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Numerical Analysis of Critical Parameters of the "U" Tube Exchanger at Different Baffle Cut and Spacing

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Abstract—"U" tube heat exchanger are perceived as an integral part of the refinery process. Therefore, a numerical analysis of critical parameters of exchanger at different baffle cut and spacing is needed to select the correct order to improve the overall efficiency and reduce the cost of manufacturing of feed heater. So, this paper primarily focus on the comparative analysis of heat transfer, flow velocity and flow stream and recommended the correct type of baffle cut and spacing for the exchanger to improving the exchanger's performance.

Keywords— Design by analysis, Heat Transfer, Heavy Diesel Feed Heater, Shell and Tube Heat Exchanger, Baffle Cut, Baffle Spacing and Type.

1 Introduction

THE heat exchangers are one of the most widely used in oil and gas industries. The shell and tube heat exchanger shall be most commonly used for cooling, heating, condensation, boiling and evaporation. The Heavy Diesel Feed Heaters, also known as U type heat exchangers, are used for heating of the fresh feed (Hydro Carbon and Hydrogen) with the help of heavy diesel.

Optimization of shell and tube heat exchanger is an active area for exploring the new arrangements. The effectiveness and fabrication cost are the two important aspects in shell and tube heat exchanger design. The complexity with reduction Liquid will pass through shell side and exchange the maximum possible heat to each other.

The conventional experimental technique involves lot of issues and same time quantities description of heat transfer phenomena using measurement dealing with one quantity at a time for a limited range of problem and operational conditions. The HTRI is now an established design tool, offering various type of design conditions. In this analysis, a full HTRI model of U tube Heat Exchanger is considered. In this paper will discuss baffle cut and spacing and selection methods to maximize the performance of heat exchanger.

2 LITERATURE REVIEW

Time to time various methods were proposed for designing of shell and tube heat exchanger, for shell side design are as follows:

Colburn, A. P. [3]: The method of correlation here proposed is shown to be particularly valuable in the transition region between streamline and turbulent flow in tubes, since heat-transfer factors may show "dips" analogous to those for friction. The controlling variables in this region are fully discussed in the light of the available data. Grimison, E. D. [6]: The upgrade method of correlation and utilization on flow Resistance and Heat Transfer for cross flow of gases over tube banks Donohue, D. A. [5]: A correlation of the coefficient of heat transfer in unbaffled shells has been developed from the published experimental data which differs considerably from that presently used. For any particular baffled shell the coefficient of heat transfer is expressed by the relation as shown in paper. The pressure drop test show that only partial flow penetration of the tube bundle occurs. The effect of this partial flow penetration on coefficients of heat transfer and on friction factor is considered. Interdependency of the coefficient of heat transfer and friction factor is noted. Higher coefficients of heat transfer were obtained with disk and doughnut baffles than with segmental baffles for equal values of fluid flow rate and pressure drop in all units tested. Tinker, T. [15]: They introduce five different streams at shell side and proposed effects of streams on the heat transfer coefficient. Kern, D.Q. [8]: Kern methods are mainly based on the experimental and research work, they were considered standard tolerances for standard design of heat exchanger. Palen, T. [13]: A procedure is presented for evaluating the shell side pressure drop in shell and tube heat exchangers with segmental baffles. The procedure is based on correlations for calculating the pressure drop in an ideal

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tube bank coupled with correction factors, which take into account the influence of leakage and by pass streams, and

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Bell, K. J. [2]: developed therefore Delaware method in which correction factors were introduced for the following elements Leakages through the gaps between the tubes and the baffles and the baffles and the shell, respectively, Bypassing of the flow around the gap between the tube bundle and the shell. The results based on that method are more satisfactory in terms of heat transfer coefficient and pressure drop.

ht = Nut (kt/di)

Where Nut is the Nusselt number for the tube-side fluid, kt is the thermal conductivity of the tube-side fluid, and di is the tube inside diameter.

Shell Side heat transfer coefficient:

hs = hsi (JcJlJbJrJs) = hsiJtot

Where hsi is the heat transfer coefficient for an ideal tube bundle, and Jc, Jl, Jb, Jr and Js are correction factors for the baffle cut, baffle leakage effects, bundle bypass flow, laminar flow and unequal baffle spacing in the inlet and outlet sections, respectively.

The total shell-side pressure drop Δps

Δps = Δpc + Δpw + Δpe

The pressure drop in the interior cross flow section (Baffle to Baffle), the combined pressure drop of all the interior cross flow section is on equations for calculating the pressure drop in a window section from the Delaware method.

Δpc = Δpbi (Nb – 1)RlRb

Where Nb is the number of baffles, Rl is the leakage correction factor (A and E streams) Rb is the bypass correction factor.

