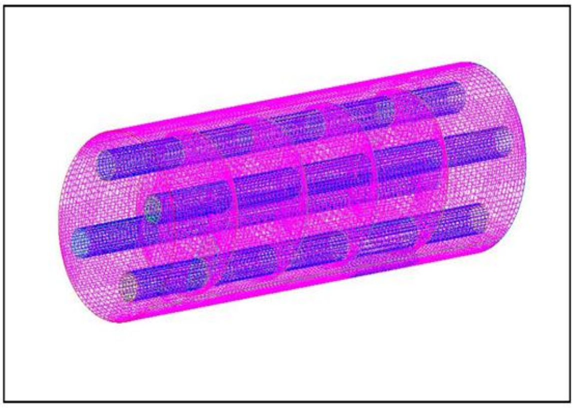

Fig 9. Mesh generated for without sealer baffles inside the shell

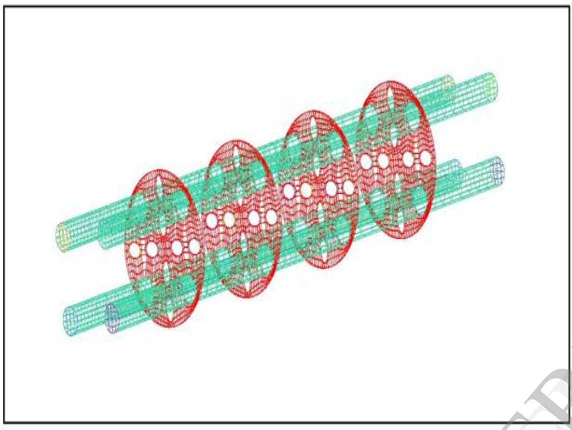

Fig 10. Mesh generated for without sealer baffles with oval shaped holes on the baffles

Fluid properties [3]

The properties of the hot fluid (Kerosene) and cold fluid (Crude oil) are taken at averaged temperatures in the design calculations. Hence the same values have been considered in the CFD analysis.

(i) Shell side fluid (Kerosene, T_{avg}=419.26 K)

Density, ρ = 779 Kg/m^3

Thermal conductivity, K= 0.1288 W/m K.

Specific heat, Cp = 2.46KJ/kg K.

Viscosity, μ = 1.5485 kg/ m sec.

(ii) Tube side fluid (Crude oil, T_{avg}=330.27 K)

Density, ρ =854Kg/m^3

Thermal conductivity, K = 0.1332 W/m K.

Specific heat, Cp = 2.05KJ/kg K.

Viscosity, μ = 12.9648 kg/ m sec.

Boundary conditions[3]

(i) Shell side

Mass flow rate of 5.517 kg/sec is imposed at inlet of the shell, along with the temperature value of 472K.

Outflow conditions are imposed at the outlet of the shell.

(ii) Tube side

Mass flow rate of 18.77kg/sec is imposed at the inlet of each tube, along with the temperature value of 311K.

Outflow conditions are imposed at the outlet of each tube.

Case 1: *Results for the heat exchanger with baffles and without turbulators*

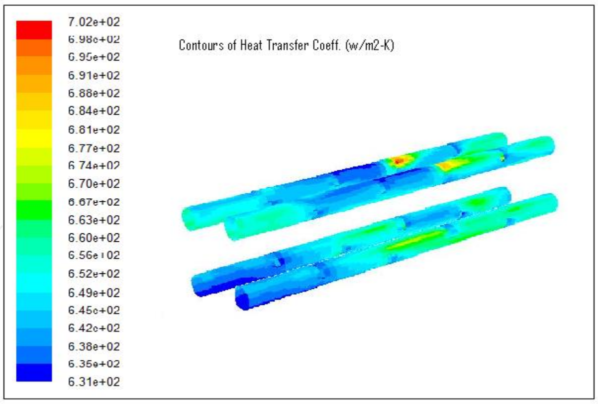

Fig 11. Heat transfer coefficient on tube surfaces with baffles and withoutturbulators

