Process Design of a Shell and Tube Heat Exchanger

<u>Group-6 Members</u>: -

Name-Yash Jhunjhunwala

Roll No.-18CH10070

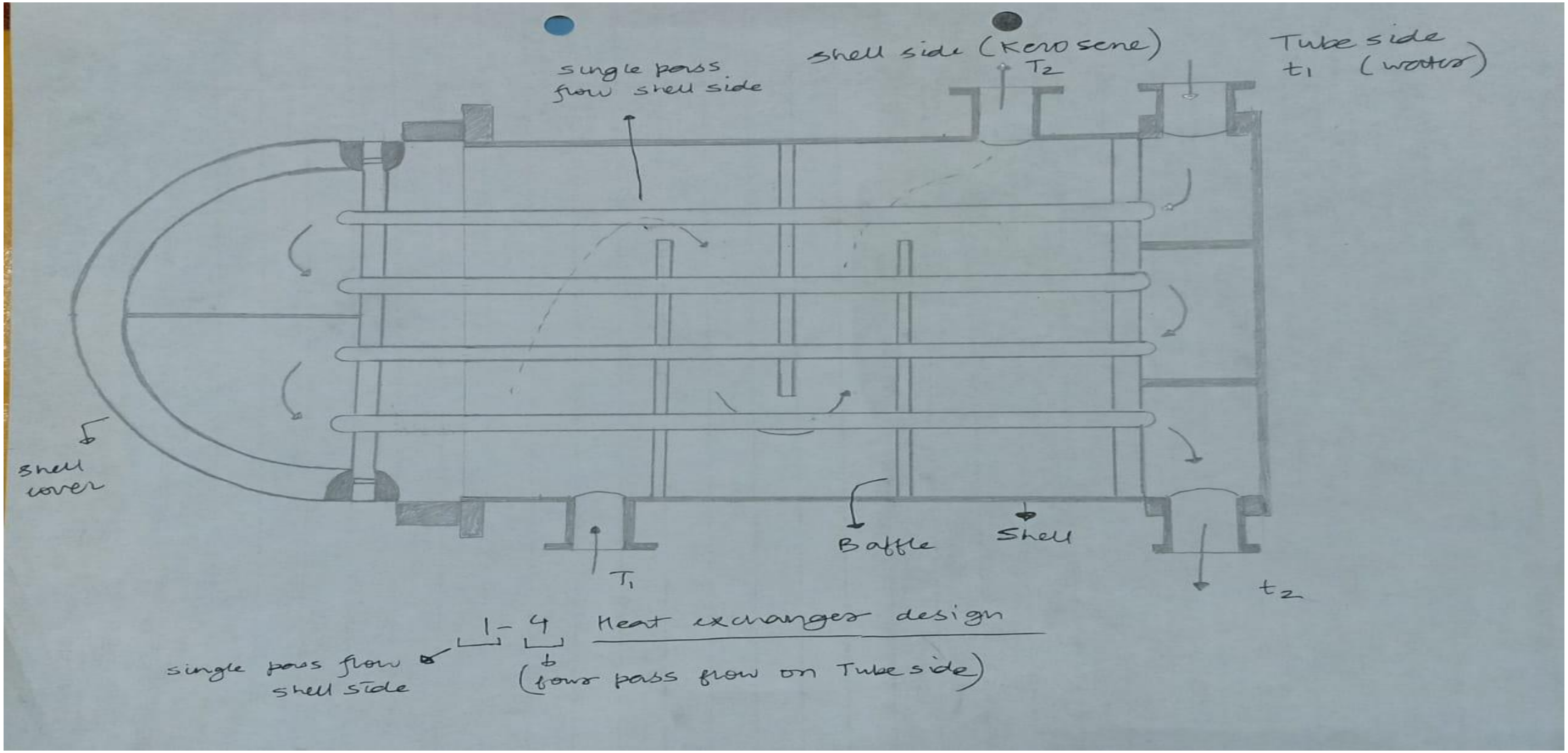
Name-Anshuman Agrawal

Roll no.-18CH10071

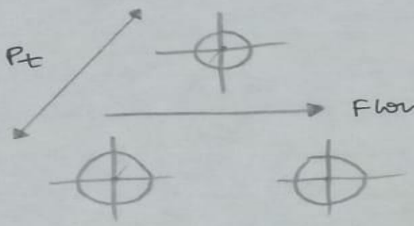
Problem Statement:

- Kerosene (42^{o} API) is required to be cooled from 110°C to 40°C by supplying cooling water (10^{o} API) stream from 33 °C to 45 °C.
- The maximum pressure drop of 0.7 kg/cm^2 for both streams is permissible.
- Design for a 1-2 shell and tube heat exchanger for this service.
- Flow rate of kerosene: - $\frac{75000}{Z}$+(500×Z) kg/h where Z is our group number.
- Considering 1’’ OD tubes on 1.25’’ triangular pitch, 16 ft length.