Typically, Rb= 0.5 to 0.8, depending on the construction type and number of sealing strips, and Rl = 0.4 to 0.5

The baffle window Δpw is defined as follows:

For turbulent flow, Re ≥ 100, Δpw is

Δpw = Nb [(2+0.6 Ntcw) ((ṁ2w)/2ϱs)) (10-3)]Rl

For laminar flow, Res < 100, Δpw is

Δpw = Nb { 26(((ṁ w)(cp)s)/ ϱs) [Ntcw/(Ltp-d0) + B / (Dw)2] + [2 (10-3) ((ṁw) 2/2ϱs))]}Rl

Where ṁ w is the shell side flow mass velocity through segmental baffle window, Dw hydraulic diameter of the baffle window as shown in above equations, the first term in brackets reports for the cross flow and longitudinal friction, respectively; the second term in brackets account two velocity heads for the turnaround in the window. It should be noted that only the leakage correction factor Rl is applied to the baffle window Δpw, whereas the bypass correction factor Rb is considered not applicable. Comparing the results of two equations of turbulent flow and laminar flow and large value should be taken.

The pressure drop in the entrance and exit sections which is calculated with the help of below numerical formula and is affected by bypass but not by leakage. The pressure drop in the two end zones Δpe is

Δpe = (Δpbi)[(1+ (Ntcw/ Ntcc))] Rb Rs

Where Rb: Bypass correction factor and Rs: End zone correction factor

Tube-Side heat transfer coefficient: The method proposed for tube side design are as follows: Petukhov, B.S, [14]: All

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that has been said regarding heat transfer in turbulent pipe flow can be summarized in the following manner. The analytical methods allow us to describe heat transfer mechanisms for constant liquid properties quite satisfactorily and to take into account the influence of the variation of physical properties with temperature versus heat transfer and skin friction in a number of important cases. Disagreement between theoretical and experimental results observed in other cases, in particular, with a considerable change in physical properties over the flow cross section, may be attributed to

Imperfect methods of estimating the effect of the variation of physical properties on turbulent diffusivity. Therefore, further refinement of the analytical methods demands enhanced study of turbulent diffusivity with respect to variable physical properties. Important experimental material has been accumulated on heat transfer and skin friction for variable physical properties. However, certain portions of this material possess relatively low accuracy that prevents its successful use. For a number of important cases there has been no systematic data collection, or that which is available is scanty and contradictory. Therefore, the need for further experimental investigations, with a high degree of accuracy, into the fluid mechanics and heat transfer for variable physical properties is quite urgent.

Baffles are general be involved on the shell side to serve two important functions, to support the tubes during assembly and operation and help prevent vibration from flow induced eddies and to maintain the tube spacing to direct the shell side fluid back and forth across the tube bundle to provide effective velocity and better heat transfer rates.

Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher transfer co-efficient. The distance between adjacent baffles is called baffle-spacing. Baffles are held in positioned by means of baffle spacers. Closer baffle spacing gives greater transfer co-efficient by inducing higher turbulence. The pressure drop is more with closer baffle spacing. The various types

Gnielinski, V, [6]: Equations are developed for calculating the mean heat transfer coefficients of single tube rows and banks of tubes in cross flow and are checked against numerous measured values from the literature for gases and liquids.

The stream flow model as proposed by Tinker [15] showing five streams one is a main cross-flow stream, four leakage or bypass streams. They calling these streams the main cross-flow stream (B), a tube to baffle hole leakage stream (A), a bundle bypass stream (C), a pass partition by pass stream (F) and a baffle to shell leakage stream (E).

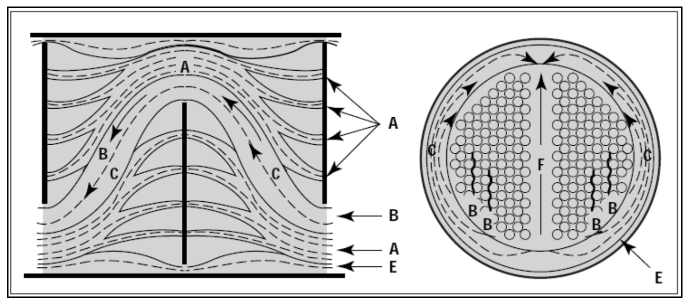

Figure-2 Stream Flow Model [3]

of baffles are shown in Figure 3 In case of cut-segmental baffle, a segment (called baffle cut) is removed to form the baffle expressed as a percentage of the baffle diameter. An optimum baffle cut provide a good heat-transfer with the reasonable pressure drop. The % cut for segmental baffle refers to the cut away height from its diameter. Figure 3 also shows two other types of baffles.

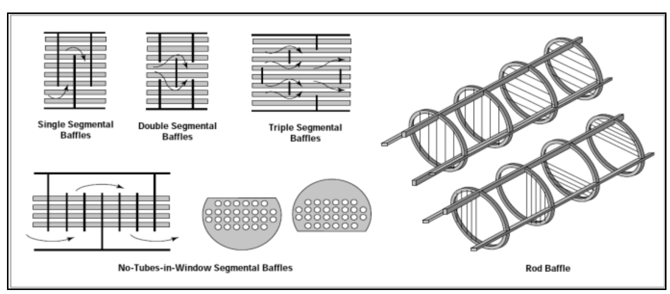

Figure-3 Types of Baffle [15]

