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Innovative Methodology to Improve Shell and Tube Heat Exchangers Performance

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Abstract:- The objective of this technical paper is to study the effect of optimizing the internal baffle spacing (L_b) on the thermal and hydraulic performance of shell and tube heat exchangers. The thermal effects on the terminal temperatures of both shell and tube sides and heat duty are also studied. The changes in LMTD correction factor (F_N) due changing the baffle spacing are also addressed in this report. TEMA is specifying the minimum baffle spacing as one fifth of the shell inside diameter or 50.8 mm, whichever is greater. The maximum unsupported length is one and half (1½) meters for nineteen (19.05) mm outside tube diameter. This specification was investigated in this report. For this purpose, TEMA E (shell) type is used as a base for this study. A broad review of the published literatures was made. Most of the literatures were found dealing with number of baffles (N_b) instead of internal baffle spacing. New equation, results and economical recommendations are obtained from this study.

Assumption:

In all of the results presented in this paper, the usual idealizations for heat exchanger analysis are invoked;

- Steady state operation
- Single phase fluids
- Negligible heat loss to the surrounding
- Uniform flow distribution
- Uniform overall heat transfer coefficient with constant properties
- Negligible longitudinal conduction in the tube wall or fluids
- Heat exchangers are operating under overall counter flow condition

I. BAFFLE DESIGN

Baffles are used to serve two important functions. They support the tubes during assembly and operation and help prevent vibration from flow induced eddies and direct the shell side fluid back and forth across the tube bundle to provide effective velocity and heat transfer rates. There are two types of baffles which are plate and rod. Plate baffles may be single-segmental, double-segmental, or triple-segmental, as shown in figure No. 1. The diameter of the baffle must be slightly less than the shell inside diameter to allow assembly, but must be close enough to avoid the substantial performance penalty caused by fluid bypass around the baffles. Shell roundness is important to achieve effective sealing against excessive bypass. Baffles can be made from a variety of materials compatible with the shell side fluid. They can be punched or machined. Some baffles are made by a punch which provides a lip around the tube hole to provide more surfaces against the tube and eliminate tube wall cutting from the baffle edge. The tube holes must be precise enough to allow easy assembly and field tube replacement, yet minimize the chance of fluid flowing between the tube wall and baffle hole, resulting in reduced thermal performance and increased potential for tube wall cutting from vibration. Baffles do not extend edge to edge, but have a cut that allows shell side fluid to flow to the next baffled chamber. For most liquid applications, the cut areas represent 20- 25 % of the shell diameter. For gases, where a lower pressure drop is desirable, baffle cuts of 40-45 % is common. Baffles must overlap at least one tube row in order to provide adequate tube support. They are spaced throughout the tube bundle somewhat evenly to provide even fluid velocity and pressure drop at each baffled tube section.

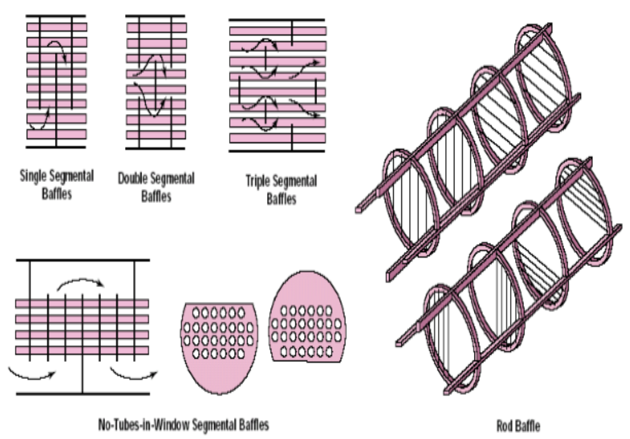

Figure No. 1: Types of baffles

II. STREAM ANALYSIS OF FLOW DISTRIBUTION IN BAFFLED HEAT EXCHANGERS:

In a baffled shell and tube heat exchanger, only a fraction of the fluid flow thought the shell side of a heat exchanger actually flows across the tube bundle in the idealized path normal to the axis of the tubes. The remaining fraction of the fluid flows through “bypass” areas. As can be expected, the fluid seeks the flow path of less resistance from the inlet to the outlet of the exchanger. In a typical design, the non-ideal flows represent up to 40 % of the total flow and hence it is imperative to account for their effects on the heat transfer and pressure drop.