Schematics:

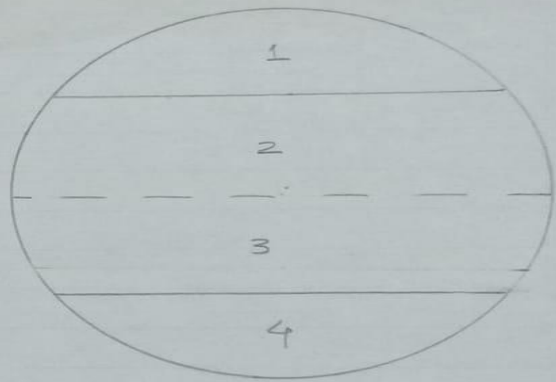


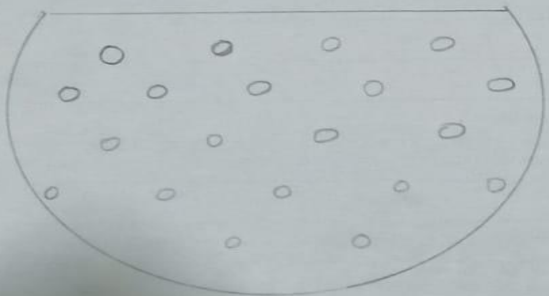
single pass
flow shell side
shell side (Kerosene)
T_2
Tube side
t_1 (water)
shell
cover
Baffle
Shell
T_1
t_2
1 - 4 Heat exchanger design
single pass flow
shell side
(four pass flow on Tube side)



(Tube pattern (Triangular))

(Four pass)





(25% baffle cut)

Reference :
Coulson and Richardson

Design Calculations to Follow from the Next Page….

Physical Properties :-

Tube side fluid : Water	Shell side fluid : ~~Kerosene~~ Kerosene
API : 10°	API : 42°
Inlet temperature = 33°C	Inlet temperature = 110°C
Outlet temperature = 45°C	Outlet temperature = 40°C
Mean temperature = 39°C	Mean temperature = 75°C
Density = 993 kg/m^3	Density = 775 kg/m^3
Absolute viscosity = 0.7 cp	Absolute viscosity = 1 cp
Specific heat capacity = 4179 J/kg°C	Specific heat capacity = 2155 J/kg°C
Thermal conductivity = 0.64 W/m°C	Thermal conductivity = 0.138 W/m°C
Fouling resistance = 0.00024 m^2 °C/W	Fouling resistance = 0.0002 m^2 °C/W
Mass flow rate = $\dot{m}_w$ kg/h	Mass flow rate = $\frac{75000}{Z} + (500 \times Z)$
$\therefore \dot{m}_w = 46625.49$ kg/hr.	$= \because Z = 6, \frac{75000}{6} + (500 \times 6)$
	$= 15500$ kg/h

~~Velocity~~

Heat balance :-

$\dot{m}_w \times 4179 \times (45 - 33) = 15500 \times 2155 \times (110 - 40)$

$\Rightarrow \dot{m}_w = 46625.49$ kg/hr

$\therefore \boxed{\dot{m}_w = 46625.49 \text{ kg/hr}}$

Heat duty :- $\dot{Q} = 15500 \times 2155 \times (110 - 40) / 3600$

$= 649.49$ kW.

Specifications of Exchanger :-

Type : Shell and Tube

No. of passes : 2

Material : Brass [Thermal conductivity (k_w) = 109 W/m°C]

Allowable pressure drop : 0.7 kg/cm^2 (in both shell and tube).

Tube OD = 1 inch

Pitch = 1.25 inch △ (triangular pitch).

Tube length = 16 ft. , Thickness = 15 BWG.

Heat duty = 649.49 kW.

$$LMTD = \frac{(110-33)-(45-40)}{\ln\left(\frac{100-33}{45-40}\right)} = 26.33°C.$$

For given pair of liquids,

Overall heat transfer co-efficient = $U_{o,assm}$ = 550 W/m^2°C

$$R = \frac{110-40}{45-33} = \frac{70}{12} = 5.83$$

$$S = \frac{45-33}{110-33} = \frac{12}{77} = 0.156$$

F_t = 0.75.

