

# Design, Development and Analysis of Shell and Tube Heat Exchanger Using Computational Fluid Dynamics

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**ABSTRACT:** In the textile industry hot water is required for dyeing process so a boiler is used to heat the water. To increase the efficiency of boiler supply water should be preheated. So to pre-heat the supply water shell and tube heat exchanger is can be used. After dyeing process the left hot water is drained into sewage, this hot water can be utilized to pre-heat the supply (incoming) water of boiler. The heat exchanger is designed with standard procedure and then according to the dimensions heat exchanger is manufactured and with the same values a CFD model is generated. The experimental results and CFD results were compared and some conclusions were made.

**KEYWORDS:** design of heat exchanger, shell & tube heat exchanger, CFD analysis, development, performance evaluation

## I. INTRODUCTION

A heat exchanger is a device that is used to transfer thermal energy between two or more fluids, through a solid surface and a fluid, or between solid and fluid, at different temperatures and in thermal contact. There are usually no external heat and work interactions. In general, if the fluids are immiscible, the separating wall may be eliminated, and the interface between the fluids replaces a heat transfer surface, as in a direct-contact heat exchanger [3]. A heat exchanger consists of heat transfer elements such as a core or matrix containing heat transfer surface, and fluid distribution elements such as headers, manifolds, tanks, inlet and outlet nozzles or pipes, or seals. Usually, there are no moving parts in a heat exchanger [3, 11].

## II. LITERATURE REVIEW

Wang, S., et. al. [1] performed an experimental investigation of shell and tube heat exchanger for heat transfer enhancement, configuration of a shell and tube heat exchanger improved through installation of sealers at shell side. The gap is blocked between baffle plates and shell by sealers. Shell side heat transfer coefficient by 18.2–25.5%, overall coefficient of heat transfer by 15.6–19.7%. Magadum, A., et. al. [2] experimentally investigated tube in tube heat exchanger with parallel and counter flow arrangements. Heat transfer rate was found more in counter flow nearly by 30% compared to parallel flow. LMTD increases discharge and efficiency increases this was conclusion of their work. Sangsawang r., et. al. [4] studied plate type heat exchanger channels of isosceles triangular geometry. The cross section of plates is of isosceles triangle with an apex. Analytical and experimental solutions are made by varying the apex angle by 30°, 60°, 90°, 120°. As the apex angle goes on increasing the temperature difference also goes on increasing. Kulkarni, V., P., et. al. [5] Design and analysis of double spiral counter flow heat exchanger using CFD. Strip is used for passage of fluid and it is constructed on a target plate Due to the spiral shape used the fluids flow

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through the periphery of strip experiencing a centrifugal force due to which velocity rate is increased and heat transfer rate increases. **Ananth, S., et. al. [6]** Analysis of overall heat transfer coefficient and effectiveness in split flow heat exchanger using nano fluids is done in this, different fluids are used for cooling like tap water, distilled water, mixture of ethylene glycols and water for experiment. Results are compared; result shows that using mixture as cooling fluid gives more heat transfer rate. **Shinde, S., S., et. al. [7]** designed shell and tube HE in which helical baffles are introduced in shell by 20° inclination angle due to this velocity of fluid increases because of this heat transfer rate gets increased. The velocity is increased by increasing inclination angle. **Lunsford, K., M., et. al. [8]** discussed about enhancement of heat exchanger, the fouling factor plays vital role for reducing performance of heat exchanger by creating resistance to heat transfer which can be reduced by providing radial flow from the centre of the wall, due to this material deposition on wall get decreases. **Ahire, S., et. al. [9]** constructed and analysed counter flow helical coil heat exchanger. Helical coil shape is given to tubes. They found that centrifugal force due to curvature of tubes results in secondary flow development, this secondary flow enhances heat transfer rate. Conclusion of their work was helical coils are efficient in low Reynolds number. **Zhang, J., F., et. al. [10]** for developing a shell and tube heat exchanger with middle overlapped baffles, a comprehensive simulation model by using commercial code FLUENT and grid generation program GAMBIT. The validation of 40° helix angle is performed and results which got those shown a reasonable agreement with available experiment data. **Kundu, B., [12]** designed Un-baffled shell and tube heat exchanger with attachments of longitudinal fins having trapezoidal profile; a parametric variation studied by Kern's method. While keeping the outer shell diameter is a constant along with all other constraints, the HEAT TRANSFER rate in trapezoidal fins was lesser than rectangular cross section of a heat exchanger. **Maheshwari, D., A., and Trivedi, K., M., [13]** they did experimental investigation of U tube HE using plain and corrugated structure of tube. Corrugated tube heat exchanger gives more heat transfer coefficient and heat transfer rate than straight heat transfer tube heat exchanger. **Logeshan, K., L., et. al. [14]** studied how to increase fluid velocities which results in large heat transfer coefficient and consequently less heat transfer area. **Guo, J., et. al. [15]** developed a new heat exchanger based on second law of thermodynamics. In this approach, modified entropy generation amount which can avoid entropy creation is taken as the objective function. **Boda, M., A., et. al. [19]** according to this article daily 840 m<sup>3</sup> waste water is released from the textile industry this waste water is left in sewage after filtration is done.