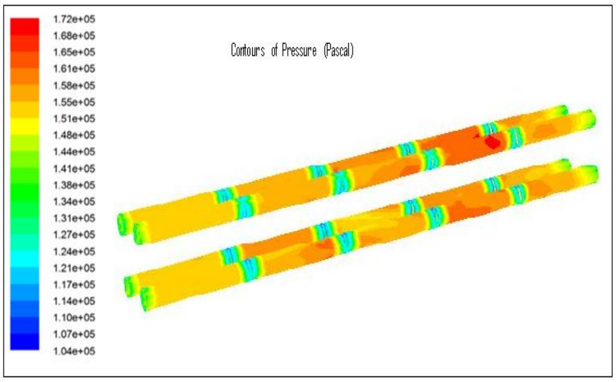

Fig 12. Pressure drop with baffles and without turbulators

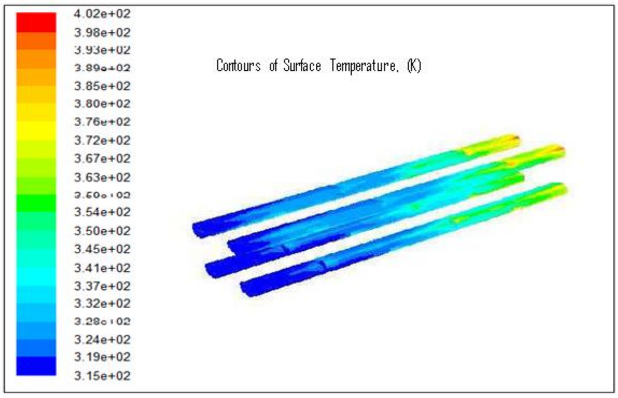

Fig 13. Surface temperature of tubes with baffles and without turbulators

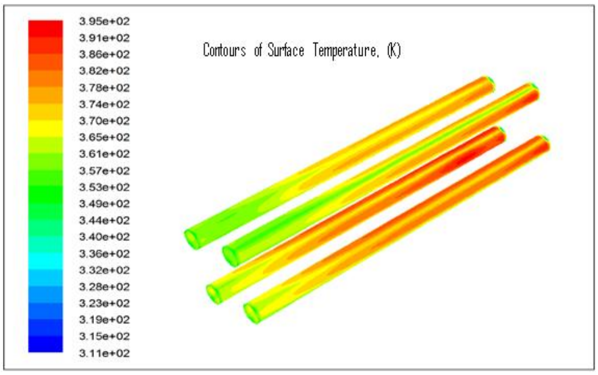

Fig 16. Surface temperature of tube without baffles and without turbulators

Case 2: *Results for the heat exchanger without baffles and withoutturbulators*

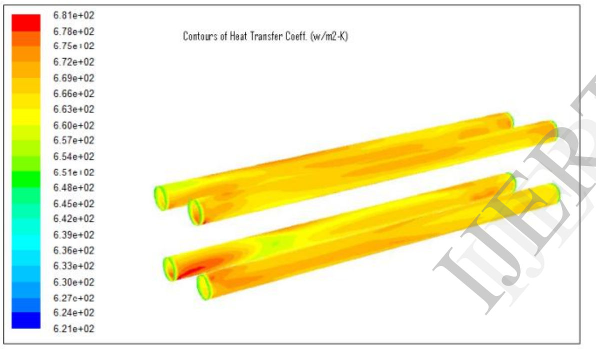

Fig 14. Heat transfer coefficient on tube surfaces without baffles and without turbulators