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Bell-Delaware method is used in this study to estimate the shell side heat transfer coefficient and pressure drop under the effect of changing the internal baffle spacing. These results were combined with tube side heat transfer coefficient and pressure drop to study the effects on the performance of heat exchangers. The baffle spacings are shown in figure No. 2.

The study was done on the conventional shell type which is classified based on the construction by TEMA to be E type. Six (6) different heat exchangers were studied here. They were installed at operating facility in Saudi Arabia. These heat exchangers have different fluid parameters and size dimensions. They are also classified mechanically to be 1-2, 1-4, 1-6 shell and tube passes.

In this study the baffle spacing (L_b) is changed from 0.2 to 2 meters to study its effects on the performance of heat exchangers. Also, the reliability of this criteria, maximum and minimum baffle spacing, which is adapted by TEMA is tested here. Its economical effects are also addressed in this technical report.

New equation was developed and tested in this report. This equation replaces the traditional one which was developed by Kern to calculate the number of baffles in the tube bundle. The accuracy of Dhawi's equation is better than Kern since Kern did not include the effects of inlet and outlet baffle spacings and tubesheet thickness in his equation. So Dhawi's equation gives the actual baffles number for a specific baffle spacing. Kern's equation gives more baffles than required while Dhawi's equation gives that exact number of baffles. The reliability of Dhawi's equation was tested using six different heat exchangers which are currently operating at a Refinery. The following two equations show the differences between Dhawi and Kern.

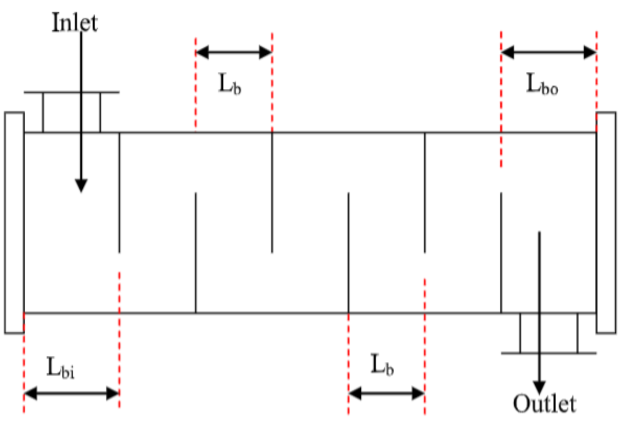

Figure No. 2: Baffle spacing

$$N_b = \left(\frac{L_s - (t_1 + t_2) - (L_{bi} + L_{bo})}{L_b + t_b} + 1 \right)$$

Dhawi's Equation

$$N_b = \left(\frac{L_s}{L_b + t_b} - 1 \right)$$

Kern's Equation

Bell-Delaware method is used for the shell side and the traditional (internal flow) method is used for the tube side to estimate the exchanger performance at different internal baffle spacings. The optimum baffle spacing for each heat exchanger is evaluated. Also, the critical velocity at that baffle spacing was estimated and found higher than the shell side operating velocity. The following paragraphs illustrate the effects of changing the internal baffle spacing on the performance of 1-2, 1-4 and 1-6 shell and tube passes heat exchangers. Also, the economical effects of varying L_b on the capital cost are illustrated.

