Baffles Spacing Arrangement to Enhance Heat Transfer of a Shell and Tube Heat Exchanger

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Abstract: ***Heat exchangers are used to transfer heat between two fluids. The term exchanger applies to all equipment used to transfer heat between two streams. However, the term is commonly used to equipment in which two process streams exchange heat with each other. This research paper explains case study of fixed end shell and tube heat exchanger design with internal baffles different spacing arrangement. Additionally, understand effect of baffles where the flow become more turbulent that it will increase the heat transfer coefficient. The purpose of heat transfer enhancement, the configuration of a shell-and tube heat exchanger was improved by considering the baffles with different spacing.***

Keywords: Heat exchangers, coefficient of heat transfer, length of heat exchanger, baffles spacing

1. Introduction

Shell and tube heat exchanger is the most widely used heat exchangers and are among the most effective means of heat exchange. Shell and tube heat exchanger is a device where two working fluids exchange heats by thermal contact using tubes housed within a cylindrical shell. The fluid temperature inside the shell and tube are different and this temperature difference is the driving force for temperature exchange. Additionally, heat transfer from fluid to other inside the heat exchanger by convection and conduction together, where heat transfer between the fluid layer by convection and inside the tube by conduction

Baffles are mounted on the shell side to supply a higher heat transfer rate, consequently increasing turbulence of the flow. Also, these heat exchanger parts help to support the tubes and reduce problems due to vibration. Where, Baffles are used to change the directional flow of the fluid medium in shell side. Changing the direction ensures an even heat distribution throughout the heat exchanger.

Segmental baffles are the most used. They improve the heat transfer by enhancing fluid turbulence or local mixing on the shell side because of causing the shell side fluid to flow in a zigzag manner across the tube bundle. It also increases the pressure drop. As a result, it requires high pumping power, so it increases the electricity consumption.

2. Research Methods

Heat transfer mode in a shell-and-tube heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids. In the analysis of shell-and-tube heat exchangers, it is convenient to work with an overall heat transfer coefficient U that accounts for the contribution of all these modes at heat transfer. The rate of heat transfer between the two fluids at a location in a heat exchanger depends on the magnitude of the temperature difference at that location, which varies along the shell-and-tube heat exchanger. Therefore, in the heat transfer analysis of heat exchangers, it is convenient to establish an appropriate mean value of the temperature difference between the hot and cold fluids such that the total heat transfer rate Q& between the fluids, and that can be determined during the next equations.

$$Q^{\circ} = U \times As \times LMTD$$

Eqt 1

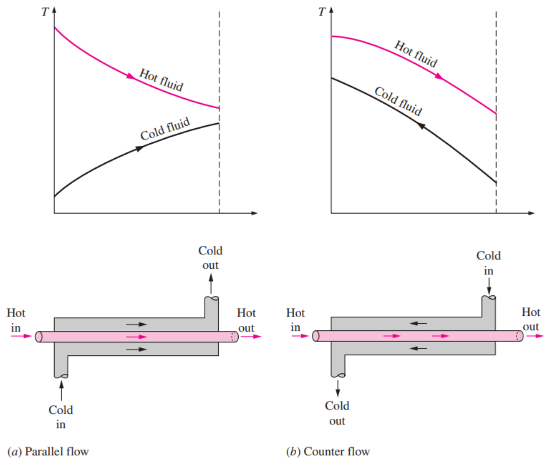
$$\frac{1}{UAs} = \frac{1}{hi\ Ai} + \frac{\ln\left(do/di\right)}{2\pi kL} + \frac{1}{ho\ Ao}$$

Eqt 2

A is the total hot-side or cold-side heat transfer area. U is the average overall heat transfer coefficient based on that area. ΔTLMTD is a function of Th_1, Th_2, Tc_1, and Tc_2 LMTD (Log Mean Temperature Difference) method is very suitable for determining the size of a heat exchanger to realize prescribed outlet temperatures, when the mass flow rates, the inlet, and outlet temperatures of the hot and cold fluids are specified.

