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Delaware Method Improvement for the Shell and Tubes Heat Exchanger Design

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Abstract

In this paper the Delaware Method published in 1963 is analyzed and upgraded with using correction factors which take into account the undesirable currents of the mean flow. However, this method presents graphically these correction factors which imply an impediment to fulfill the software calculations. Thus, the equations corresponding to the correction factor equations and a Fortran 77 numerical program were established. This system is given to explore different design alternatives in order to find the optimal solution to each proposed problem. The results of this work was a simple software that can perform calculations with the introduction of parameters depending only on the geometry of the heat exchanger, *i.e.*, geometry, temperature and fluid characteristics eliminating the human errors and increasing the calculations speed and accuracy.

Keywords

Delaware Method; Flow; Correction Factor; Heat Exchanger

1. Introduction

The method is established in the heat transfer analysis and in the pressure losses of the fluid which flows through the shell side [1] [2].

In order to complete the heat exchanger analysis, it is essential to consider the different currents generated by the shell side flow, as is shown in **Figure 1**. This figure has been modified by Palen and Taborek [3] [4] in regard to

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the original version proposed by Tinker [5]. Here five different streams are identified side of the shell. The current B is known as the mean mixed flow and flows through the mixed flow section and the window section of the heat exchanger. This is the ideal current flowing in the shell side of a heat exchanger.

Besides of flow B, there are four more flows which are present due to the free spaces and cavities between the shell and the deflectors and they provoke a modification of the current B performance.

The different leakages and recirculation currents influence the heat flux transfer in two ways:

1) Reduce the current B resulting in a drop of the heat transfer global coefficient.

2) Modify the shell-side temperature distribution.

The Delaware method considers these effects as correction factors in the heat transfer coefficient and the loss pressure calculations.

The basic equations of the heat exchangers thermal design are:

$$Q = U_{dc} A F T_{mlc} \tag{1}$$

$$U_{dc} = \frac{1}{\frac{1}{h_{io}} + \frac{1}{h_{cc}} + R_d + \frac{e_t}{k}} \tag{2}$$

In the Equation (2), h_{cc} is the fluid convection coefficient flowing in the shell and it is obtained by Equation (3). In this equation the correction factors are included, the correction factors J_i, J_c, J_l, J_b, J_r, J_r^* and J_s, which consider the different currents shown in **Figure 1**.

$$h_{cc} = J_i C p_c \left(\frac{W_c}{S_m}\right)\left(\frac{k_c}{C p_c \mu_c}\right)^{2/3}\left(\frac{\mu_c}{\mu_{wc}}\right)^{0.14} J_c J_l J_b J_r J_s \tag{3}$$

For the hydraulic design is required to determine the fluid pressure loss through the shell side and it must be included the correction factors f_i, R_b, R_l and R_s. The corresponding calculation is made using the next equation:

$$\Delta P_c = \left\{ (N_b - 1)\left[\frac{4 f_i W_c^2 N_c}{2 g \rho_c S_m^2}\left(\frac{\mu_{wc}}{\mu_c}\right)^{0.14}\right] R_b R_l + 2\Delta P_{b,i}\left(1 + \frac{N_{cw}}{N_c}\right) R_b R_s + N_b \Delta P_{w,i} R_l \right\} \tag{4}$$

It is observed that the principal problem using the Delaware Method is the determination of the eleven correction factors of which nine are obtained graphically. In the next section, the nine correction factors will be presented analytically. The original version only presents analytically the J_s and R_s correction factors.

2. Shell Side Correction Factor Equations

According to the Delaware method, after the geometrical parameters computations, the heat transfer and loss pressure are estimated considering the correction factors. This special case will be shown in the next section by using the appropriate Equations [6]-[8].