- *1-2 TEMA E Type Heat Exchangers*

Two shell and tube heat exchangers with 1-2 tube passes were used for studying the effect of changing L_b on the performance. These heat exchangers are J64-E-355 & 233 which are located at a Refinery. Their outside tube diameter, tube pitch and pitch angle are 19 mm, 25 mm and 90 degrees respectively. The baffle spacing (L_b) is changed from 0.2 to 2 meters to study its effects on the terminal temperatures (T_{co} & T_{ho}), overall heat transfer coefficient (U_o), shell side pressure drop (ΔP_s), heat duty (Q), LMTD correction factor (F_N) and number of baffles (N_b). Figures No.3 to 6 illustrate the abovementioned effects. It is clear from figure No. 3, the effects of changing L_b is insignificant on the terminal temperatures. Also, U_o is not affected significantly by changing L_b. However, shell side pressure drop (ΔP_s) and heat duty (Q) are affected by L_b. The effect is clear on ΔP_s as shown in figure No. 4. The LMTD correction factor (F_N) is improved and the number of baffles (N_b) is reduced by increasing L_b. These are shown in figure No. 6. Therefore, 1.9 meters L_b can be used instead of the existing 0.365 meter for J64-E-355. This will reduce the number of baffles to 3 instead of 10 which will save approximately $2000 for each baffle. The effects on T_{co}, T_{ho}, U_o and Q will be insignificant compared to the capital cost saving in the number of baffles. The shell side pressure drop (ΔP_s) will be lower so it will not affect the downstream processes. The critical and maximum cross sectional operating velocities of the shell side when using 1.9 meters L_b are 0.271 m/s and 0.176 m/s respectively. Therefore, the effect of the critical velocity is overcome. Also, TEMA maximum baffle spacing limit (1½ meters) can be exceeded without effecting the thermal performance and mechanical integrity of the heat exchanger. This will lead to capital cost reduction by avoiding using unnecessary number of baffles.

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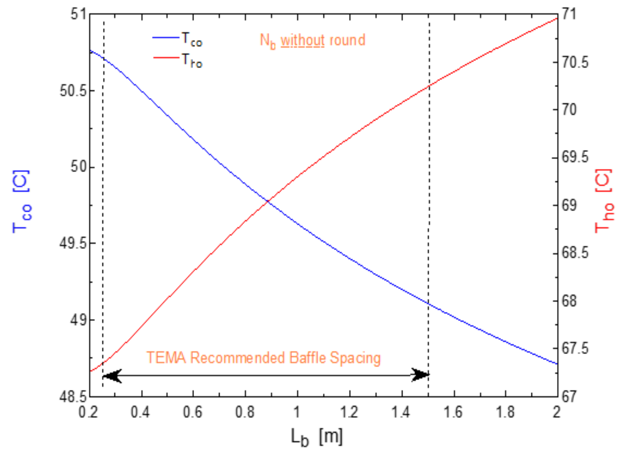