$$LMTD = \frac{(\Delta T1 - \Delta T2)}{\ln\left(\Delta T1/\Delta T2\right)}$$

Eqt 3



(*a*) Parallel flow (*b*) Counter flow

Figure 1: Fluid flow stream

Where:

$$\Delta T1 = Th1 - Tc2$$

Eqt 4

$$\Delta T2 = Th2 - Tc1$$

Eqt 5

2. 1 Flow inside tubes:

$$Q^\circ = m^\circ 1 \ x \ cp1 \ x \ (Th1 - Th2)$$

Eqt 6

$$Q^\circ = \rho 1 \ xV^\circ 1 \ x \ cp1 \ x \ (Th1 - Th2)$$

Eqt 7

$$m^\circ = \rho \ x \ \frac{\pi}{4} \ x \ di^2 \ x \ Vm$$

Eqt 8

Where:
Vm, mean velocity inside tubes, m/sec.
Q° total heat removes, W.
$m^\circ 1$ industrial water flow rate, kg/sec.
$V^\circ 1$ industrial volume flow rate, m^3/sec.

$$Re = \frac{m^\circ \ x \ di}{Ac \ x \ \mu}$$

Eqt 9

R_e, Reynolds Number.
A_c, cross section area

$$Ac = \frac{\pi}{4} \ x \ di^2 \ x \ \frac{Nt}{Np}$$

Eqt 10

Nt, Number of tubes.
Np, number of passes.
The convective heat transfer coefficient hi is dependent upon the physical properties of the fluid inside tubes and the physical situation. For tube side the convective heat transfer coefficient, h_i can be calculated by

$$Nui = \frac{hi \ x \ di}{kf}$$

Eqt 11

Nui, Nusselt Number.
Kf, Thermal conductivity of fluid inside tubes, W/m · °C.
For fully developed turbulent flow with smooth surface we have

$$f = (0.790 \ x \ ln \ Re - 1.64)^{-2}$$

Eqt 12

$$10^4 < Re < 10^6$$

$$Nu = 0.125 \ f \ Re \ Pr^{1/3}$$

Eqt 13

$$Nu = 0.023 \ Re^{0.8} Pr^n$$

Eqt 14

$$0.7 < Pr < 160$$

$$Re < 10000$$

Where:
n=0.3 for cooling of fluid

$$Nu = \frac{\left(\frac{f}{8}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)}$$

Eqt 15

$$0.5 < Pr < 2000$$

$$3x \ 10^3 < Re < 5x \ 10^6$$

$$\Delta P = 4\left(\frac{f \ Lt}{di} + 1\right) xNp \ x \ \frac{1}{2} \ \rho \ Vm^2$$

Eqt 16

2. 2 Flow inside shell:

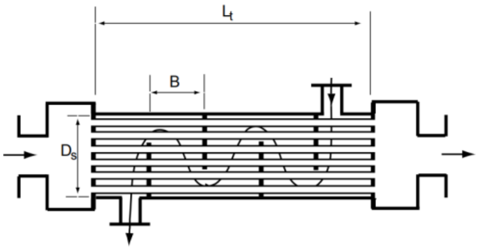


Figure 2: Shell and Tube heat exchanger

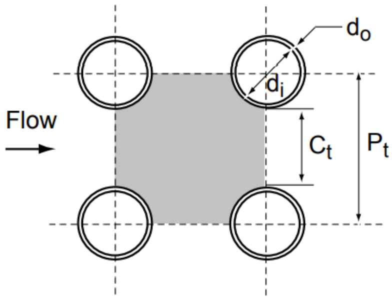


Figure 3: Square pitch layout

C_t, clearance
Lt = tube length
Nt = number of tubes
Np = number of pass
Ds = Shell inside diameter
Nb = number of baffles
B = baffle spacing
Pt, pitch

$$Pt = 1.25 \ x \ do$$

Eqt 17

$$Ct = Pt - do$$

Eqt 18

$$Nt = CTP \ x \ \frac{\pi}{4} \ x \ \frac{Ds^2}{shade \ area}$$

Eqt 19

where CTP is the tube count constant that accounts for the incomplete coverage of the shell diameter by the tubes, due to necessary clearance between the shell and the outer tube circle and tube omissions due to tube pass lanes for multiple pass design.
CTP = 0.93 for one-pass heat exchanger.

$$Shade \ area = Cl \ x \ Pt^2$$

Eqt 20

where C_L is the tube layout constant. CL = 1 for square-pitch layout.

$$Ds = \frac{4\left(Pt^2 - \frac{\pi \ do^2}{4}\right)}{\pi \ do}$$

Eqt 21

$$Ac = \frac{Ds \ Ct \ B}{Pt}$$

Eqt 22

$$B = \frac{Lt}{Nb + 1}$$

Eqt 23

$$Re = \frac{\rho \ x \ Vm \ x \ De}{\mu} = \frac{m^\circ \ x \ De}{Ac \ x \ \mu}$$