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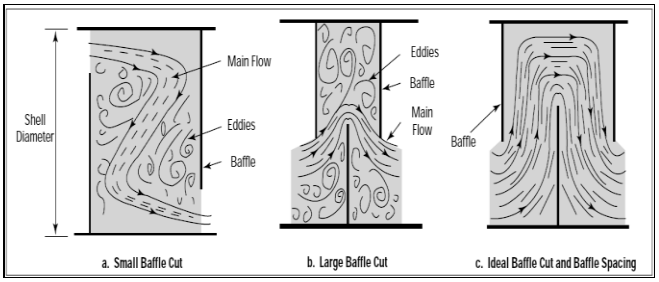

Figure-4 Types of Baffle Cut [15]

3 DESCRIPTION OF PROBLEM

In figure-1 shows is "U" tube heat exchanger. In the heater shell side fluid is fresh feed (HC + H2) and Tube side fluid is Heavy Diesel. The fluid is heated with the help of tube side Heavy Diesel for the designed heat duty of 47853382 BTU/h. Shell side and tube side inlet pressures as 127.20 psia and 230.61 psia respectively. Fresh feed is available at 269°F and has to be heated up to 388°F. The heater is designed in such a way that Heavy Diesel located on tube side and Fresh Feed located on shell side and the flow is 306570 lb/hr and 725784 lb/hr respectively. The geometry of exchanger are ID of shell is 40.551 inch and Tube Length is 24 ft., Tube OD is 0.75 inch, average thickness of tube is 0.109 inch and Total tube numbers is 501U, and Single Segmental Baffle.

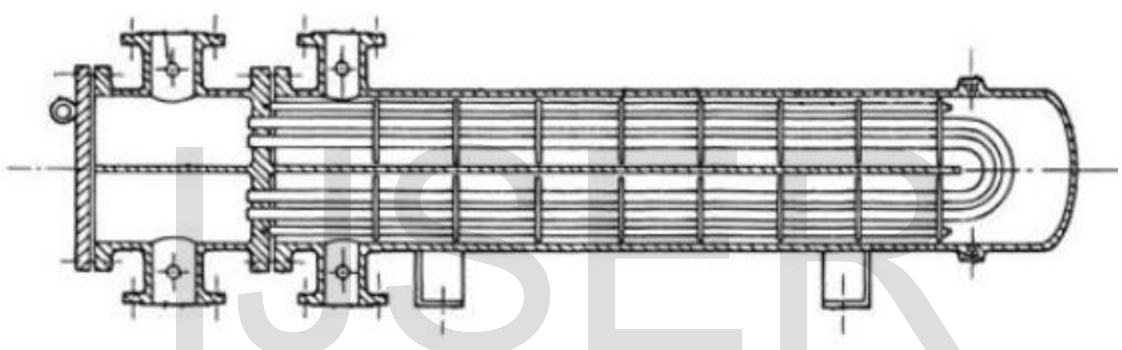

FIGURE-1 SCHEMATIC REPRESENTATION OF U TYPE HEAT EXCHANGER [16]

A Heavy Diesel feed heater (U-Type shell and tube heat exchanger) has process parameter as given below in Table 1.

TABLE 1: PROBLEM SPECIFICATION

Fluid Allocation	Shell Side		Tube Side	
Fluid Name	Fresh Feed (HC+H2)		Heavy Diesel	
Fluid Quantity, Total, lb/hr	725784		306570	
Vapor (In/Out)				
Liquid (In/Out)	725784	725784	306570	306570
Steam				
Water				
Noncondensables				
Temperature (In/Out), F	269.60	388.40	629.60	399.20
Specific Gravity	0.8751	0.8382	0.6231	0.7246
Viscosity, cP	3.6440	1.4281	0.1640	0.4590
Specific Heat, Btu/lb-F	0.5251	0.5853	0.7251	0.6293
Thermal Conductivity, Btu/hr-ft-F	0.0514	0.0480	0.0370	0.0485
Latent Heat, Btu/lb				

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Inlet Pressure, psia	127.20		230.61	
Velocity, ft/sec	1.94		4.91	
Pressure Drop, Allow/Calc, psi	10.153	---	10.153	---
Fouling Resistance (min), ft2-hr-F/Btu	0.00193		0.00148	

4 Numerical Modeling And Results

The thermal design of heavy diesel feed heater (U-Type shell and tube heat exchanger) has been performed using a commercial program called HTRI Suite 7.0. Which allows thermal analysis of reactor feed heater.
The experimental data consist of pressure, temperature, actual flow and the gas and liquid compositions, density and viscosity and the values being obtain from the numerical analysis software Heat Transfer Research Institute (HTRI)

Consider the heat exchanger process condition as specified in Table-1.
Case A: We will keep the baffle cut at constant at 15% and vary the centre baffle spacing and we will analysis the stream parameters in Table 2

Table 2. A summary of the calculated data at different baffle spacing for a constant 15% baffle cut