Figure No. 3: The effects on T_{co} & T_{ho}

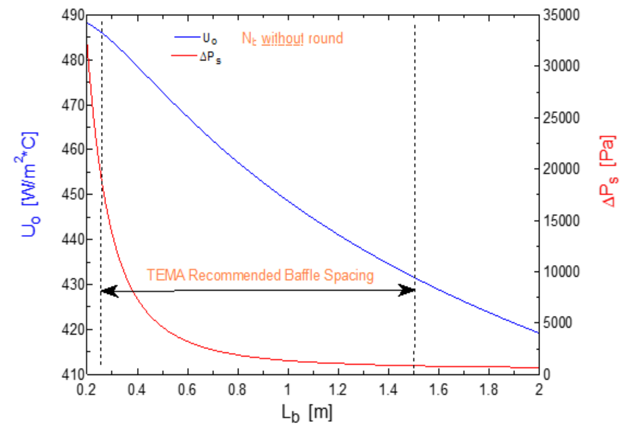

Figure No. 4: The effects on U_o & ΔP_s

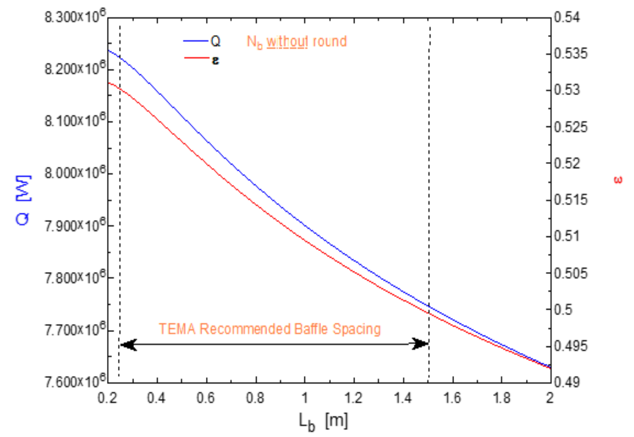

Figure No. 5: The effects on Q & ε

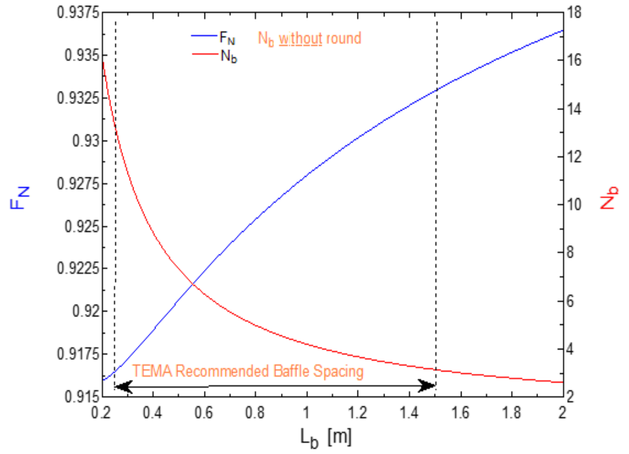

Figure No. 6: The effects on F_N & N_b

- *1-4 TEMA E Type Heat Exchangers:*

Two shell and tube heat exchangers with 1-4 tube passes were used for studying the effect of changing L_b on the performance. These heat exchangers are J64-E-224 & 350 which are located at a Refinery. Their outside tube diameter, tube pitch and pitch angle are 19 mm, 25 mm and 90 degrees respectively. The baffle spacing (L_b) is changed from 0.2 to 2 meters to study its effects on the terminal temperatures (T_{co} & T_{ho}), overall heat transfer coefficient (U_o), shell side pressure drop (ΔP_s), heat duty (Q), LMTD correction factor (F_N) and number of baffles (N_b). Figures No.7 to 10 illustrate the abovementioned effects. It is clear from figure No. 7, the effects of changing L_b is insignificant on the terminal temperatures. Also, U_o is not affected significantly by changing L_b. However, shell side pressure drop (ΔP_s) and heat duty (Q) are affected by L_b. The effect is clear on ΔP_s as shown in figure No. 8. The LMTD correction factor (F_N) is improved and the number of baffles (N_b) is reduced by increasing L_b. These are shown in figure No. 10. Therefore, 1.9 meters L_b can be used instead of the existing 0.207 meter for J64-E-350. This will reduce the number of baffles to 3 instead of 15 which will save approximately $2000 for each baffle. The effects on T_{co}, T_{ho}, U_o and Q will be insignificant compared to the capital cost saving in the number of baffles. The shell side pressure drop (ΔP_s) will be lower so it will not affect the downstream processes. The critical and maximum cross sectional operating velocities of the shell side when using 1.9 meters L_b are 0.272 m/s and 0.217 m/s respectively. Therefore, the effect of the critical velocity is overcome. Also, TEMA maximum baffle spacing limit can be exceeded without effecting the thermal performance and mechanical integrity of the heat exchanger. This will lead to capital cost reduction.