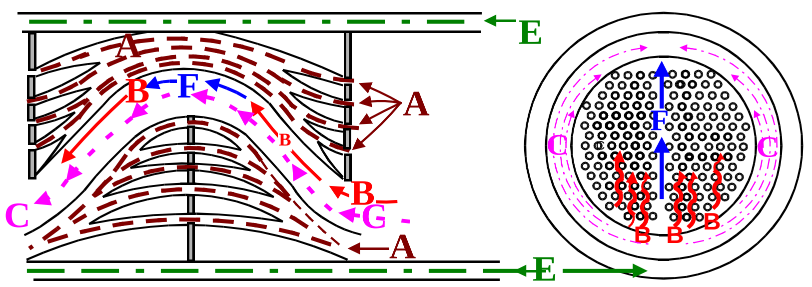

Figure 1. Ideal design of the currents flowing in the shell side. A. Currents flowing through the free spaces between tubes and baffles; B. Mean current flow; C. Recirculation current; D. Leakage current between shells and deflectors; E. Recirculation current in the past partition.

2.1. Correction Factor J_i

This factor depends on the Reynolds Number Re_c and the tube arrangement as is established in the next equation:

$$J_i = \exp\left[\mathrm{A} + \mathrm{B}\ln(\mathrm{Re}_c) + \mathrm{C}\ln(\mathrm{Re}_c)^2 + \mathrm{D}\ln(\mathrm{Re}_c)^3 + \mathrm{E}\ln(\mathrm{Re}_c)^4 + F\ln(\mathrm{Re}_c)^5\right]a \quad (5)$$

This equation is applied to the different arrangement tube types: triangular, square, and rhombic. For each case, the constant are presented in Table 1. It was determined 4% as that the maximum error between the equations and the graphic presentation.

2.2. Correction Factor J_c by the Baffle Configuration Effect

The deflector geometry and especially the window cross-section shape provoke currents where the effects are considered in the correction factor J_c. This factor is determined in a mathematical way as following:

$$J_c = \mathrm{A} + \mathrm{B}F_c + \mathrm{C}F_c^2 + \mathrm{D}F_c^3 + \mathrm{E}F_c^4 \quad (6)$$

The values of each constant are presented in Table 2. Comparing the graphics obtained by Equation (6) and the original one, the maximum error established is 5%.

2.3. Correction Factor by Baffle Leakages Effect, J_l

The fluid that does not exchange heat owing to the leakage through the gap formed by the tubes and the baffles as well as through the shell and baffle is considered in the correction factor J_l. This factor is obtained using the Equation (7) where:

$$S_1 = S_{sb}/(S_{sb} + S_{tb}) \text{ and } S_2 = (S_{sb} + S_{tb})/S_m$$

The constants required by this equation are available in Table 3. Comparing the original graph against that one getting by Equation (7), the maximum error is 2%.

$$\begin{aligned} J_l = {} & \left[\mathrm{A} + \mathrm{B}(S_1) + \mathrm{C}(S_1)^2 + \mathrm{D}(S_1)^3\right] + \left[\mathrm{E} + \mathrm{F}(S_1) + \mathrm{G}(S_1)^2 + \mathrm{H}(S_1)^3\right](S_2) \\ & + \left[\mathrm{I} + \mathrm{J}(S_1) + \mathrm{K}(S_1)^2 + \mathrm{L}(S_1)^3\right](S_2)^2 + \left[\mathrm{M} + \mathrm{N}(S_1) + \mathrm{O}(S_1)^2 + \mathrm{P}(S_1)^3\right](S_2)^3 \end{aligned} \quad (7)$$

Table 1. Constants for the equation for the correction factor J_i.

Arrangement	A	B	C	D	E	F
Triangular	0.627615	−0.69064	−0.0507472	0.0141049	−0.000937714	1.7683×10^{-5}
Square	0.374177	−0.671577	−0.0784051	0.02507191	−0.00224983	0.0000673254
Rhombic	−0.273166	−0.472896	−0.109701	0.023299	−0.00145983	0.0000242675

Table 2. Constants for the equation for the correction factor J_c.