Title	Calculated data at different baffle spacing for a constant 15% baffle cut				
	Design A	Design B	Design C	Design D	Design E
Central Baffle Spacing, in	8.1102	12.1653	16.2204	20.2755	24.3306
(A) Baffle hole tube leakage stream, fraction	0.371	0.281	0.233	0.039	0.026
(B) Main cross flow stream, fraction	0.350	0.453	0.514	0.674	0.704
(C) Bundle bypass stream, fraction	0.014	0.018	0.020	0.026	0.028
(E) Baffle to Shell leakage stream, fraction	0.228	0.2	0.176	0.185	0.162
(F) Pass Partition lane bypass stream, fraction	0.037	0.049	0.057	0.075	0.081
Shell Side Velocity, ft/sec					
Cross Flow Velocity	1.18	1.25	1.16	1.14	1.08
Window Flow Velocity	2.22	2.34	2.29	2.43	2.37
Shell Side Heat Transfer Coefficient, Btu/ft2-hr-F	196.05	185.62	171.05	170.73	160.58
Tube Side Heat Transfer Coefficient, , Btu/ft2-hr-F	325.47	325.40	325.27	324.78	324.57
Shell Side Pressure Drop	18.038	11.289	7.529	7.487	5.792
Tube Side Pressure Drop	7.794	7.799	7.798	7.802	7.8
Over Design, %	0.81	-0.61	-3.30	-3.40	-5.52

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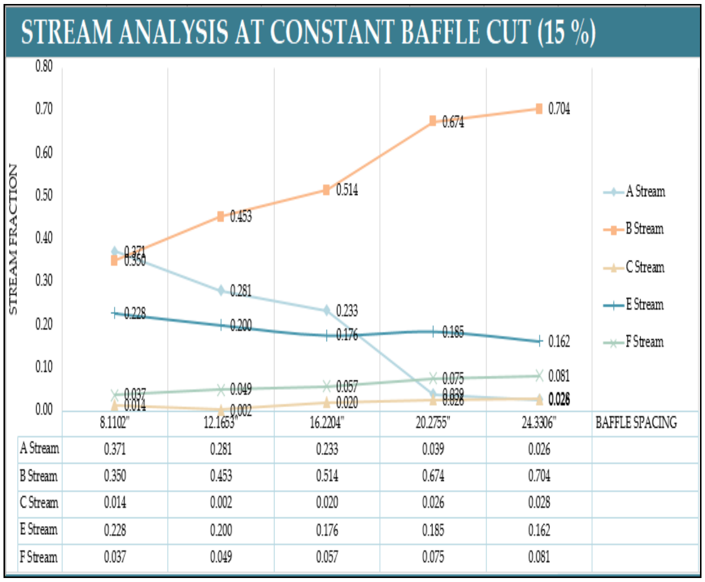

FIGURE-5 STREAM ANALYSIS AT CONSTANT BAFFLE CUT (15 %)

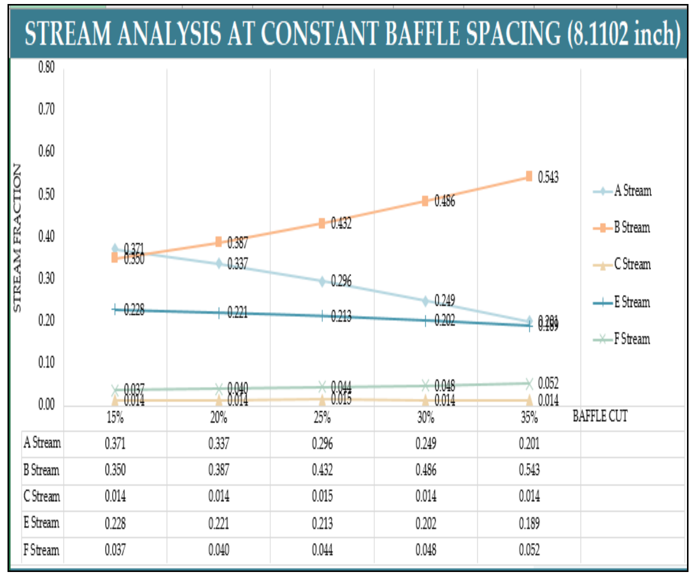

FIGURE-6 STREAM ANALYSIS AT CONSTANT BAFFLE SPACING (8.11 INCH)

Case B: We will keep the baffle cut at constant at 20% and vary the centre baffle spacing and we will analysis the stream parameters in Table 3

Table 3. A summary of the calculated data at different baffle spacing for a constant 20% baffle cut

Title	Calculated data at different baffle spacing for a constant 20% baffle cut				
	Design A	Design B	Design C	Design D	Design E
Central Baffle Spacing, in	8.1102	12.1653	16.2204	20.2755	24.3306
(A) Baffle hole tube leakage stream, fraction	0.337	0.247	0.204	0.032	0.021
(B) Main cross flow stream, fraction	0.387	0.491	0.546	0.690	0.714
(C) Bundle bypass stream, fraction	0.014	0.018	0.02	0.026	0.027
(E) Baffle to Shell leakage stream, fraction	0.221	0.191	0.167	0.172	0.151
(F) Pass Partition lane bypass stream, fraction	0.040	0.053	0.062	0.081	0.087
Shell Side Velocity, ft/sec					
Cross Flow Velocity	1.20	1.28	1.18	1.16	1.09
Window Flow Velocity	2.01	2.08	2.00	2.03	1.97
Shell Side Heat Transfer Coefficient, Btu/ft2-hr-F	200.88	195.14	182.32	183.61	173.88
Tube Side Heat Transfer Coefficient, , Btu/ft2-hr-F	325.33	325.20	325.02	324.52	324.29
Shell Side Pressure Drop	18.2	10.729	6.945	6.473	4.934
Tube Side Pressure Drop	7.793	7.796	7.795	7.798	7.796
Over Design, %	1.75	1.31	-0.81	-0.54	-2.38