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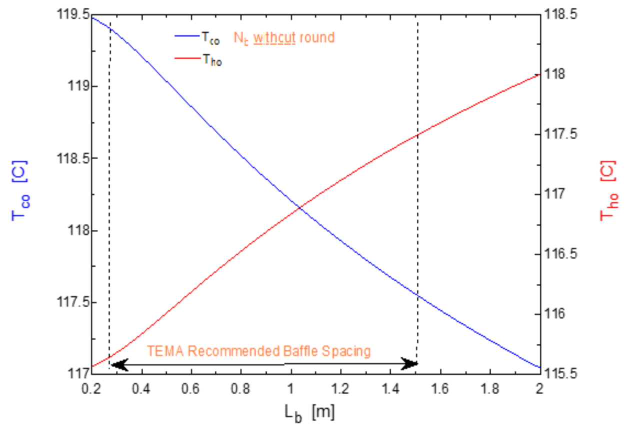

Figure No. 7: The effects on T_{co} & T_{ho}

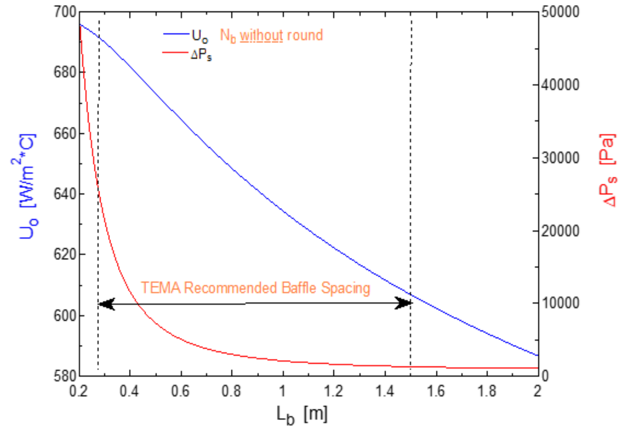

Figure No. 8: The effects on U_o & ΔP_s

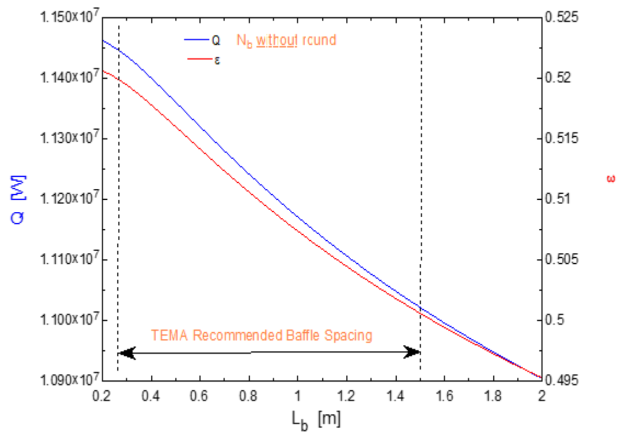

Figure No. 9: The effects on Q & ε

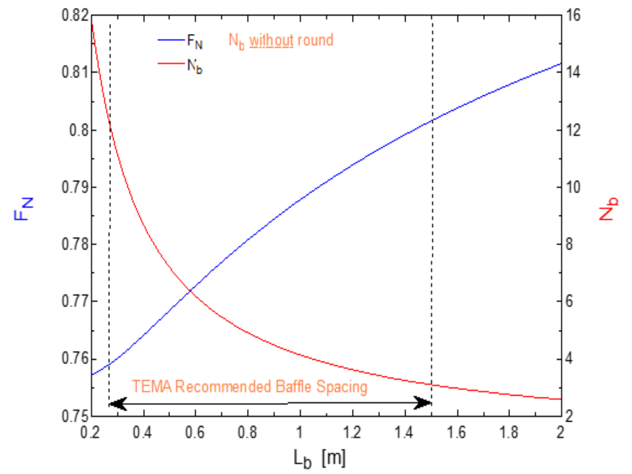

Figure No. 10: The effects on F_N & N_b

- *1-6 TEMA E Type Heat Exchangers:*

Two shell and tube heat exchangers with 1-6 tube passes were used for studying the effect of changing L_b on the performance. These heat exchangers are J64-E-230 & 240 which are located at a Refinery. Their outside tube diameter, tube pitch and pitch angle are 19 mm, 25 mm and 90 degrees respectively. The baffle spacing (L_b) is changed from 0.2 to 2 meters to study its effects on the terminal temperatures (T_{co} & T_{ho}), overall heat transfer coefficient (U_o), shell side pressure drop (ΔP_s), heat duty (Q), LMTD correction factor (F_N) and number of baffles (N_b). Figures No.11 to 14 illustrate the abovementioned effects. It is clear from figure No. 11, the effects of changing L_b is insignificant on the terminal temperatures. Also, U_o is not affected significantly by changing L_b. However, shell side pressure drop (ΔP_s) and heat duty (Q) are affected by L_b. The effect is clear on ΔP_s as shown in figure No. 12. The LMTD correction factor (F_N) is improved and the number of baffles (N_b) is reduced by increasing L_b. These are shown in figure No. 14. Therefore, 1.3 meters L_b can be used instead of the existing 0.4242 meter for J64-E-230. This will reduce the number of baffles to 4 instead of 10 which will save approximately $2000 for each baffle. The effects on T_{co}, T_{ho}, U_o and Q will be insignificant compared to the capital cost saving in the number of baffles. The shell side pressure drop (ΔP_s) will be lower so it will not affect the downstream processes. The critical and maximum cross sectional operating velocities of the shell side when using 1.3 meters L_b are 0.52 m/s and 0.476 m/s respectively. Therefore, the effect of the critical velocity is overcome. Using 1.3 meters internal baffle spacing L_b will lead to capital cost reduction by avoiding using unnecessary number of baffles.