Heat Transfer area :-

$$A_o = \frac{649.49 \times 10^3}{550 \times 0.75 \times 26.33} = 59.8\ m^2.$$

No. of tubes :-

Area of 1 tube $= \pi \times (1 \times 25.4 \times 10^{-3}) \times (16 \times 12 \times 2.54 \times 10^{-3})$

$= 0.3892 \ m^2$.

No. of tubes $= \frac{59.8}{0.3892} \simeq 154$.

Standard no. of tubes for 1" OD, 1.25" pitch tube $= 152 = N_t$

Tube per pass $= \frac{152}{2} = 76$, Tube ID $= 0.856$ inch

Tube cross-sectional area $= \frac{\pi}{4} \times 0.856^2$

$= 0.576 \text{ inch}^2 = 3.72 \times 10^{-4} \ m^2$

Total area per pass $= 76 \times 3.72 \times 10^{-4}$

$= 0.028 \ m^2$

Tube side velocity $= \frac{46625.49}{3600} \times \frac{1}{0.028 \times 993}$

$= 0.466 \ m/s. \ (u_t)$.

Bundle and Shell diameter :-

$K_1 = 0.249, \ n_1 = 2.207$

shell ID standard value $= 19\frac{1}{4}$ inch

$= 0.49 \ m$

Bundle diameter $= (25.4 \times 1)\left(\frac{152}{0.249}\right)^{1/2.207}$

$= 0.464 \ m$

Clearance $= 0.056 \ m$

shell ID calculated $= 0.464 + 0.056 = 0.52 \ m$.

Tube-side heat transfer coefficient :-

$$Re = \frac{0.466 \times 993 \times 0.856 \times 0.0254}{7 \times 10^{-4}} = 14367.$$

$K_{tube} = 0.37\ Btu/hr\ ft\ ^\circ F = 0.64\ W/m^\circ C$

$$\frac{L}{d} = \frac{16 \times 12}{0.856} = 224.3$$

$$Pr = \frac{2.155 \times 10^3 \times 7 \times 10^{-4}}{0.64} = 4.57, \quad j_H = 0.004.$$

$$Nu = 0.004 \times 14367 \times (4.57)^{1/3} = 95.37$$

$$h_i = \frac{95.37 \times 0.64}{0.856 \times 0.0254} = 2807.2\ W/m^2\ ^\circ C$$

Shell-side heat transfer coefficient :-

$D_s = 0.52\ m$, Baffle spacing $(l_B) = 0.5 D_s$

$= 0.26\ m.$

Baffle cut $= 25\%$ ($\because$ 0.3 - 0.5 is an optimum factor).

$$A_s = \left(\frac{1.25 - 1}{1.25}\right) \times 0.52 \times 0.26 = 0.02704\ m^2$$

$$d_e = \frac{1.1}{1 \times 25.4}\left(1.25^2 - 0.917 \times 1^2\right) 25.4^2 \times 10^{-3}$$

$= 0.01804\ m.$

$$u_s = \frac{15500}{3600} \times \frac{1}{0.02704} \times \frac{1}{775}$$

$= 0.205\ m/s.$

$$Re = \frac{0.205 \times 775 \times 0.01804}{10^{-3}} = 2872.51$$

$K_{shell} = 0.138 \ W/m^\circ C$

$$Pr = \frac{2155 \times 10^{-3}}{0.138} = 15.62$$

$j_H = 1.1 \times 10^{-2} = 0.011$

$$h_o = \frac{0.138}{0.01804} \times 0.011 \times 2872.51 \times (15.62)^{1/3}$$

$$= 604.21 \ W/m^2 \, ^\circ C.$$

Overall co-efficient :-

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{od}} + \frac{d_o}{d_i}\left(\frac{1}{h_i} + \frac{1}{h_{id}}\right) + \frac{d_o \ln\left(\frac{d_o}{d_i}\right)}{2k_w}$$

$h_o = 604.21 \ W/m^2 \, ^\circ C$, $h_i = 2807.2 \ W/m^2 \, ^\circ C$,

$k_w = 109 \ W/m^\circ C$, $h_{id} = (0.00024)^{-1} \ W/m^2 \, ^\circ C$,

$h_{od} = (0.0002)^{-1} \ W/m^2 \, ^\circ C$.

