Design and Performance Study of Shell and Tube Heat Exchanger with Single Segmental Baffle Having Perpendicular & Parallel-Cut Orientation.

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Abstract:- **Shell and Tube Heat Exchangers are having special importance in boilers, oil coolers, condensers, pre-heaters .They are widely used for process operations as well as in the refrigeration and air conditions industries. Therefore a critical analysis of important parameters in needed in order to improve the overall efficiency and reduce the costs involved in processes. This paper primarily focuses on the design and comparative analysis of Single segmental Shell and tube Heat Exchanger with perpendicular & parallel baffle cut orientation. For designing Kern Method is used. It predicts heat transfer coefficient, Pressure drop of both arrangements. This method gives us clear idea that rate of heat transfer is greater in Perpendicular-cut baffle orientation than Parallel-cut , Pressure drop approximately remaining same. The Shell side fluid used is Lithium-bromide with average concentration of 58.5% and tube side fluid is hot water. All other parameters of fluid remaining same.**

INTRODUCTION:-

There are often numerous heat transfer problems involved in the petroleum, chemicals, power, metallurgy, energy and other industrial sectors. The shell and tube heat exchanger (STHE) is the heat transfer equipment most widely used in the current industrial production. Compared with other types, its main advantages are the large heat transfer area in the unit volume and good heat transfer characteristics. Combined with a simple structure, wide range of materials required in manufacturing, and greater operation flexibility, it is more and more widely used in the chemical engineering fields. In many heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix or leak. Such exchangers are referred to as direct transfer type or simply recuperate. In contrast, exchanger which there is intermittent heat exchange between hot and cold fluid via thermal energy storage and release to the exchanger surface and matrix are referred to as indirect transfer type or simply regenerator.
To further optimize this existing STHE system, with the intentions of minimizing the energy consumption and finances involved. With this objective in mind, we concluded that the most important parameter that had to be worked upon was the heat transfer coefficient as it had a direct bearing on the energy consumption and the finances. For this a comparative analysis, including design, needed to be done.

Shell & Tube Heat Exchanger Design:-
Shell & tube type heat exchangers are built of tubes (round or rectangular in general) mounted in shells (cylindrical, rectangular or arbitrary shape).
The differences lie mainly in the detailed features of construction and provisions for differential thermal expansion between the tubes and the shell.

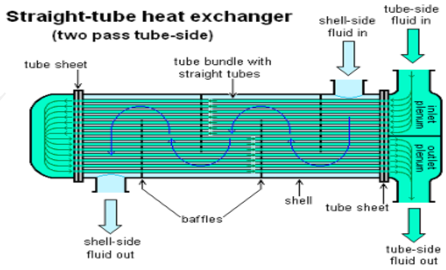


Figure - Shell & Tube Heat Exchanger

BAFFLES:-

Baffles are installed on the shell side to give a higher heat-transfer rate due to increased turbulence and to support the tubes thus reducing the chance of damage due to vibration. One of the most important parts in shell and tube heat exchanger.

Baffles serve mainly two functions:

- To fix the tubes in the proper position during assembly and prevent tube vibration caused by flow-induced eddies.
- Guiding the shell-side fluid across the tube field, increasing the velocity and the heat transfer coefficient.

There are a number of different baffle types, which support the tubes and promote flow across the tubes. The different baffle arrangements used are given below:

Segmental:

- *Single Segmental* (this is the most common)
- *Double Segmental* (this is used to obtain a lower shell side velocity and pressure drop)
- *Disc and Doughnut*.

Baffle Pitch:-
The centre-to-centre distance between baffles is called the baffle-pitch and this can be adjusted to vary the cross-flow velocity. In practice the baffle pitch is not normally greater than a distance equal to the inside diameter of the shell or closer than a distance equal to one-fifth the diameter or 50.8 mm (2 in) whichever is greater.

Baffle Cut:-
In order to allow the fluid to flow backwards and forwards across the tubes part of the baffle is cut away. The height of this part is referred to as the baffle-cut and is measured as a percentage of the shell diameter, e.g., 25 per cent baffle-cut. The size of the baffle-cut (or baffle window) needs to be considered along with the baffle pitch. It is normal to size the baffle-cut and baffle pitch to approximately equalize the velocities through the window and in cross-flow, respectively.