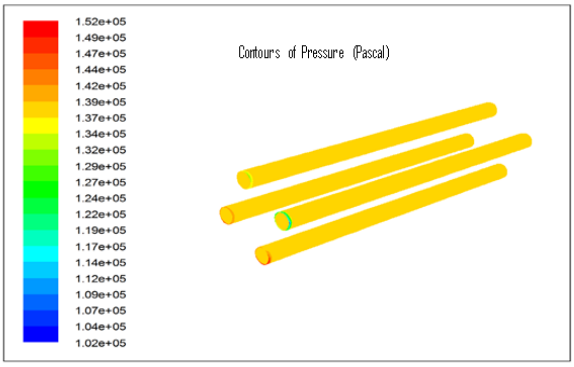

Fig 15. Pressure drop without baffles and without turbulators

Case 3: *Results for the heat exchanger with baffles and with turbulators*

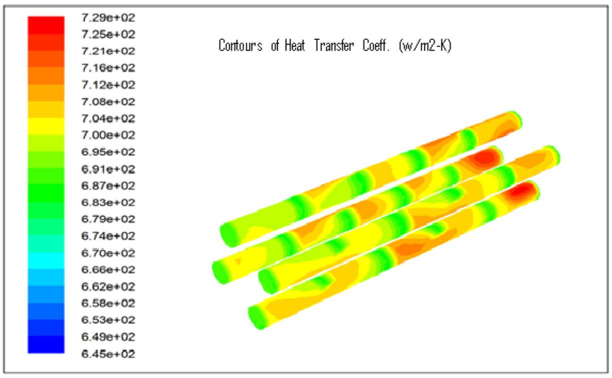

Fig 17. Heat transfer coefficient on tube surfaces with baffles and turbulators

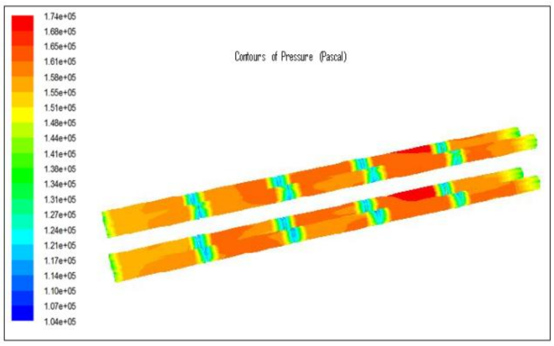

Fig 18. Pressure drop with baffles and turbulators

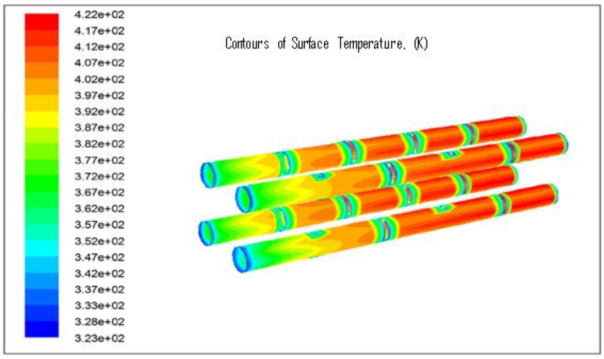

Fig 19. Surface temperature of tube with baffles and turbulators

Case 4: *Results for the heat exchanger without sealer baffles and without turbulators*

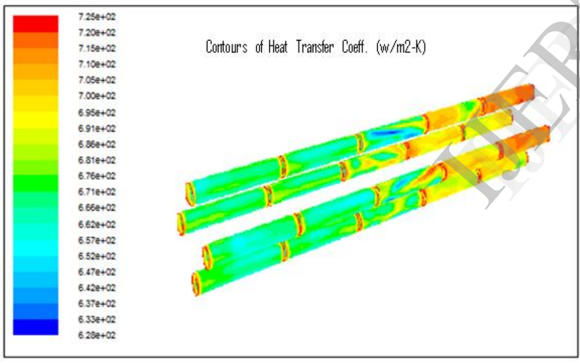

Fig 20. Heat transfer coefficient on tube surfaces without sealer baffles and without turbulators