For values of F_c between	A	B	C	D	E
0 and 0.9	0.533574545	0.69059596	0.290909091	−0.295959596	0
0.9 and 1	−27.84837787	152.5274893	−301.9699773	265.12743360	−86.76640715

Table 3. Constants for the equation for the correction factor J_l.

Values of S_2	A	B	C	D	E	F	G	H
0 to 0.1	1	0	0	0	−2.5903333	−4.8677761	8.773331	−7.0222218
0.1 to 0.7	0.90063003	−0.0389402	0.1363475	0.05531749	−0.4299145	−1.0949101	1.4689544	0.7341744
Values of S_2	I	J	K	L	M	N	O	P
0 to 0.1	15.8742857	50.8190476	−133.48571	106.666666	−39.6381	−168.31699	486.093325	−391.10933
0.1 to 0.7	−0.0567309	1.72685112	−4.2124254	2.4290305	0.04115536	1.3220234	3.32880672	−1.99187

2.4. Correction Factor by Recirculation Flow Effect, J_b

The recirculation currents do not exchange heat through the tubes and this issue is considered by the correction factor J_b. This factor is computed by Equation (8) which is based on F_{sbp}. The constant of the Equation $N_2 = N_{ss}/N_c$ are defined in **Table 4** in terms of Re_c.

$$\begin{aligned} J_b = & \left[\mathrm{A}+\mathrm{B}(N_2)+\mathrm{C}(N_2)^2+\mathrm{D}(N_2)^3+\mathrm{E}(N_2)^4\right]+\left[\mathrm{F}+\mathrm{G}(N_2)+\mathrm{H}(N_2)^2+\mathrm{I}(N_2)^3+\mathrm{J}(N_2)^4\right]F_{sbp} \\ & +\left[\mathrm{K}+\mathrm{L}(N_2)+\mathrm{M}(N_2)^2+\mathrm{N}(N_2)^3+\tilde{\mathrm{N}}(N_2)^4\right]F_{sbp}^2+\left[\mathrm{O}+\mathrm{P}(N_2)+\mathrm{Q}(N_2)^2+\mathrm{R}(N_2)^3+\mathrm{S}(N_2)^4\right]F_{sbp}^3 \\ & +\left[\mathrm{T}+\mathrm{U}(N_2)+\mathrm{V}(N_2)^2+\mathrm{W}(N_2)^3+\mathrm{X}(N_2)^4\right]F_{sbp}^4 \end{aligned} \quad (8)$$

A maximum error of 1.3% is result of comparing the original graph against that one obtained by Equation (8).

2.5. Correction Factor by Adverse Temperature Gradient J_r

This factor has the value of 1 if $\mathrm{Re}_c \geq 100$. When Re_c fluctuation is between 0 and 100, the next criterion is used:

1) If $\mathrm{Re}_c \leq 20$, J_r will acquire the same value as J_r^* using the Equation (9), and knowing that N_b and $N_1 = N_c + N_{cw}$ are constants which are shown in **Table 5**.

$$\begin{aligned} J_r^* = & \left[\mathrm{A}+\mathrm{B}(N_1)+\mathrm{C}(N_1)^2+\mathrm{D}(N_1)^3+\mathrm{E}(N_1)^4\right]+\left[\mathrm{F}+\mathrm{G}(N_1)+\mathrm{H}(N_1)^2+\mathrm{I}(N_1)^3+\mathrm{J}(N_1)^4\right]N_b \\ & +\left[\mathrm{K}+\mathrm{L}(N_1)+\mathrm{M}(N_1)^2+\mathrm{N}(N_1)^3+\tilde{\mathrm{N}}(N_1)^4\right]N_b^2+\left[\mathrm{O}+\mathrm{P}(N_1)+\mathrm{Q}(N_1)^2+\mathrm{R}(N_1)^3+\mathrm{S}(N_1)^4\right]N_b^3 \\ & +\left[\mathrm{T}+\mathrm{U}(N_1)+\mathrm{V}(N_1)^2+\mathrm{W}(N_1)^3+\mathrm{X}(N_1)^4\right]N_b^4 \end{aligned} \quad (9)$$

A maximum error of 1.9% is result of comparing the original graph against that one obtained by Equation (8).