Eqt 24

The convective heat transfer coefficient h_o is dependent upon the physical properties of the fluid in the shell side and the physical situation. For shell side the convective heat transfer coefficient, h_o can be calculated by

$$Nuo = \frac{ho \ x \ De}{kf}$$

Eqt 25

$$Nu = 0.023 \, Re^{0.8} Pr^{n}$$

Eqt 26

$$0.7 < Pr < 160$$
$$Re < 10000$$

Where:
n=0.4 for heating of fluid.
Nusselt Number can calculate by using the previous empirical correlation no (15).

$$f = \exp\,(0.576 - 0.19 \ln Re)$$

Eqt 27

$$\Delta P = f \, \frac{Ds}{De} \, (Nb + 1) \frac{1}{2} \, \rho \, Vm^2$$

Eqt 28

3. Research Results

The Tables 1 and 2 shows the available design data and properties of both tube side and shell side fluids.

Table 1: Available design data

Data	Tube side	Shell side
Fluid Name	Industrial water	Child water
Mass flow rate	2.73 kg/sec	4.6 kg/hr.
Inlet temperature	30 C	6 C
Outlet temperature	20 C	12 C
d_i	9 mm	--
d_o	12 mm	--
D_s	--	210 mm
Inlet pressure	3 bars	4 bars

Balk temperature tube side, Tb1 = (30+20)/2 = 25 C
Balk temperature shell side, Tb2 = (6+12)/2 = 9 C

Table 2: Fluid's properties at balk temperature

Properties	Tb1 = 25 C	Tb2 = 9 C
Cp, **kJ/kg.C**	4.180	4.190
Thermal conductivity, K. **W/m · °C**	0.614	0.578
Dynamic viscosity, μ. **N s/m2**	0.8729 x 10^{-3}	0.0013060
Prandtl No, Pr.	6.13	9.46
Kinematic viscosity, υ, **m2 /s**	0.893 x 10^{-6}	1.3065 x 10^{-6}
Density, ρ, **kg/m³**	997.05	999.7

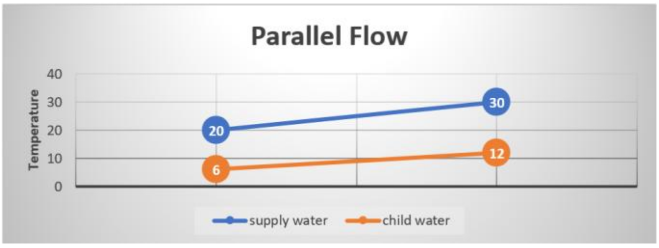


Figure 4: fluid flow temperature arrangement

3.1 Heat Exchanger Design Assumptions.

3.1.1 Flow stream is parallel,
3.1.2 Industrial supply water flow inside the tubes and child water inside shell,
3.1.3 Square pitch tubes layout,
3.1.4 Flow inside tubes and inside shell in one pass,
3.1.5 No change of viscosity due to change of water temperature inside tubes or inside shell,
3.1.6 No effect of fouling inside tubes or shell, and
3.1.7 The thickness of tubes very thin, the resistance of conduction is neglected.

Summary Design Calculation.

Table 3: Summary design data at different baffles spacing

Parameter	Design A	Design B	Design C	Design D
Baffles spacing, m	0.1	0.2	0.3	0.4
Coefficient of heat transfer inside tubes, h_i	4,987.4	4,987.4	4,987.4	4,987.4
Coefficient of heat transfer inside shell, h_o	22,778.4	11,732.1	7,799.2	5,748.1
Overall heat transfer coefficient, U	4,091.5	3,499.6	3,042.05	2,670.4
Reynolds No inside tubes	8,853.5	8,853.5	8,853.5	8,853.5
Reynolds No inside shell	24,520.8	12,260.4	8,173.6	6,130.2
Length of heat exchanger, L	0.94	1.09	1.26	1.44
No of baffles, Nb	10	6	5	4
Pressure drops in shell side, Kpa	91.55	16.3	6.3	3.3