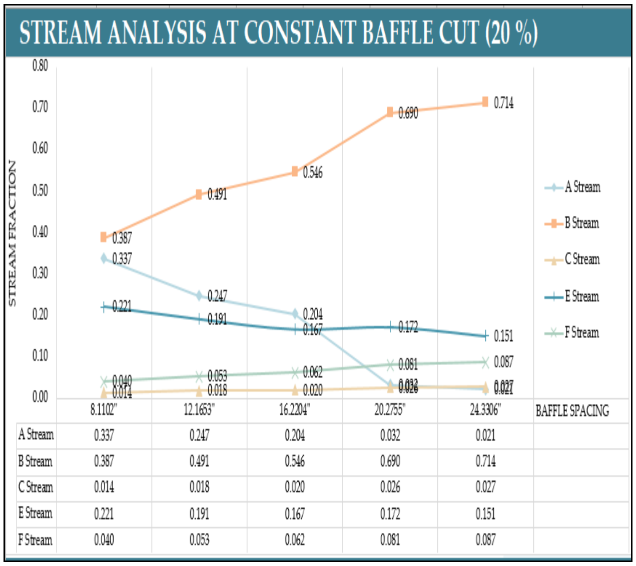

FIGURE-7 STREAM ANALYSIS AT CONSTANT BAFFLE CUT (20 %)

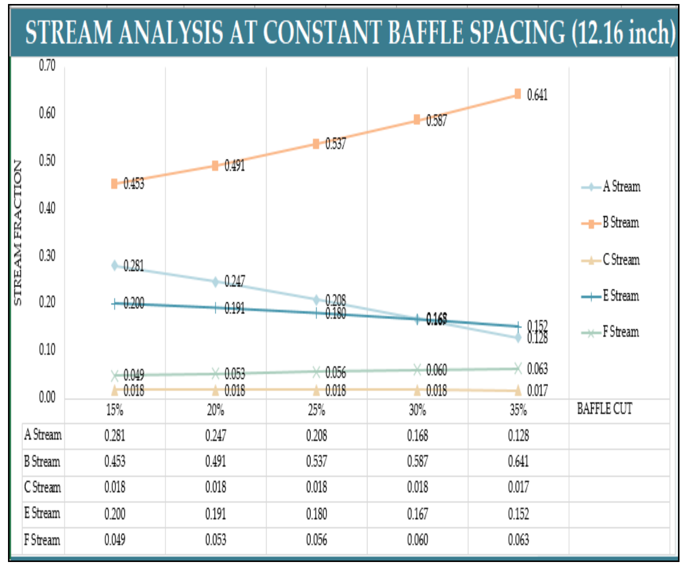

FIGURE-8 STREAM ANALYSIS AT CONSTANT BAFFLE SPACING (12.16 INCH)

Case C: We will keep the baffle cut at constant at 25% and vary the centre baffle spacing and we will analysis the stream parameters in Table 4

Table 4. A summary of the calculated data at different baffle spacing for a constant 25% baffle cut

Title	Calculated data at different baffle spacing for a constant 25% baffle cut				
	Design A	Design B	Design C	Design D	Design E
Central Baffle Spacing, in	8.1102	12.1653	16.2204	20.2755	24.3306
(A) Baffle hole tube leakage stream, fraction	0.296	0.208	0.168	0.024	0.015
(B) Main cross flow stream, fraction	0.432	0.537	0.592	0.716	0.736
(C) Bundle bypass stream, fraction	0.015	0.018	0.02	0.025	0.025
(E) Baffle to Shell leakage stream, fraction	0.213	0.180	0.155	0.154	0.134
(F) Pass Partition lane bypass stream, fraction	0.044	0.056	0.065	0.082	0.089
Shell Side Velocity, ft/sec					
Cross Flow Velocity	1.23	1.32	1.22	1.18	1.11
Window Flow Velocity	1.79	1.84	1.77	1.78	1.72
Shell Side Heat Transfer Coefficient, Btu/ft2-hr-F	195.10	194.12	184.75	186.93	178.57
Tube Side Heat Transfer Coefficient, , Btu/ft2-hr-F	325.40	325.22	324.99	324.49	324.24
Shell Side Pressure Drop	18.705	10.267	6.431	5.623	4.267
Tube Side Pressure Drop	7.791	7.794	7.792	7.794	7.792
Over Design, %	0.74	1.21	-0.20	0.29	-1.22