2) If $20 \leq \mathrm{Re}_c \leq 100$, J_r is computed by Equation (10) which depends on J_r^*, Re_c and **Table 6** constants.

Table 4. Constants for the equation for the correction factor J_b.

For	A	B	C	D	E	F	G	H	I
$\mathrm{Re}_c > 100$	0.99939474	0.01085613	−0.0171267	−0.1003071	0.19198207	−1.2394301	13.4729632	−85.593388	252.064457
$\mathrm{Re}_c < 100$	0.9991889	0.02071706	−0.185339	0.59250929	−0.5964414	−1.3564474	16.400326	−116.51387	362.367998
For	**J**	**K**	**L**	**M**	**N**	**Ñ**	**O**	**P**	**Q**
$\mathrm{Re}_c > 100$	−249.7121	0.74529366	−9.5329177	82.1849019	−321.67178	378.959635	−0.3575412	3.12005087	−71.95138
$\mathrm{Re}_c < 100$	−368.18466	1.18264455	−19.614535	140.62959	−451.59784	478.689065	−1.1031648	16.9758369	−113.6298
For	**R**	**S**	**T**	**U**	**V**	**W**	**X**		
$\mathrm{Re}_c > 100$	422.592705	−576.65103	0.20001675	−3.866875	70.1962129	−363.1866875	473.343386		
$\mathrm{Re}_c < 100$	396.869404	−457.40996	0.59140536	−8.7366322	56.8613935	−210.10305	253.214998		

Table 5. Constants for the equation for the correction factor J_r^*.

A	B	C	D	E	F	G	H	I
1.11286866	−0.0444079	0.0019872	-4.324×10^{-5}	3.4787×10^{-7}	−0.0289065	2.241×10^{-4}	1.5142×10^{-6}	9.5563×10^{-8}
J	**K**	**L**	**M**	**N**	**Ñ**	**O**	**P**	**Q**
-3.11×10^{-9}	0.0008806	2.8301×10^{-5}	-2.088×10^{-6}	3.4527×10^{-8}	-9.296×10^{-11}	-1.363×10^{-5}	-9.749×10^{-7}	5.9493×10^{-8}
R	**S**	**T**	**U**	**V**	**W**	**X**		
-8.947×10^{-10}	1.618×10^{-12}	8.3072×10^{-8}	8.7699×10^{-9}	-4.727×10^{-10}	5.7282×10^{-12}	8.9289×10^{-15}		

Table 6. Constants for the equation for correction factor J_r.

A	B	C	D	E	F	G	H
−0.2477376	0.0129611	-1.127×10^{-5}	6.5427×10^{-8}	1.26556042	−0.0129666	2.5357×10^{-6}	1.5481×10^{-8}
I	**J**	**K**	**L**	**M**	**N**	**O**	**P**
−0.0481867	2.2364×10^{-4}	1.6928×10^{-5}	-1.708×10^{-7}	0.03112154	-2.758×10^{-4}	-6.979×10^{-6}	8.3062×10^{-8}

$$J_r = \left(A + B\,\mathrm{Re}_c + C\,\mathrm{Re}_c^2 + D\,\mathrm{Re}_c^3\right) + \left(E + F\,\mathrm{Re}_c + G\,\mathrm{Re}_c^2 + H\,\mathrm{Re}_c^3\right) J_r^* + \left(I + J\,\mathrm{Re}_c + K\,\mathrm{Re}_c^2 + L\,\mathrm{Re}_c^3\right) J_r^{*2} + \left(M + N\,\mathrm{Re}_c + O\,\mathrm{Re}_c^2 + P\,\mathrm{Re}_c^3\right) J_r^{*3} \quad (10)$$

In the previous equation, J_r^* is calculated by Equation (9). Comparing both graphics, the original and that one obtained by Equation (10), it is observed as maximum error 3.8%.