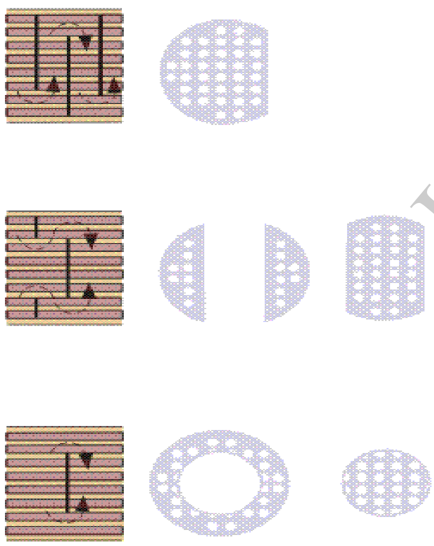


Figure: - Baffle Arrangement

Baffle Orientations:

- *For single-phase service*, single-segmental baffles with a perpendicular (horizontal) baffle-cut orientation in an E- or J-shell are preferred to improve flow distribution in the inlet and outlet regions.
- With vertical inlet or outlet nozzles, parallel-cut (vertical) baffles are preferred if the shell side process fluid condenses and needs a means of drainage.
- Parallel-cut baffles should also be used when the shell side fluid has the potential for particulate fouling, and in multi-pass F-, G-, or H-type shells to facilitate flow distribution.

Horizontal Cut:

- For single-phase fluids on the shell side, a horizontal baffle cut is recommended.
- This minimizes accumulation of deposits at the bottom of the shell and also prevents stratification.

Vertical Cut:

- In the case of a two-pass shell (TEMA F), a vertical cut is preferred for ease of fabrication and bundle assembly.

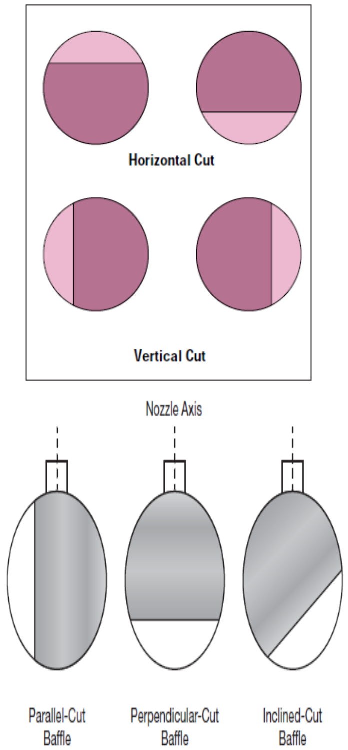


Figure - Baffle Orientation

KERN"s Method:-
This method was based on experimental work on commercial exchangers with standard tolerances and gives a reasonably satisfactory prediction of the heat transfer coefficient for standard designs. The prediction of pressure drop is less satisfactory as pressure drop is more affected by leakage and bypassing than heat transfer. The shell side heat transfer and friction factors are correlated in a similar manner to those for tube side flow by using hypothetical shell velocity and shell diameter. As the cross sectional area of flow will vary across the shell diameter, the linear and mass velocities are based on the maximum area for cross flow.

Shell side and factors for use in this method are given in the figures below for calculating the heat transfer:
The parameters required for calculating the heat transfer coefficient by this method are:

- Area of Cross flow As
- Shell side mass velocity Gs
- Outer diameter of tubes do
- Reynolds Number Re
- Prandtl Number Pr
- Heat transfer factor j_h

BELL METHOD:-

In Bell's method the heat transfer coefficient and pressure drop are estimated from correlations for flow over ideal tube banks, and the effects of leakage, bypassing and flow in the window zone are allowed for by applying correction factors. This approach will give more satisfactory predictions of the heat transfer coefficient and pressure drop than Kerns Method and, as it takes into account the effects of leakage and bypassing, can be used to investigate the effects of constructional tolerances and the use of sealing strips .