### III. DESIGN OF HEAT EXCHANGER

The design part it plays a very important role in any system. The detailed design of a shell and tube heat exchanger is discussed below, in that some data considered and assumed wherever it is required.

#### 3.1 Considerations for Heat Exchanger [20, 21]

- i. **Temperature-** The cold inlet temperature is taken as 29°C and the cold outlet temperature is 40°C. The hot inlet temperature is taken as 60°C.
- ii. **Mass flow rate-** For cold water is taken as 0.015 and hot water is 0.030kg/s.
- iii. **Tube-** Four copper tubes 0.0127meter diameter is used.

#### 3.2 Assumptions [20, 21]

- i. The fluid flow and heat transfer processes are turbulent and in steady state.
- ii. The natural convection induced by the fluid density variation is neglected.
- iii. The tube wall temperature kept constant in the whole shell side.

#### 3.3 Design of shell and tube heat exchanger component

The design part it plays a very important role in any engineering. The detailed design of a shell and tube heat exchanger is discussed below, in that some data assumed wherever it is required.

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### 3.3.1 Preliminary Stage [16, 17, 18]

- Heat transfer rate

$$Q = \dot{m}C_p \Delta T = 0.015 \times 4179 \times (29 - 40) = 690$$

- Calculate over all heat transfer coefficient

Assume over all heat transfer coefficient from the table given below [18, 22]  
 $U_o = 1300$

- Calculate log mean temperature difference

$$\Delta T_{lm} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln \left( \frac{T_{hi} - T_{ci}}{T_{ho} - T_{ci}} \right)} = \frac{(60 - 40) - (55 - 29)}{\ln \frac{60 - 40}{55 - 29}} = 22.86$$

- Calculate Provisional length

$$A_o = \frac{Q}{U_o \Delta T_{lm}} = \frac{690}{1300 \times 22.86} \times 0.023$$

- Calculate dimensions of heat exchanger

To calculate shell diameter and no. of tubes for single pass take

CTP=0.93 this value is for single tube pass, CL=1 this value is for 45° and 90° degree tube layout

$$PR = \frac{P_T}{d_o} = \frac{2.54}{1.27} = 2$$

$$D_s = 0.637 \sqrt{\frac{CL}{CTP} \left( \frac{A_o (PR)^2 d_o}{L} \right)} = 0.637 \sqrt{\frac{1}{0.93} \left( \frac{0.023(2)^2 \times 0.0127}{0.15} \right)} = 0.062$$

Assume L=0.15

$$N_t = 0.785 \left( \frac{CTP}{CL} \right) \frac{D_s^2}{(PR)^2 d_o^2} = 0.785 \left( \frac{0.93}{1} \right) \frac{(0.062)^2}{(2)^2 (0.0127)^2} = 4$$

- $B = 0.6D_s = 0.6 \times 0.060 = 0.036$

Now rate the heat exchanger according to TEMA standard and recalculate the length of heat exchanger, from Table number 8.3, page number 293, [18]