2.6. Correction Factor by Uneven Baffle Spacing at the Inlet and/or Outlet, J_s

This factor has an effect when exist a different baffle distribution at the inlet and/or outlet and along the tube bundle and it is computed by Equation (11):

$$J_s = \frac{(N_b - 1) + \left(l_{s,I}^*\right)^{1-n''} + \left(l_{s,o}^*\right)^{1-n''}}{(N_b - 1) + l_{s,I}^* + l_{s,o}^*} \quad (11)$$

where n'' = 0.6 for turbulent flow and ($\mathrm{Re}_c > 100$).
n'' = 1/3 for laminar flow and ($\mathrm{Re}_c < 100$).

2.7. Correction Factor by Friction of an Ideal Bank Tubes f_i

The correction factor by friction in a triangular and rotated square set is determined in function of Re_c and the constants presented in **Table 7** by the Equation (12).

$$f_i = \exp\left\{\mathrm{A} + \mathrm{B}\ln(\mathrm{Re}_c) + \mathrm{C}\ln(\mathrm{Re}_c)^2 + \mathrm{D}\ln(\mathrm{Re}_c)^3 + \mathrm{E}\ln(\mathrm{Re}_c)^4 + \mathrm{F}\ln(\mathrm{Re}_c)^5 + \mathrm{G}\ln(\mathrm{Re}_c)^6 + \mathrm{H}\ln(\mathrm{Re}_c)^7 + \mathrm{I}\ln(\mathrm{Re}_c)^8 + \mathrm{J}\ln(\mathrm{Re}_c)^9\right\} \quad (12)$$

A maximum error of 4.9% is result of comparing the original graph to that one obtained by Equation (12).

2.8. Pressure Loss Correction Factor by Tube-Baffle Leakage R_l

The introduction of this correction factor is due to the leakage of the tube bundle and it is computed by Equation (13) which is in terms of $S_1 = S_{sb}/(S_{sb} + S_{tb})$ and $S_2 = (S_{sb} + S_{tb})/S_m$.

$$R_l = \left[\mathrm{A} + \mathrm{B}(S_1) + \mathrm{C}(S_1)^2 + \mathrm{D}(S_1)^3\right] + \left[\mathrm{E} + \mathrm{F}(S_1) + \mathrm{G}(S_1)^2 + \mathrm{H}(S_1)^3\right] S_2 + \left[\mathrm{I} + \mathrm{J}(S_1) + \mathrm{K}(S_1)^2 + \mathrm{L}(S_1)^3\right](S_2)^2 + \left[\mathrm{M} + \mathrm{N}(S_1) + \mathrm{O}(S_1)^2 + \mathrm{P}(S_1)^3\right](S_2)^3 \quad (13)$$

The constants required by the equations are established in **Table 8**. Comparing the original graph and that one obtained by Equation (13) is observed a maximum error of 4.5%.

Table 7. Constants for the equation for the correction factor f_i.