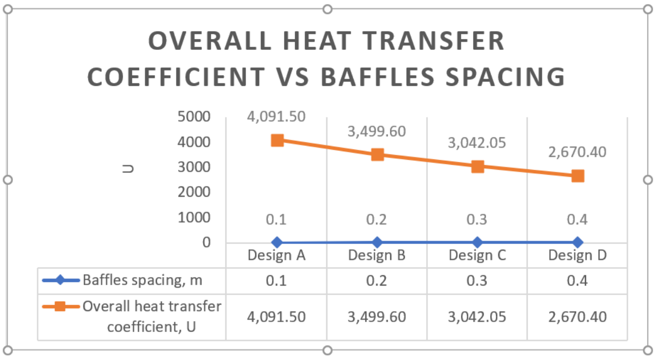


Figure 5: Overall H.T coefficient and baffles spacing

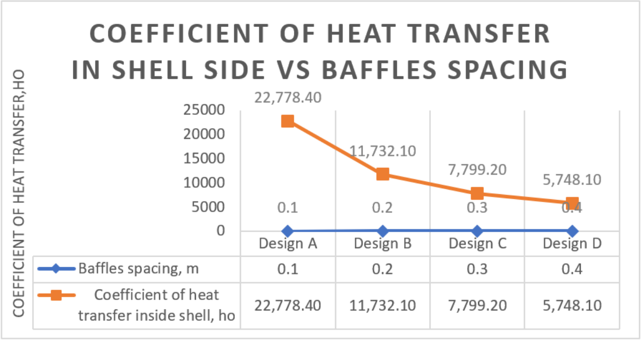


Figure 6: Coefficient of HT in shell and baffles spacing

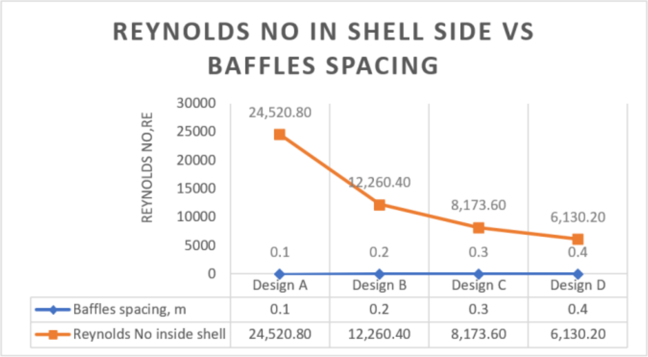


Figure 7: Reynolds No in shell and baffles spacing

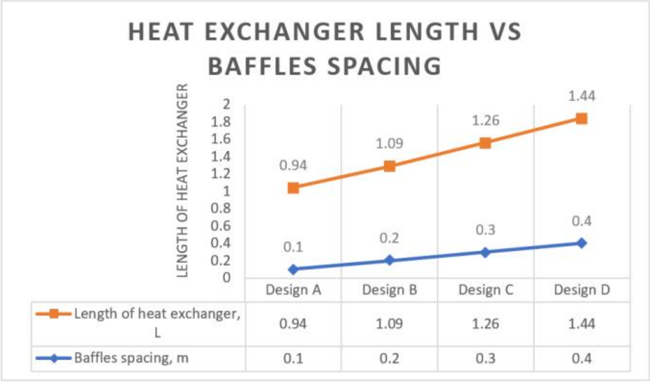


Figure 8: Length of HE and baffles spacing

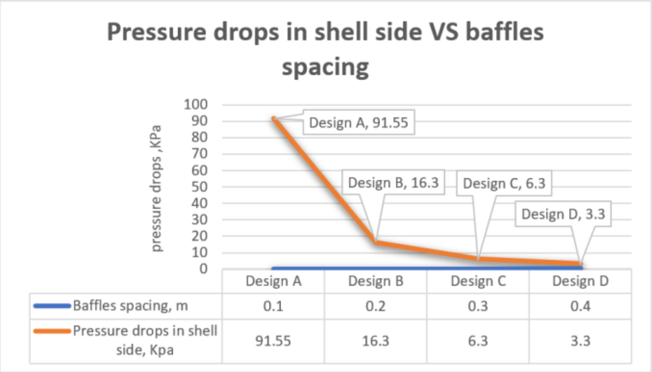


Figure 9: pressure drops in shell side and baffles spacing

4. Conclusions

In this paper we presented a detail design of a shell and tube heat exchanger for cooling line related to industrial water supply used for purified water treatment station, which is considered as an important plant in pharmaceuticals industries especially for medicine preparation purposes. The effects of changing single segmental baffle spacing of the exchanger on heat transfer and pressure drop have been studied. Therefore, we considered four designs that follows TEMA standard, From the results we noticed that between designs A and D the heat transfer coefficient of shell side decreases, and pressure drop of shell side decreases according to increase the baffles spacing. Additionally, Baffles can play a vital role in enhancing heat transfer by increasing velocity and direct the fluid stream. Single segmental considers as common baffle type.

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