### 3.3.2 Secondary Stage [16, 17, 18]

- Calculate heat transfer coefficient

Shell side heat transfer coefficient

$$D_e = \frac{4(P_T^2 - \pi d_o^2 / 4)}{\pi d_o} = \frac{4(2.54^2 - \pi \times 0.0127^2 / 4)}{\pi \times 0.0127} = 0.051$$

$$C = P_T - d_o = 0.0254 - 0.0127 = 0.0127$$

$$A_s = \frac{D_s C B_s}{P_T} = \frac{0.060 \times 0.0127 \times 0.036}{0.0254} = 1.08 \times 10^{-3}$$

$$G_s = \frac{\dot{m}_s}{A_s} = \frac{0.030}{1.08 \times 10^{-3}} = 27.77$$

$$R_e = \frac{G_s D_e}{\mu} = \frac{27.77 \times 0.051}{4.66 \times 10^{-4}} = 3039.20$$

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$$N_u = 0.36(R_e)^{0.55} (p_r)^{0.33} = 0.36(3039.2)^{0.55} (2.99)^{0.33} = 42.58$$

.....for  $2 \times 10^3 < R_e < 10^6$

$$h_o = \frac{N_u K}{D_e} = \frac{42.58 \times 0.651}{0.051} = 543$$

Tube side heat transfer coefficient, Take  $C_p, \rho, \mu, P_r$  at cold fluid mean temperature from appendix Table B.2 [15]

$$A_p = \frac{\pi d_i^2 N_t}{4} = \frac{\pi \times 0.0127^2 \times 4}{4} = 5 \times 10^{-4}$$

$$v = \frac{\dot{m}_t}{\rho_t A_p} = \frac{0.015}{998 \times 5 \times 10^{-4}} = 0.033$$

$$R_e = \frac{\rho v d_i}{\mu} = \frac{998 \times 0.033 \times 0.012}{0.618} = 563$$

$$N_u = (3.66^3 + 1.61^3 (R_e P_r d_i / L))^{0.33} = 3.66^3 + 1.61^3 (563 \times 5.57 \times 0.012 / 0.15)^{0.33} = 10$$

$$h_i = \frac{N_u K}{d_i} = \frac{10 \times 0.651}{0.012} = 501$$

Over all heat transfer coefficient for fouled surface

$$U_f = \frac{1}{\frac{d_o}{d_i h_i} + \frac{d_o R_{ft}}{d_i} + \frac{d_o \ln(d_o / d_i)}{2K} + R_{fo} + \frac{1}{h_o}} = 230$$

Take  $R_{ft}$  and  $R_{fo}$  from table of fouling factor as 0.000176 for tap water.

8. To calculate tube length

$$A_{of} = \frac{Q}{U_{of} \Delta T_{lm}} = \frac{690}{230 \times 22.86} = 0.11$$

$$L = \frac{A_{of}}{\pi d_o N_t} = \frac{0.11}{\pi \times 0.0127 \times 4} = 0.62$$

9. Calculating number of baffles

$$N_b = \frac{L}{B} - 1 = \frac{0.61}{0.036} - 1 = 16$$

### IV. EXPERIMENTAL SET-UP

The fig shows the actual experimental set up of shell and tube heat exchanger. The shell and tube heat exchanger consists of shell of length 0.61m and 0.064 m diameter; the material of shell is steel. 4 copper tubes having 386w/m.K thermal conductivity of length 0.61m and 0.0127 m diameter are arranged in square pitch layout, the tubes are placed in shell. 16 baffles are arranged inside the shell with segmental type arrangement; the spacing between two baffles is 0.036m. The material of baffle is steel. The baffle has semicircle shape of radius 0.030m. In this heat exchanger hot water is made to flow in shell side and cold water is flow in tube side. Geyser used for heating the water. The geyser used is of 3000W capacity and can heat the water up to 100°C. The outlet of geyser is connected to inlet of shell. Two flow control valves are used in the system to control the flow of water, one for controlling hot water in shell side and one for cold water in tube side.