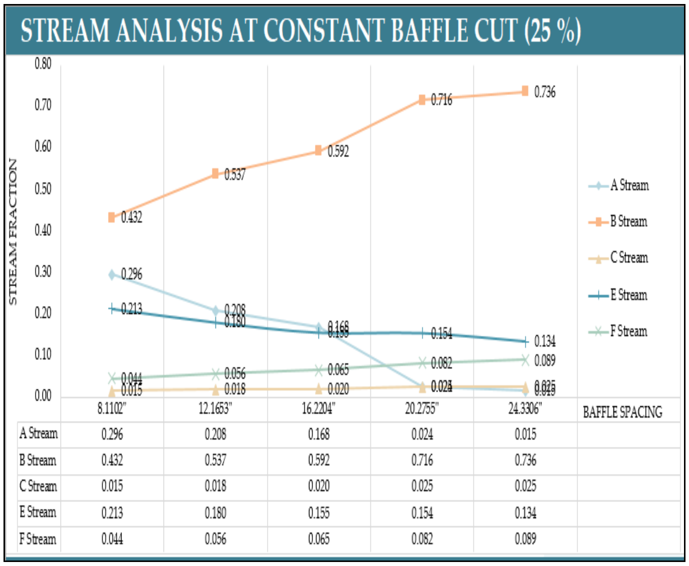

FIGURE-9 STREAM ANALYSIS AT CONSTANT BAFFLE CUT (25 %)

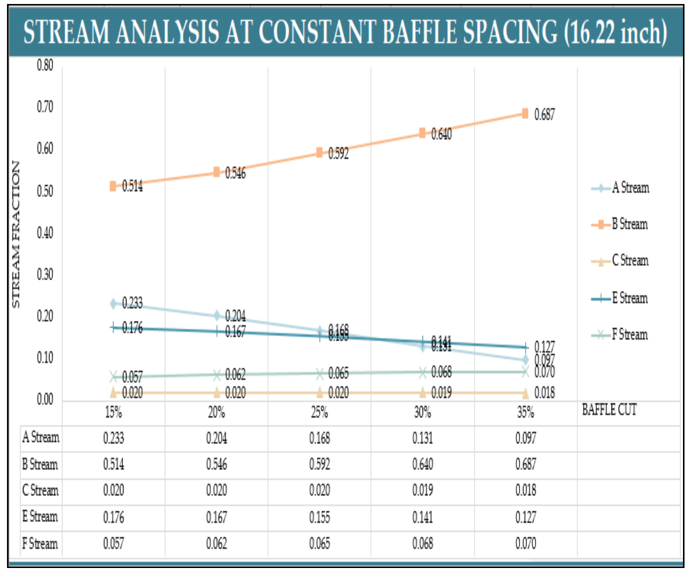

FIGURE-10 STREAM ANALYSIS AT CONSTANT BAFFLE SPACING (16.22 INCH)

Case D: We will keep the baffle cut at constant at 30% and vary the centre baffle spacing and we will analysis the stream parameters in Table 5

Table 5. A summary of the calculated data at different baffle spacing for a constant 30% baffle cut

Title	Calculated data at different baffle spacing for a constant 30% baffle cut				
	Design A	Design B	Design C	Design D	Design E
Central Baffle Spacing, in	8.1102	12.1653	16.2204	20.2755	24.3306
(A) Baffle hole tube leakage stream, fraction	0.249	0.168	0.131	0.017	0.011
(B) Main cross flow stream, fraction	0.486	0.587	0.640	0.741	0.755
(C) Bundle bypass stream, fraction	0.014	0.018	0.019	0.023	0.023
(E) Baffle to Shell leakage stream, fraction	0.202	0.167	0.141	0.136	0.119
(F) Pass Partition lane bypass stream, fraction	0.048	0.06	0.068	0.084	0.091
Shell Side Velocity, ft/sec					
Cross Flow Velocity	1.27	1.35	1.25	1.20	1.13
Window Flow Velocity	1.62	1.67	1.60	1.60	1.54
Shell Side Heat Transfer Coefficient, Btu/ft2-hr-F	183.35	185.42	179.52	181.66	175
Tube Side Heat Transfer Coefficient, , Btu/ft2-hr-F	325.60	325.38	325.11	324.66	324.39
Shell Side Pressure Drop	18.797	9.918	5.947	4.962	3.813
Tube Side Pressure Drop	7.790	7.792	7.790	7.790	7.787
Over Design, %	-1.46	-0.40	-1.17	-0.62	-1.85

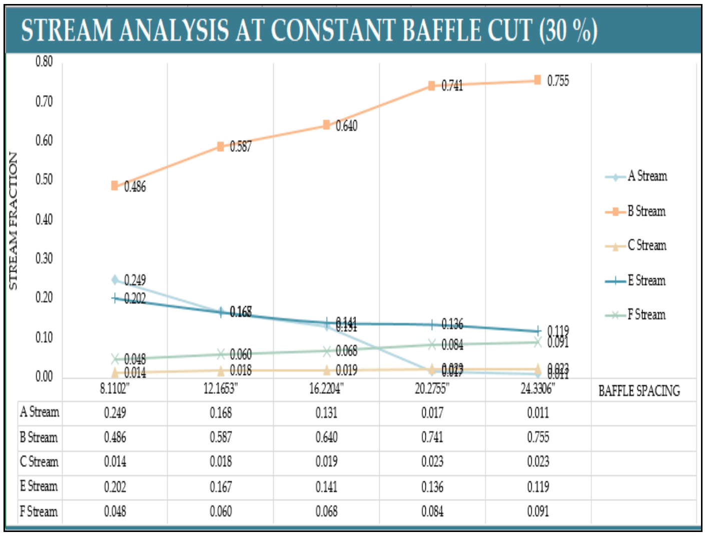

FIGURE-11 STREAM ANALYSIS AT CONSTANT BAFFLE CUT (30 %)