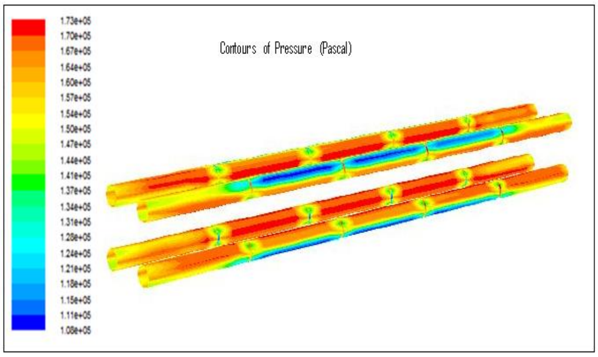

Fig 21. Pressure drop without sealer baffles and without turbulators

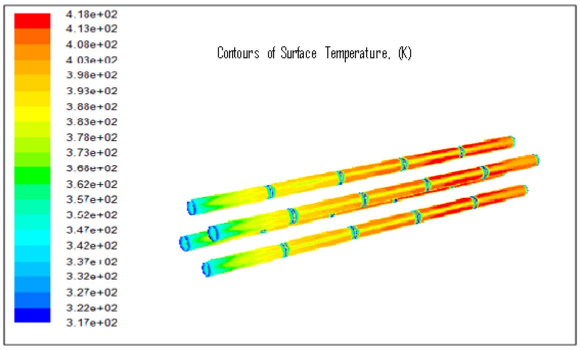

Fig 22. Surface temperature on tube walls for without sealer baffles and without turbulators

Case 5: *Results for the heat exchanger without sealer baffles with oval shaped holes on the bafflesand without turbulator model*

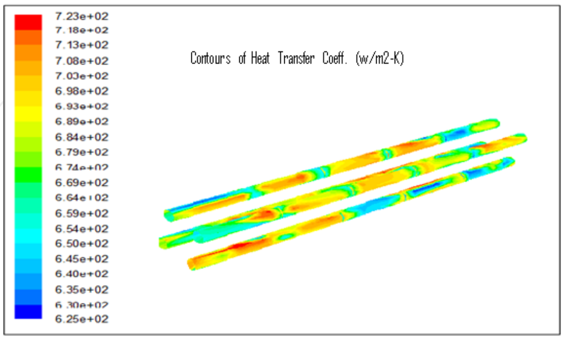

Fig 23. Heat transfer coefficient fortubes without sealer with oval shaped holes on the baffles and without turbulators

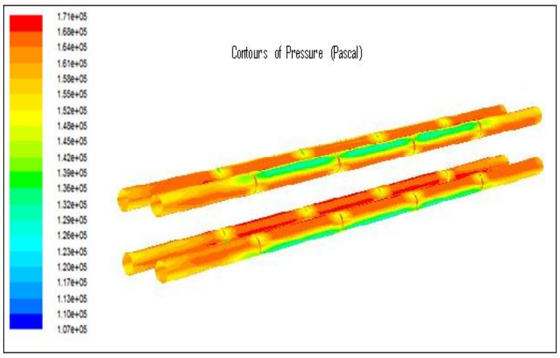

Fig 24. Pressure drop without sealer with oval shaped holes on the baffles and without turbulators

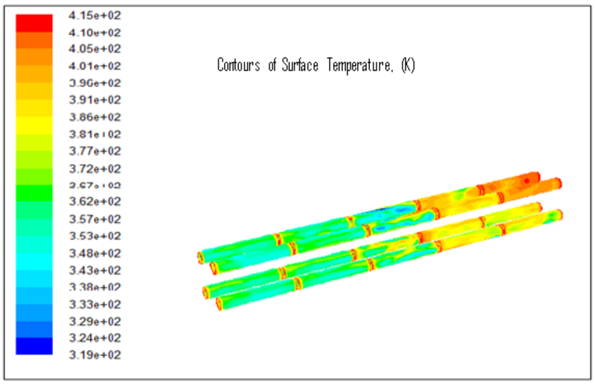

Fig 25. Surface temperature for the tubes without sealer with oval shaped holes on the baffles and without turbulators