Type arrangement, outside diameter and pitch between tubes							
Arrangement	Diameter	Pitch	A	B	C	D	E
Triangular	19.05 mm	23.8125 mm	4.15076	−0.675323	−0.254615	0.0590471	−0.00431448
Triangular	25.4 mm	31.75 mm	4.15076	−0.675323	−0.254615	0.0590471	−0.00431448
Rhombic	19.05 mm	25.4 mm	3.69311	−1.18662	0.281179	−0.136488	0.0280708
Triangular	19.05 mm	25.4 mm	3.85004	−0.609235	−0.278939	0.0630913	−0.00452036
Rhombic	25.4 mm	31.75 mm	3.97656	−0.796179	−0.1565	0.0319655	−0.00143937
Square	19.05 mm	25.4 mm	3.76203	−0.9323	−0.0827537	0.0678788	−0.0281861
Square	25.4 mm	31.75 mm	3.99352	0.768721	−0.32634	0.176985	−0.0326325
Type arrangement, outside diameter and pitch between tubes							
Arrangement	**Diameter**	**Pitch**	**F**	**G**	**H**	**I**	**J**
Triangular	19.05 mm	23.8125 mm	0.000102933	0	0	0	0
Triangular	25.4 mm	31.75 mm	0.000102933	0	0	0	0
Rhombic	19.05 mm	25.4 mm	−0.00237654	0.0000713989	0	0	0
Triangular	19.05 mm	25.4 mm	0.000103903	0	0	0	0
Rhombic	25.4 mm	31.75 mm	0.00547024	−0.000459287	0.000013822	0	0
Square	19.05 mm	25.4 mm	−0.00409219	0.00245958	0.0003604	0.0000227548	-5.37988×10^{-7}

Table 8. Constants for the equation for the correction factor R_l.

Values of S_1	A	B	C	D	E	F	G	H
0 to 0.3	0.9930511	0.04163241	−0.07862612	0.01413662	−4.092978	−6.546514	4.516072	−2.525205
0.3 to 0.8	0.7499537	−0.4381533	0.2981431	0.1471556	−0.709333	0.0847061	1.053554	−4.215857
Values of S_1	I	J	K	L	M	N	O	P
0 to 0.3	15.6087	30.3289	−23.86598	14.08358	−23.22663	−41.67332	24.92778	−15.50438
0.3 to 0.8	0.3060496	1.27137	−12.85256	19.67211	−0.212271	−3.186438	18.491314	−23.16708

2.9. Pressure Loss Correction Factor by Recirculation Effect R_b

This correction factor is provoked by circulation currents in the heat exchanger and it is computed by Equation (14) which is in terms of F_{sbp} and $N_2 = N_{ss}/N_c$.

$$\begin{aligned} R_b = {} & \left[\mathrm{A}+\mathrm{B}(N_2)+\mathrm{C}(N_2)^2+\mathrm{D}(N_2)^3+\mathrm{E}(N_2)^4\right]+\left[\mathrm{F}+\mathrm{G}(N_2)+\mathrm{H}(N_2)^2+\mathrm{I}(N_2)^3+\mathrm{J}(N_2)^4\right]F_{sbp} \\ & +\left[\mathrm{K}+\mathrm{L}(N_2)+\mathrm{M}(N_2)^2+\mathrm{N}(N_2)^3+\tilde{\mathrm{N}}(N_2)^4\right]F_{sbp}^2+\left[\mathrm{O}+\mathrm{P}(N_2)+\mathrm{Q}(N_2)^2+\mathrm{R}(N_2)^3+\mathrm{S}(N_2)^4\right]F_{sbp}^3 \\ & +\left[\mathrm{T}+\mathrm{U}(N_2)+\mathrm{V}(N_2)^2+\mathrm{W}(N_2)^3+\mathrm{X}(N_2)^4\right]F_{sbp}^4 \end{aligned} \tag{14}$$

The constants demanded by the equation are defined in **Table 9** and they are in terms of Re_c number. Comparing the original graph and that one obtained by Equation (14), the maximal error found is 1.3%.

2.10. Pressure Loss Correction Factor by Uneven Baffle Spacing at the Inlet and Outlet

This correction factor is proposed by the uneven baffle spacing at inlet and outlet of the heat exchanger and this factor is calculated by Equation (15).

$$R_s = \frac{1}{2}\left[\left(l_{s,I}^*\right)^{-n'}+\left(l_{s,o}^*\right)^{-n'}\right] \tag{15}$$

where $n' = 1.6$ for turbulent flow ($\mathrm{Re}_c > 100$).
$n' = 1$ for laminar flow ($\mathrm{Re}_c < 100$).