Heat transfer coefficient:

The shell side heat transfer coefficient by this method is given by

Hs=hoc * Fn * Fw * Fb * FL

Where,

Hoc = heat transfer coefficient calculated for cross flow over an ideal tube bank, no leakage no bypassing

Fn = correction factor to allow for the effect of the number of vertical tube rows

Fw = window effect correction factor

Fb = Bypass stream correction factor

FL = leakage correction factor

The total correction will vary from 006 for a poorly designed exchanger with large clearances to 0.94 for a well designed exchanger.

Lithium-Bromide solution specifications:-

SrNo	Quantity	Symbol	Value
1	Lithium Bromide Concentration dilute	X_{dil}	57%
2	Lithium Bromide Concentration strong	X_{Strong}	60%
3	Lithium Bromide inlet temperature	Ti	68.3
4	Lithium bromide outlet temperature	To	75.5
5	Flow rate dilute	G_{Dil}	12750 kg/hr
6	Flow rate strong	G_{Conc}	11983 kg/hr
7	Average flow rate	Ws	3.435 kg/sec
8	Density of lithium bromide	ρ	1660 kg/
9	Viscosity	µ	9.80 kg/ m hr
10	Thermal conductivity	K_L	0.392
11	Heat capacity	C_{PL}	0.384 kcal/ kg ^{0} C
12	Viscosity at wall temperature		7.908 kg/m hr

Parallel Cut (Vertical baffle)

SrNo	Quantity	Symbol	Value
1	Shell side fluid		LiBr
2	Tube Side Fluid		Water
3	Tube outer diameter	do	0.019m
4	Tube length	l	3.7m
5	Number of Baffles		9
6	Tube transverse pitch	pt	0.0225m
7	Tube Vertical pitch	pt'	0.0195m
8	Number of tube columns		27
9	Baffle width	B_H	0.326m
10	Shell length at c/s		0.5346 m
11	Baffle cut width	H_C	0.2086 m
12	Baffle cut fraction	B_C	39.65%
13	No of tube rows in cross flow area	N_{cv}	5

Perpendicular Cut (Horizontal baffle)

SrNo	Quantity	Symbol	Value
1	Shell Side Fluid		LiBr
2	Tube Side Fluid		Water
3	Tube outer diameter	do	0.019m
4	Tube length	l	3.7m
5	Number of Baffles		5
6	Tube transverse pitch	pt	0.0195 m
7	Tube Vertical pitch	pt'	0.0225 m
8	Number of tube columns		11
9	Shell length at c/s		0.243 m
10	Baffle width	B_H	0.1895 m
11	Baffle cut width	H_C	0.073 m
12	Baffle cut fraction	B_C	30.04 %
13	No of tube rows in cross flow area		6

Leakage and bypass clearances:-

Clearance between tube and shell bundle = 0.0055 m

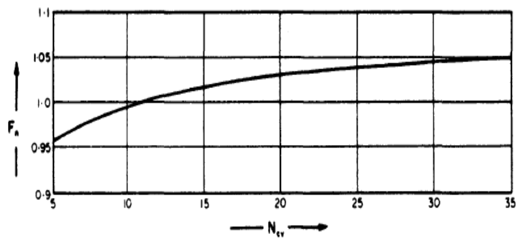
Bypass area ratio =0.10167

Tube to baffle clearance = 0.0099

Shell to baffle clearance area = 0

Influence of Number of tube rows:-

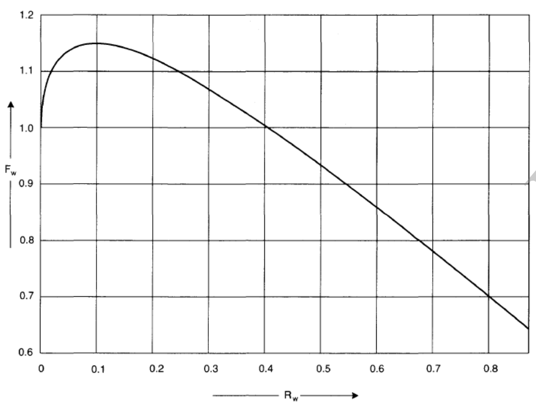
It is known that in laminar flow the heat transfer coefficient decreases with increasing distance from the start of heating. This is due to the fact that with increasing distance of the tube inlet, the temperature gradient at the tube wall decreases and it also decreases the heat transfer coefficient. This phenomenon also exists during flow across tube banks. For large heat exchangers in deep laminar flow, it can result in a decrease in the average heat transfer coefficient by a factor of 2 or more compared with what would have been predicted based on calculations. Therefore Bell proposed to introduce a correction factor that depends on the total number of tube rows in the fluid path across the heat exchanger.