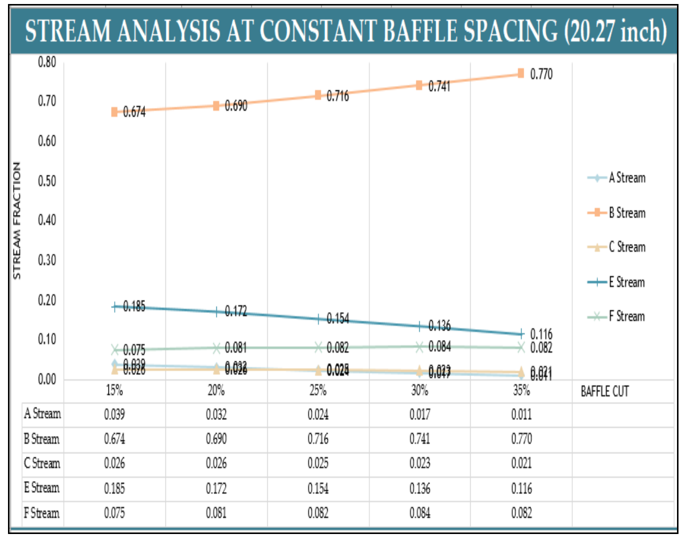

FIGURE-12 STREAM ANALYSIS AT CONSTANT BAFFLE SPACING (20.27 INCH)

Case E: We will keep the baffle cut at constant at 35% and vary the centre baffle spacing and we will analysis the stream parameters in Table 6

Table 6. A summary of the calculated data at different baffle spacing for a constant 35% baffle cut

Title	Calculated data at different baffle spacing for a constant 35% baffle cut				
	Design A	Design B	Design C	Design D	Design E
Central Baffle Spacing, in	8.1102	12.1653	16.2204	20.2755	24.3306
(A) Baffle hole tube leakage stream, fraction	0.201	0.128	0.097	0.011	0.007
(B) Main cross flow stream, fraction	0.543	0.641	0.687	0.770	0.780
(C) Bundle bypass stream, fraction	0.014	0.017	0.018	0.021	0.021
(E) Baffle to Shell leakage stream, fraction	0.189	0.152	0.127	0.116	0.102
(F) Pass Partition lane bypass stream, fraction	0.052	0.063	0.070	0.082	0.090
Shell Side Velocity, ft/sec					
Cross Flow Velocity	1.30	1.39	1.28	1.23	1.15
Window Flow Velocity	1.50	1.54	1.48	1.46	1.41
Shell Side Heat Transfer Coefficient, Btu/ft2-hr-F	150.58	156.54	155.22	158.76	155.46
Tube Side Heat Transfer Coefficient, , Btu/ft2-hr-F	326.41	326.11	325.76	325.29	324.97
Shell Side Pressure Drop	18.488	9.296	5.468	4.234	3.311
Tube Side Pressure Drop	7.781	7.783	7.781	7.781	7.778

Over Design, %	-8.80	-6.68	-6.59	-5.58	-6.23

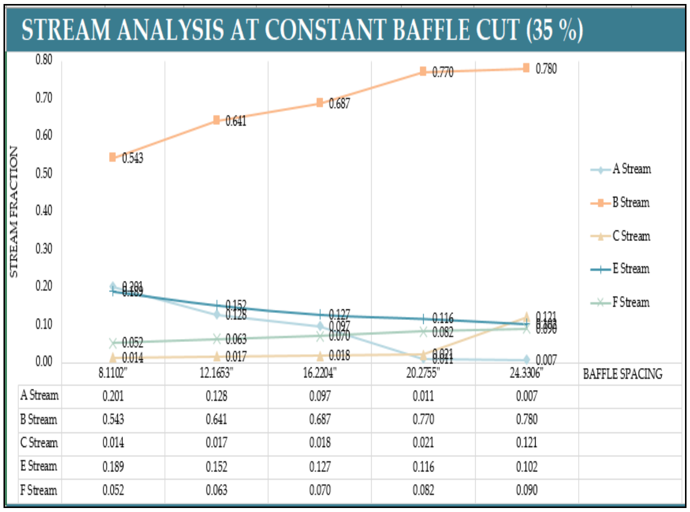

FIGURE-13 STREAM ANALYSIS AT CONSTANT BAFFLE CUT (35 %)