3. Calculus Program

Having the correction factors in an analytical form, it was developed a calculus program using the FORTRAN 77 language which will design quickly the shell and tubes heat exchanger through the improvement DELAWARE Method. This computing program is described next:

Flow Chart Program

The flow chart used for the shell and tubes heat exchanger is presented in **Figure 2**.

As from this flow chart, it was made the heat exchanger design program using the executable BELL since it runs in MS DOS platform.

4. Conclusions

This work has presented the improvements to the Delaware method for the shell and tube heat exchanger design. These improvements were made up not only of obtaining the correction factor equations which were only available in graphic forma but also of developing the computing program in Fortran 77 language.

Thus, a new and easy tool for the shell and tubes heat exchanger design is available which allows accomplishing the numerical computing in a quick form minimizing the errors of the graphical lecture. This system gives the opportunity to explore different design alternatives in order to find the optimal solution to each proposed problem.

Recent years, heat exchanger is often used for the request of technology. But the relevant design is not provided by the actual standards. This work presents the improvements to the Delaware method for the shell and

Table 9. Constants for the equation for the correction factor R_b.

For	A	B	C	D	E	F	G	H	I
$Re_c > 100$	0.9999956	0.02427714	−0.2498571	0.87688954	−0.9389413	−3.7854133	42.7281376	−285.42201	841.836875
$Re_c < 100$	0.9989929	0.10536115	−0.8164392	2.13589149	−1.8323906	−4.7393642	60.6001915	−402.43318	1138.26259
For	**J**	**K**	**L**	**M**	**N**	**Ñ**	**O**	**P**	**Q**
$Re_c > 100$	−823.25082	6.9400004	−114.27156	831.289197	−2493.3366	2464.67857	−7.1165478	129.6448	−995.82525
$Re_c < 100$	−1075.7794	11.8151337	−238.94173	1739.20139	−4979.2121	4724.16651	−17.614757	423.093405	−3227.2538
For	**R**	**S**	**T**	**U**	**V**	**W**	**X**		
$Re_c > 100$	3071.9304	−3083.9014	3.21390213	−60.119316	480.616728	−1521.5693	1550.23124		
$Re_c < 100$	9354.34611	−8902.6809	11.6766845	−302.46692	2376.53333	−6980.2925	6687.42629		