Graph for tube row correction factor

Effect of baffle window:-

In order to correlate the experimental data properly it is important to take into account the effect of flow in the window area of the baffle. This factor corrects for the effect of flow through the baffle window and is a function of heat transfer area in the window zones and total heat transfer area. For this it is necessary to use a velocity defined as the geometric mean between the cross flow velocity and the window velocity. The need to define this velocity arises due to the fact that by increasing the baffle spacing, the pressure drop through the window changes but the velocity of flow through the window section is constant

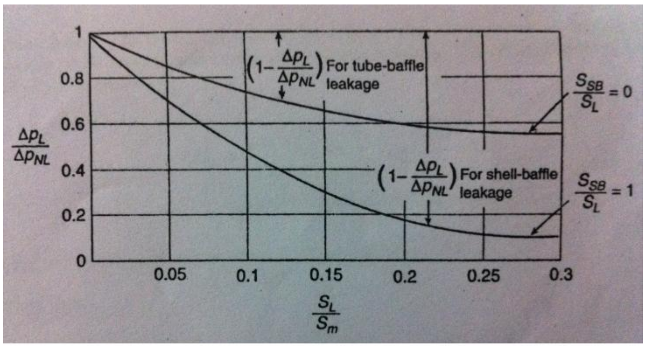


The correction factor is shown the figure plotted vs. Rw, the ratio of the number tubes in the window zones to the total number of tubes in the bundle.

Effect of Leakage:-

Owing to the leakage existing between baffles and tubes and between baffles and shell, both heat transfer coefficient and pressure drop differ from the values of an ideal bank. This was taken into account by Bell who simplified the calculations by assuming that the ratio between leakage flow rate and cross flow area is independent of the flow regime and depends only on the ratio between leakage area and cross flow area.

According to Bell, the ratio of between pressure drop for a heat exchanger with no leakage and pressure drop for a heat exchanger with leakage can be represented by a curve shown of the type shown in the figure below. The upper curve corresponds to a heat exchanger where the leakage occurs between tubes and baffle exclusively and the lower curve corresponds to a heat exchanger with leakage only between shell and baffles



Thus the mathematical treatment can be simplified using a single curve which is that of tube - baffle leakage as shown in the figure below.

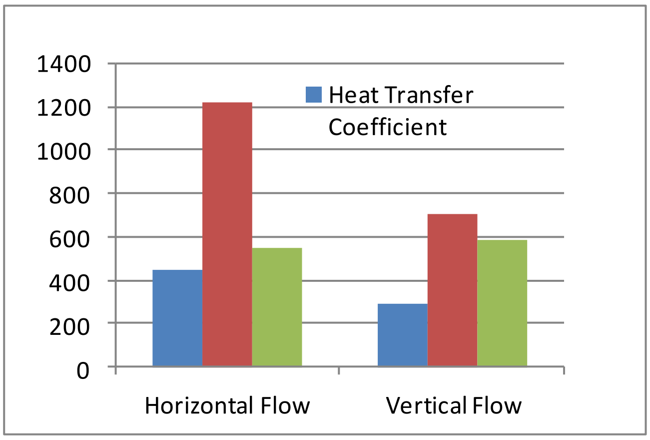
RESULTS:-

After calculating with the help of Kerns method the results are obtained are more than satisfactory.