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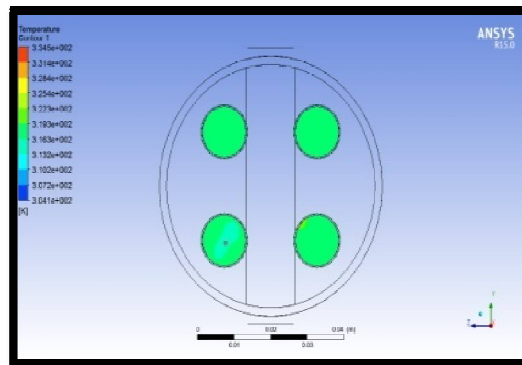


Fig1: Actual Experimental Set-Up

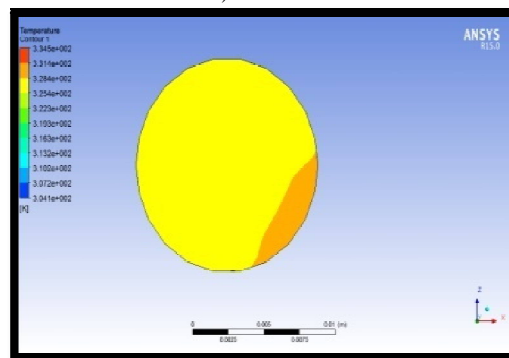
The above figure shows pictorial view of shell and tube heat exchanger's experimental setup. This contains shell, tube and baffles inside the shell, temperature indicator, geyser, inlet-outlet piping system, etc.

### V. CFD ANALYSIS

The following figures shows the results of shell side and tube side temperature distribution, these results got from CFD software as a analysis tool. Figure "a" is cold outlet and figure "b" is hot outlet in all figures.



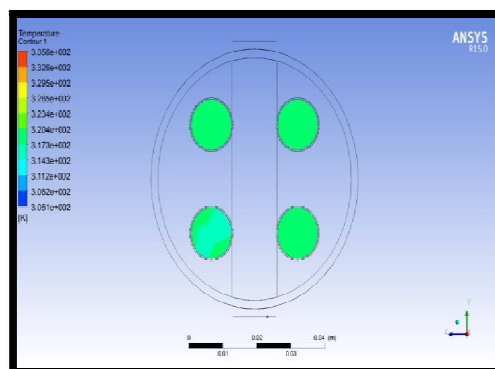
a) Cold outlet



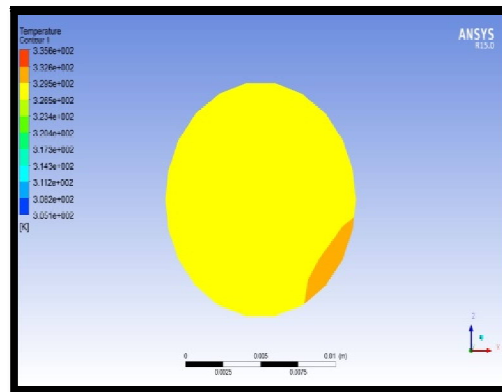
2. b) Hot outlet

Fig 2: Temperature Variation in Counter Flow Arrangement, were mass flow rate of shell side and tube side are 0.030kg/s and 0.015kg/s respectively.

The figure 2 shows a temperature variation of shell and tube heat exchanger of counter flow arrangement. Figure 2a shows cold outlet temperature at mass flow rate of 0.030 kg/s and figure 2b shows hot outlet temperature at mass flow rate of 0.015 kg/s. The colour indicates the temperature range and colour difference shows temperature variation.



3. a) Cold outlet



3. b) Hot outlet

Fig. 3: Temperature Variation in Parallel Flow Arrangement, were mass flow rate of shell side and tube side are 0.030kg/s and 0.015kg/s respectively

The figure 3 shows a temperature variation of shell and tube heat exchanger of parallel flow arrangement. Figure 3a shows cold outlet temperature at mass flow rate of 0.030 kg/s and figure 3b shows hot outlet temperature at mass flow rate of 0.015 kg/s. The colour indicates the temperature range and colour difference shows temperature variation.

**CFD Results**

The table numbers 1 to 4 are observation tables of CFD results.

Table 1: Observation from CFD of temperature with respect to mass flow rate in shell side in counter flow arrangement

Sr. No.	$m_h$ (kg/s)	$T_{hi}$ ( $^{\circ}$ C)	$T_{ho}$ ( $^{\circ}$ C)	$m_c$ (kg/s)	$T_{ci}$ ( $^{\circ}$ C)	$T_{co}$ ( $^{\circ}$ C)
1	0.020	61	50	0.015	31	42
2	0.030	61	52	0.015	31	43
3	0.040	61	53	0.015	31	45

The table 1 is Results of Counter flow arrangement were mass flow rate of shell side fluid (hot water) is varying from 0.020 kg/s, 0.030 kg/s and 0.040 kg/s but tube side fluid (cold water) is constant at 0.015kg/s.