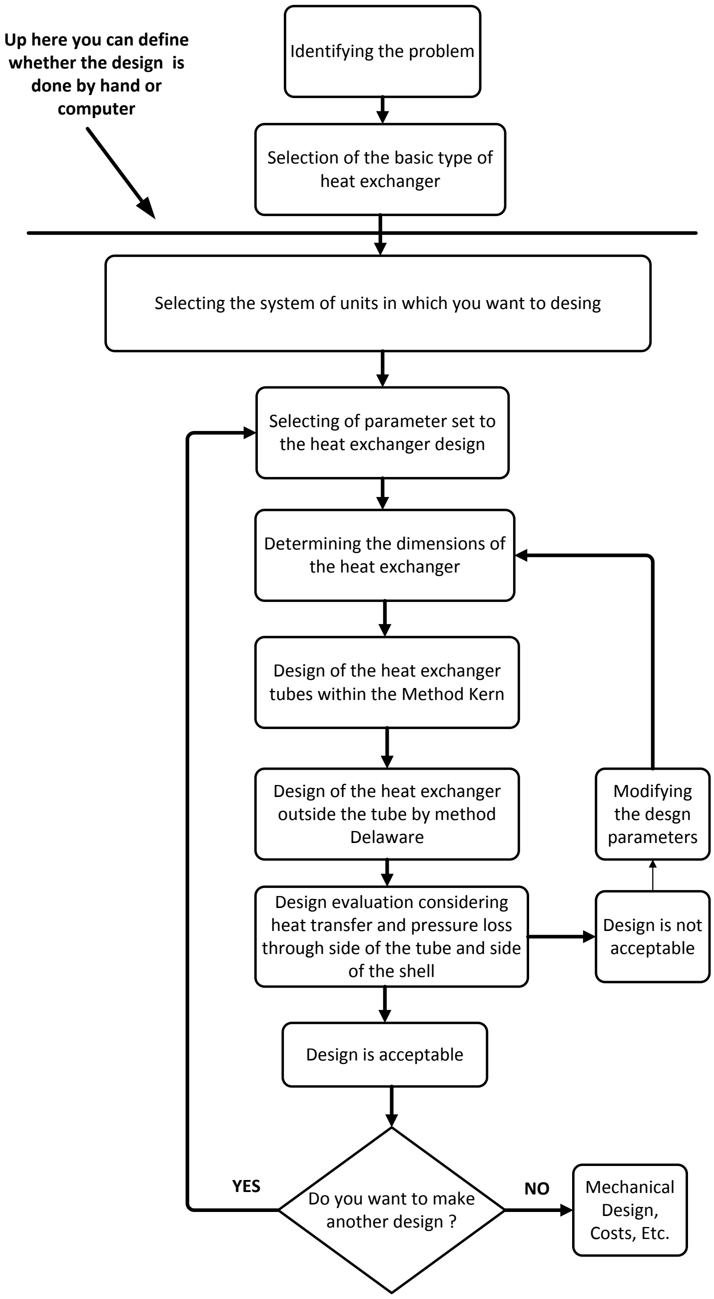

Figure 2. Flow chart program.

tube heat exchanger design.

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Nomenclature

ρ_c	Fluid density.
μ_c	Average fluid viscosity.
$\Delta P_{b,i}$	Pressure loss in a cross-flow section.
ΔP_c	Total pressure loss on the side of the shell.
$\Delta P_{w,i}$	Pressure loss in a window section.
μ_{wc}	Fluid Viscosity wall temperature.
A	Heat transfer area.
Cp_c	Specific heat.
e_t	Tube thickness.
F_c	Total fraction of tubes in cross flow.
F	Correction factor heat exchanger configuration.
f_i	Correction factor due to friction.
F_{sbp}	Fraction cross flow area available for recirculation flow.
g	Acceleration of gravity.
h_{cc}	Fluid convection coefficient outside the tubes.
h_{io}	Convection coefficient of the fluid by the tube side.
J_r^*	Basic correction factor for adverse effect of the temperature gradient.
J_b	Correction factor recirculation effect.
J_c	Effect correction factor baffle configuration.
J_i	Correction factor due to friction.
J_l	Correction factor for leakage effect.
J_r	Correction factor adverse effect of the temperature gradient.
J_s	Correction factor for baffle uneven spacing effect on entry and exit.
k	Thermal conductivity of the tube material.
k_c	Thermal conductivity of the fluid.
$l_{s,o}^* = l_{s,I}^* = l_{s,o}/l_s = l_{s,I}/l_s$	
l_s	Spacing between baffles.
$l_{s,I}$, $l_{s,o}$	Spacing of baffles at the entrance and exit.
N_b	Number of baffles.
N_c	Number of rows in cross flow section.
N_{cw}	Number of rows in section window.
N_{ss}	Numbers Stamp/sides sealed.
N_t	Number of tubes.
Q	Heat flux exchanged.
R_b	Correction factor recirculation effect.
R_d	Total coefficient of fouling.
Re_c	Reynolds number.
R_l	Correction factor for leakage effect.
R_s	Correction factor adverse effect of the temperature gradient.
S_{sb}	Correction factor for baffle uneven spacing effect on entry and exit.
S_{tb}	Thermal conductivity of the tube material.
T_{mlc}	Thermal conductivity of the fluid.
U_{dc}	Spacing between baffles.
W_c	Spacing of baffles at the entrance and exit.