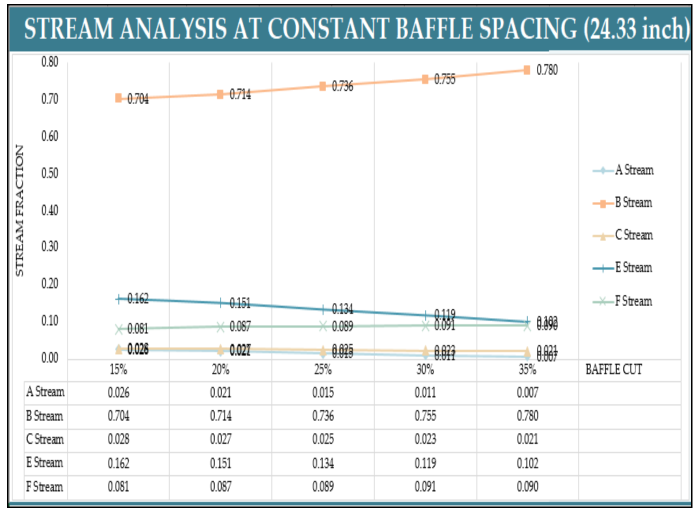

FIGURE-14 STREAM ANALYSIS AT CONSTANT BAFFLE SPACING (24.33 INCH)

5 CONCLUSION

The developed model is comparing the flow streams and flow velocities, which also indicates a reliable prediction of baffle cut and optimum ratio, since the baffle cut and spacing on the heavy diesel feed heater is determined by the effectiveness of the heat transfer. The evaluate values in table of paper has showing exchanger performance in logical selection of baffle spacing and baffle cut. The major observations are listed as follows:

1) In Figure-15, we clearly seen the tube-side heat-transfer coefficient is increase gradually with the increase of baffle cut and it is maximum at 25% baffle cut and then it decrease. The reason is at 25% baffle cut the turbulence is at maximum level.

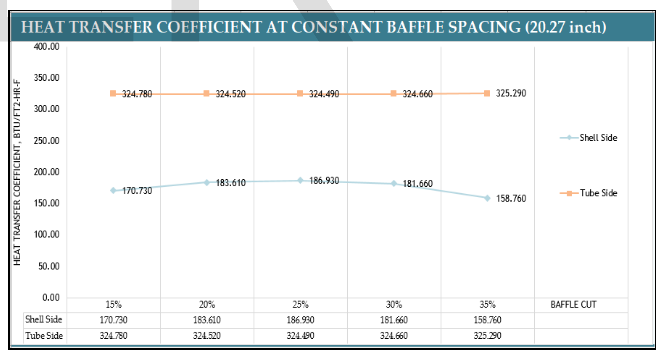

FIGURE-15 COMPARISON OF H EAT TRANSFER COEFFICIENT AT CONSTANT BAFFLE SPACING (20.27 INCH)

2) In Figure-16, the pressure drop profile of tube side is decrease gradually dropping with the increase of baffle cut and Overdesign parameter is increasing gradually up to 25% and then decreasing with the increase of baffle cut. Hence suitable baffle cut is to be select based on below profile for getting the maximum level of heat transfer rate.

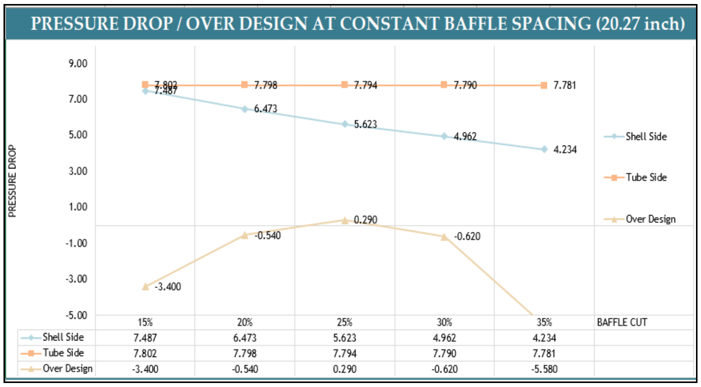

FIGURE-16 COMPARISON OF PRESSURE DROP / OVER DESIGN AT CONSTANT BAFFLE SPACING (20.27 INCH)

3) In this analysis, we clearly seen in Figure-17 the pressure drop profile of shell side is decrease gradually dropping with the increase of baffle spacing at constant baffle cut and Overdesign parameter is cyclic. Hence suitable baffle spacing 12.1653" is to be select based on below profile for getting the maximum level of overall design.

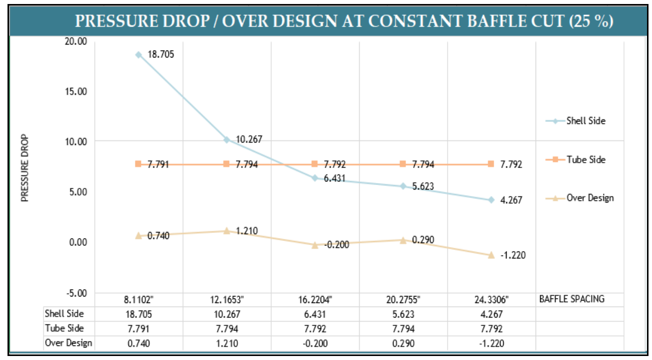

FIGURE-17 COMPARISON OF PRESSURE DROP / OVER DESIGN AT CONSTANT BAFFLE CUT (25 %)

4) The numerical analysis of stream in Case C, the Design D, shown the best result and effective design. The recommended ratio of baffle spacing to shell inside diameter should be in between 0.4 to 0.6 and Baffle cut should be in between the 20 % to 30% that will give best result in terms of pressure drop and heat transfer.

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