Table 2: Observation from CFD of temperature with respect to mass flow rate in tubes side in counter flow arrangement

Sr. No.	$m_h$ (kg/s)	$T_{hi}$ ( $^{\circ}$ C)	$T_{ho}$ ( $^{\circ}$ C)	$m_c$ (kg/s)	$T_{ci}$ ( $^{\circ}$ C)	$T_{co}$ ( $^{\circ}$ C)
1	0.030	62	57	0.005	32	55
2	0.030	62	52	0.015	32	43
3	0.030	62	51	0.025	32	42

The table 2 is Results of Counter flow arrangement were mass flow rate of tube side fluid (cold water) is varying from 0.005 kg/s, 0.015 kg/s and 0.025 kg/s but shell side fluid (hot water) is constant at 0.015kg/s.

Table 3: Observation from CFD of temperature with respect to mass flow rate in shell side in parallel flow arrangement

Sr. No.	$m_h$ (kg/s)	$T_{hi}$ ( $^{\circ}$ C)	$T_{ho}$ ( $^{\circ}$ C)	$m_c$ (kg/s)	$T_{ci}$ ( $^{\circ}$ C)	$T_{co}$ ( $^{\circ}$ C)
1	0.020	61	51	0.015	31	41
2	0.030	61	53	0.015	32	44
3	0.040	61	54	0.015	32	46

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The table 3 is Results of Parallel flow arrangement were mass flow rate of shell side fluid (hot water) is varying from 0.020 kg/s, 0.030 kg/s and 0.040 kg/s but tube side fluid (cold water) is constant at 0.015kg/s.

Table 4: Observation from CFD of temperature with respect to mass flow rate in tube side in parallel flow arrangement

Sr. No.	$m_h$ (kg/s)	$T_{hi}$ ( $^{\circ}$ C)	$T_{ho}$ ( $^{\circ}$ C)	$m_c$ (kg/s)	$T_{ci}$ ( $^{\circ}$ C)	$T_{co}$ ( $^{\circ}$ C)
1	0.030	62	58	0.005	32	54
2	0.030	62	53	0.015	32	44
3	0.030	62	53	0.025	32	39

The table 4 is Results of Parallel flow arrangement were mass flow rate of shell side fluid (cold water) is varying from 0.005 kg/s, 0.015 kg/s and 0.025 kg/s but tube side fluid (hot water) is constant at 0.030 kg/s.

## Experimental results

The table numbers 5 to 8 are observation tables of experimental setup.

Table 5: Observation from experiment of temperature with respect to mass flow rate in shell side in counter flow arrangement

Sr. No.	$m_h$ (kg/s)	$T_{hi}$ ( $^{\circ}$ C)	$T_{ho}$ ( $^{\circ}$ C)	$m_c$ (kg/s)	$T_{ci}$ ( $^{\circ}$ C)	$T_{co}$ ( $^{\circ}$ C)
1	0.020	61	49	0.015	31	39
2	0.030	61	51	0.015	31	40
3	0.040	61	52	0.015	31	41

The table 5 is Results of Counter flow arrangement were mass flow rate of shell side fluid (hot water) is varying from 0.020 kg/s, 0.030 kg/s and 0.040 kg/s but tube side fluid (cold water) is constant at 0.015kg/s.

Table 6: Observation from experiment of temperature with respect to mass flow rate in tube side in counter flow arrangement

Sr. No.	$m_h$ (kg/s)	$T_{hi}$ ( $^{\circ}$ C)	$T_{ho}$ ( $^{\circ}$ C)	$m_c$ (kg/s)	$T_{ci}$ ( $^{\circ}$ C)	$T_{co}$ ( $^{\circ}$ C)
1	0.030	62	55	0.005	33	48
2	0.030	62	52	0.015	33	40
3	0.030	62	48	0.025	33	38

The table 6 is Results of Counter flow arrangement were mass flow rate of tube side fluid (cold water) is varying from 0.005 kg/s, 0.015 kg/s and 0.025 kg/s but shell side fluid (hot water) is constant at 0.015kg/s.