Table 1. Validation of CFD results with theoretical results for with baffles and without turbulators

Location	Parameters	Theoretical results	CFD results	Remark %
Tube Side	Mass flow rate, m (kg/sec)	18.77	18.77	0.00
	Inlet Temperature, t_i (K)	310.92	310.92	0.00
	Outlet Temperature, t_o (K)	349.81	351.74	0.55
	Heat transfer coefficient, h (W/m^2K)	686.67	702	2.10
	Pressure Drop, ΔP (kPa)	63.434	67.80	6.40

From Table 1. is observed that there is a close prediction of theoretical results with that results obtained by the CFD analysis for with baffles and without turbulator model. There is an error of around ±6.5%, which is acceptable and leads to the further analysisand also pressure drop obtained by CFD analysis is within the allowable pressure drop.

Table 2. Outlet temperature values predicted by CFD analysis

Location	Inlet Temperature (K)	Outlet temperature, t (K)				
		Without baffles (Plain)	With baffles	With baffles and turbulators	Without sealer baffles	Without sealer and oval shaped holes on the baffles
Tube 1	310.92	350.08	351.80	354.30	352.90	353.47
Tube 2	310.92	350.03	352.60	355.10	353.60	354.42
Tube 3	310.92	348.99	350.71	353.21	351.71	352.63
Tube 4	310.92	348.09	351.88	354.38	352.88	353.76

Table 3. Heat transfer coefficient values predicted by CFD analysis

Sl.No	Location	Heat transfer coefficient, h (W/m^{2}K)				
		Without baffles (Plain)	With baffles	With baffles and turbulator	Without sealer baffles	Without sealer and oval shaped holes on baffles
1	Tubes	680.5	701	729	725	723

Table 4. Pressure drop predicted by CFD analysis

Location	Pressure drop, ΔP (kPa)					
	Without baffles (Plain)	With baffles	With baffles and turbulators	Without sealer baffles	Without sealer and oval shaped holes on baffles	Allowable pressure drop
Tube side	52.0	67.80	69.40	65.30	63.70	68.95

Conclusion

- In this the three dimensional model is studied for the shell and tube heat exchanger and CFD analysis is carried out for the Heat exchanger unit with different designs of baffles and semicircular turbulators.

- Investigated for augmentation of heat transfer coefficient, temperature and variation in pressure drop for the five models.

- Enhanced heat transfer coefficient of 3.01% for with baffles model, 7.1% for with baffles and turbulator model, and 6.5% for without sealer baffles and without turbulator model, 6.2% for without sealer with oval shaped holes on the baffles and without turbulator model compare to the plain model.
- Increase in outlet temperature of tube of about 2.5 K for with baffles, 4.9 K for with baffles and turbulators, 3.48 K for without sealer baffles and without turbulators,4.2Kfor without sealer with oval shaped holes on the baffles and without turbulators compare to the plain model.

- There is an increase in turbulent kinetic energy of about 38.17% for with baffles, 54.9% for with baffles and turbulators, 45.7% for without sealer baffles and without turbulators, 50.9% for without sealer with oval shaped holes on the baffles and without turbulators as compare to the plain model.

- The pressure drop also increases 23.3% for with baffles, 20.36% for without sealer baffle and without turbulators, 18.36% for without sealer with oval shaped holes on the baffles and without turbulators compare with the plain model.

- The pressure drop is increased more of about 25.07% for with baffles and turbulators compare with the plain model. The pressure drop is exceeding the allowable limit of 68.95 kPa.
- By analyzing all the cases we have got desired results in fifth case that is without sealer baffles with oval shaped holes on the baffles and without turbulator model, so this is the best and safe design compare to all the cases.

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