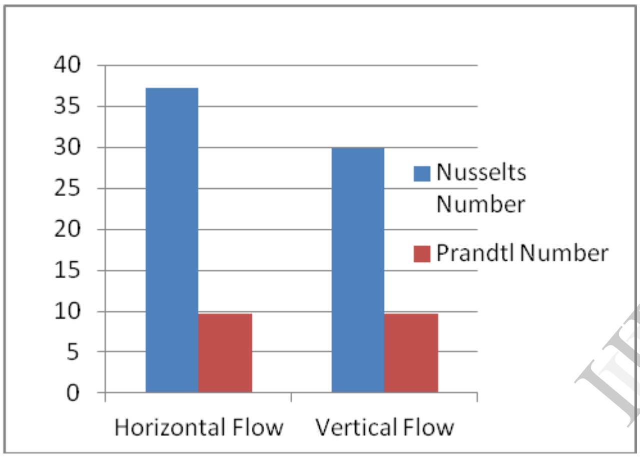
Parallel Cut Perpendicular Cut

SrNo	Quantity	Symbol	Value for Parallel-Cut	Value for Perpendicular-Cut
1	Maximum Area of Cross flow	As	0.01967	0.034
2	Shell side mass velocity	Gs	174.63 kg/ sec	101.03 kg/ sec
3	Reynolds number	Re	1218.84	705.148
4	Prandtl number	Pr	9.675	9.675
5	Nusselts number	Nu	37.18	29.19
6	Heat transfer coefficien t	ho	1458.24	1144.14
7	Total Pressure drop	p	33.74 mm of LiBr	17.85 mm of LiBr

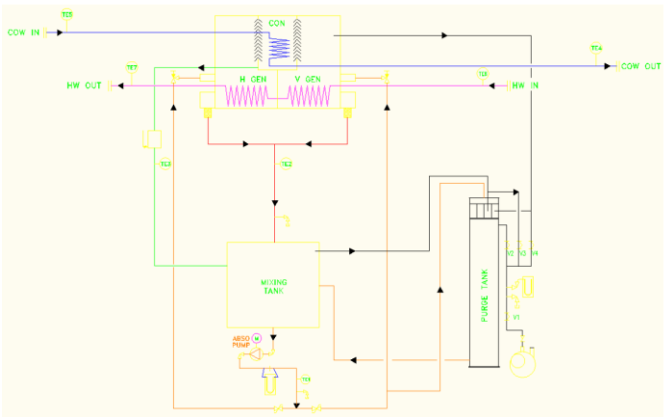
COMPARATIVE REPRESENTATION OF HTC, REYNOLDS NUMBER AND PRESSURE DROP



COMPARISON OF NUSSELTS AND PRANDTL NUMBER



THE SCEMATIC DIAGRAM OF HEAT EXCHANGER WE DESIGNED FOR THIS STUDY IS AS FOLLOWING



CON- Condenser
H GEN- Horizontal Flow Generator
V GEN- Vertical Flow Generator
TE1 - Temperature of Dilute solution of Li-Br
TE2 - Temperature of Concentrated solution of Li-Br
TE3 - Temperature of Condensate
TE4 - Temperature of Condenser cooling water outlet
TE5 - Temperature of Condenser cooling water inlet
TE6 - Temperature of Hot water inlet
TE7 - Temperature of Hot water outlet
Purge Tank - Used to remove the non-condensable gases

CONCLUSION:-

From the above graphic representation it is evident that there is significant drop in the Reynolds Number corresponding to vertical flow which in turn has a direct impact on the shell-side heat transfer coefficient which is found to be lower than that for horizontal flow.

However the shell-side pressure drop for the vertical flow is in the same range as that for the horizontal flow design. Also there is a noticeable drop in the Nusselts Number for the proposed design with the Prandtl number being the same for both designs.

Therefore based on the results we conclude that changing the flow pattern to vertical to improve the shell-side heat transfer coefficient is not feasible.

REFERENCES:-

BOOKS:-

- "Chemical Engineering" , Coulson & Richardson, 3rd Edition Volume 6
- "Heat Transfer in Process Engineering" , Eduardo Cao
- "Chemical Engineering Design" , R.K. Sinnott and G.Towler, 4th Edition, 2008
- "Investigation of the effects of baffle orientation , baffle cut , fluid viscosity on shell side pressure drop and heat transfer coefficient in an E- type shell and tube heat exchanger" by Koorosh Mohammadi , Institute of Thermodynamics and Thermal Engineering University of Stuttgart, Germany Feb -2011

LINKS:-

- http://nptel.iitm.ac.in/courses/103103032/module8/lec33/4.html
- http://www.wermac.org/equipment/heatexchanger_part4.html
- http://www.bestinnovativesource.com/2012/04/06/baffle
- http://hw-arts.blogspot.in/2011/11/industrial-design-and-animation-kettle.html
- http://www.hw-arts.blogspot.in/