Table 7: Observation from experiment of temperature with respect to mass flow rate in shell side in parallel flow arrangement

Sr. No.	$m_h$ (kg/s)	$T_{hi}$ ( $^{\circ}$ C)	$T_{ho}$ ( $^{\circ}$ C)	$m_c$ (kg/s)	$T_{ci}$ ( $^{\circ}$ C)	$T_{co}$ ( $^{\circ}$ C)
1	0.020	61	50	0.015	31	39
2	0.030	61	52	0.015	32	41
3	0.040	61	53	0.015	32	44

The table 3 is Results of Parallel flow arrangement were mass flow rate of shell side fluid (hot water) is varying from 0.020 kg/s, 0.030 kg/s and 0.040 kg/s but tube side fluid (cold water) is constant at 0.015kg/s.



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Table 8: Observation from experiment of temperature with respect to mass flow rate in tube side in parallel flow arrangement

Sr. No.	$m_h$ (kg/s)	$T_{hi}$ ( $^{\circ}$ C)	$T_{ho}$ ( $^{\circ}$ C)	$m_c$ (kg/s)	$T_{ci}$ ( $^{\circ}$ C)	$T_{co}$ ( $^{\circ}$ C)
1	0.030	62	57	0.005	32	52
2	0.030	62	52	0.015	32	41
3	0.030	62	51	0.025	32	38

The table 8 is Results of Parallel flow arrangement were mass flow rate of shell side fluid (cold water) is varying from 0.005 kg/s, 0.015 kg/s and 0.025 kg/s but tube side fluid (hot water) is constant at 0.030kg/s.

## VI. CONCLUSION

The parallel flow arrangement is less efficient than the counter flow arrangement as outlet temperature difference is more compared with counter flow arrangement. By increasing mass flow rate in shell side the heat transfer rate increases as the cold outlet temperature goes on increasing also reducing the mass flow rate in tube side heat transfer rate is increased. Reducing the mass flow rate in tube side the heat exchanger becomes more efficient than the increased mass flow rate in shell side.

Table 9: Nomenclatures

Notation	Meaning	Notation	Meaning	Notation	Meaning
$A_{of}$	Heat transfer area with fouling based on outside surface area of tube, $m^2$	$A_{pt}$	Heat transfer area based on outside surface area of tube per number of tube passes, $m^2$	$\Delta T$	Temperature difference, $^{\circ}$ C
$A_o$	Heat transfer area based on outside surface tube area, $m^2$	$\phi_s$	Viscosity correction factor for shell side fluids	$\square T_{lm}$	Log mean temperature difference, $^{\circ}$ C
$C_p$	Specific heat, J/kgK	$\mu$	Dynamic viscosity N.s/ $m^2$	$P_T$	Pitch size, m
$B$	Baffle spacing, m	$K$	Thermal conductivity, W/m.K	$D_s$	Shell diameter, m
$C$	Clearance between tubes, m	$\rho$	Density, Kg/ $m^3$	PR	Pitch ratio
$T_{ho}$	Hot fluid outlet temperature, $^{\circ}$ C	$G_s$	Shell side mass velocity, Kg/ $m^2$ K	CL	Tube layout constant
$T_{ci}$	Cold fluid inlet temperature, $^{\circ}$ C	$T_{co}$	Cold fluid outlet temperature, $^{\circ}$ C	$\dot{m}_s$	Shell side mass flow rate, m/s
CTP	Tube count calculation constant	$t_1$	Tube side inlet temperature, $^{\circ}$ C	$\dot{m}_t$	Tube side mass flow rate, m/s
$T_{hi}$	Hot fluid inlet temperature, $^{\circ}$ C	$t_2$	Tube side outlet temperature, $^{\circ}$ C	$T_1$	Shell side inlet temperature, $^{\circ}$ C,
$D_e$	Equivalent Shell diameter, m	$N_b$	Number of baffles	$\Delta P_s$	Shell side pressure drop, $P_a$
$d_o$	Tube outer diameter, m	$N_p$	Number of tube passes	$P_r$	Prandtl number
$d_i$	Tube inside diameter, m	$T_w$	Wall temperature, $^{\circ}$ C, K		

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