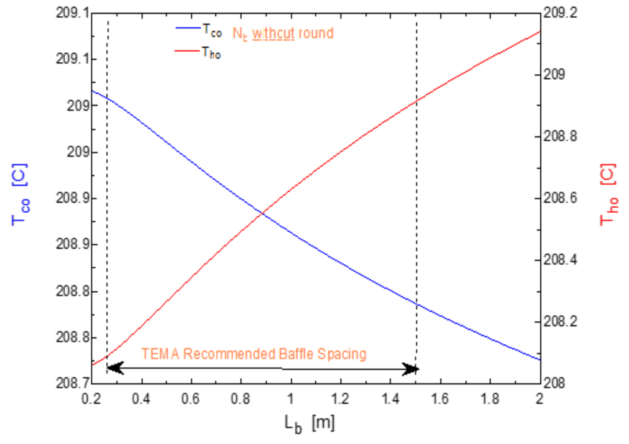

Figure No. 11: The effects on T_{co} & T_{ho}

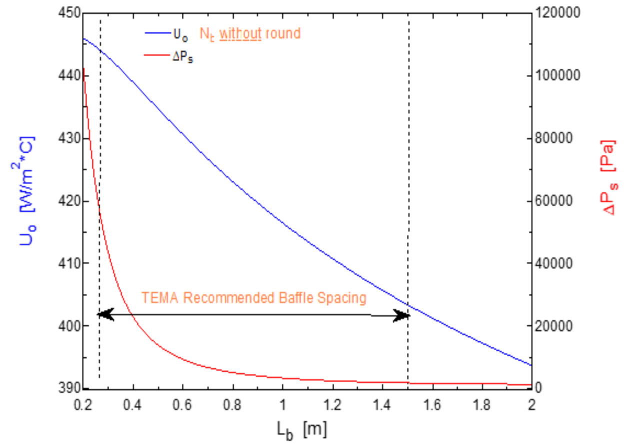

Figure No. 12: The effects on U_o & ΔP_s

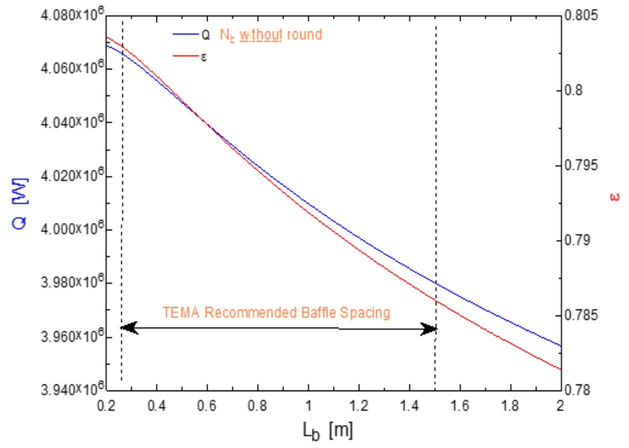

Figure No. 13: The effects on Q & ε

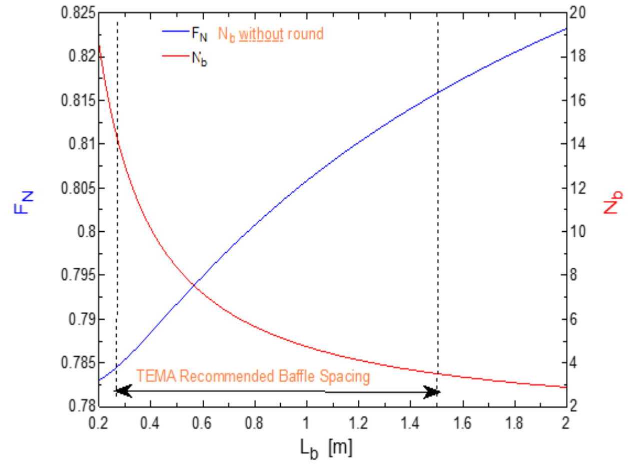

Figure No. 14: The effects on F_N & N_b

The critical parameters which relate the effect of changing the internal baffle spacing on the thermal performance and mechanical integrity of each shell and tube heat exchanger configuration are presented in the following table. The cost saving by reducing the number of baffles per one shell is also indicated at table 1. The comprehensive results for each heat exchanger are presented in appendix I.

Table No.1: Results summary

Bundle Configuration	**Existing Design**		**New Design**				**Saving For One Shell**
	L_b (m)	N_b	L_b (m)	N_b	V (m/s)	V_c (m/s)	
1-2	0.365	10	1.9	3	0.176	0.271	$ 14000
1-4	0.207	15	1.9	3	0.217	0.272	$ 24000
1-6	0.4242	10	1.3	4	0.476	0.52	$ 12000

III. CONCLUSION

This study has been carried out to evaluate the effect of changing the internal baffle spacing (L_b) on the performance of different tube passes of shell and tube heat exchangers. E type heat exchangers are used for this study. The reliability of TEMA criteria for maximum and minimum baffle spacing has been tested in this study. Based on the analysis results which include the effect of critical velocity on the heat exchanger integrity, TEMA maximum baffle spacing limit can be exceeded without effecting the thermal performance and mechanical integrity of the heat exchanger. This will lead to capital cost reduction by avoiding using unnecessary number of baffles as illustrated in the above-mentioned cases.

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- **Nomenclature:**

ΔP_s Shell side pressure drop
ε Effectiveness
F_N LMTD correction factor
L_b Internal baffle spacing
L_{bi} Inlet baffle spacing
L_{bo} Outlet baffle spacing
L_s Tube length
N_b Number of baffles
Q Heat duty
T_{co} Cold side outlet temperature
T_{ho} Hot side outlet temperature
t_1 Floating tubesheet thickness
t_2 Stationary tubesheet thickness
t_b Baffle thickness
U_o Overall heat transfer coefficient
V Maximum cross sectional operating velocity
V_c Critical velocity

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