$\Rightarrow U_o = 389.16 \ W/m^2 \cancel{K} ^\circ C \ (U_{o,calc})$

error check :- $\left|\frac{U_{o,calc} - U_{o,assm}}{U_{o,assm}}\right| \times 100 < 30\%$

$$= \left(\frac{550 - 389.16}{550}\right) \times 100 = 29\% < 30\%$$

$\therefore U_o$ value is within the limit but not very optimum.

Pressure drop :-

For tube-side, $Re = 14367$, $u_t = 0.466\ m/s$.
$j_f = 4.5 \times 10^{-3}$ (friction factor).

$$\therefore \Delta P_t = 2\left(8 \times 4.5 \times 10^{-3} \times \left(\frac{16 \times 12}{0.856}\right) \times 1 + 0.25\right)\frac{1000 \times 0.466^2}{2}$$

$$= 2237.62\ Pa = 0.023\ kg/cm^2$$

$0.023 < 0.7$, $\therefore$ Pressure drop within the limit.

For shell-side, $Re = 2872.51$, $u_s = 0.205\ m/s$.
$j_f = 6 \times 10^{-2}$ (friction factor).

$$\therefore \Delta P_s = 8 \times 0.06 \times \left(\frac{0.52}{0.01804}\right) \times \left(\frac{16 \times 12 \times 0.0254}{0.26}\right) \times 1 \times \frac{775 \times 0.205^2}{2}$$

$$= 4226.2\ Pa = 0.043\ kg/cm^2$$

$0.043 < 0.7$, $\therefore$ Pressure drop within the limit.

Conclusion : Although pressure drops and overall heat transfer co-efficient are within the limit, we need to go for a 4-pass exchanger. This is to be done for just improving the error (minimizing) and for getting higher values of velocity for better fluid flow. This will also cause a slight pressure increase but we are already well within the $0.7\ kg/cm^2$ limit, so it won't be a problem.

- For two pass design, overall heat transfer calculated came within the range of error.

- But we can still increase the number of passes and get a good design.

- The tube velocity obtained using two pass design is low. Hence calculation for four pass design is done:

For 4 pass design:

calculated No. of tubes $\simeq 154$

Using standard data tabel.

$N_t = 170$ Shell ID $= 21.25''$

$= 0.54 m$

Finding Bundle diameter:

for 4 pass.

$K_1 = 0.175$ $n_1 = 2.285$

$$D_b = 25.4 \left(\frac{170}{0.175}\right)^{\frac{1}{2.285}} \Rightarrow 0.516 m$$

Notes:

Scanned by TapScanner

Adding clearance, for split ring floating head

Shell ID $= 0.516 + (0.057) \Rightarrow 0.573m$

clearance

Tubes per pass $= \frac{170}{4} \Rightarrow 42.5$

Tube ID $= 0.856'' \Rightarrow 0.022m$

Flow area per tube $= (0.576'')^2$

$= 3.72 \times 10^{-4} m^2$

Total flow area $= 42.5 \times (3.72 \times 10^{-4})$

$= 0.01581 \ m^2$

Tube side mass velocity $= \frac{46625.49}{3600 \times 0.01581}$

$= 819.2 \ \frac{Kg}{m^2 s}$

$Re_{tube} = \frac{819.2 \times 0.022}{7 \times 10^{-4}}$

Notes:

$= 25746.28$

$$\frac{L}{d} = \frac{16 \times 12}{0.856} \Rightarrow 224.3$$

$$Pr = \frac{4179 \times 7 \times 10^{-4}}{0.64} \Rightarrow 4.57$$

$$j_H = 0.0044.$$

$$h_i = \frac{0.0044 \times 25746.28 \times (4.57)^{1/3} \times 0.64}{0.022}$$

$$= 5468.86 \cdot \frac{W}{m^2 \, ^oC}.$$

$$\text{Baffle spacing} = (0.2) \times 0.573$$

$$= 0.1146 \, m$$

$$A_s = \left(\frac{1.25 - 1}{1.25} \right) \times 0.573 \times 0.1146$$

$$= 0.014 \, m^2.$$

$$d_e = \frac{1.1}{1 \times 25.4} \left(1.25^2 - 0.917 \times 1^2 \right) \frac{25.4^2}{1000}$$

$$= 0.0164 \, m.$$

$$G_s = \frac{15500}{3600 \times 0.014} \Rightarrow 307.54 \, \frac{kg}{m^2 s}$$

Notes:

$$Re_{shell} = \frac{307.54 \times 0.0164}{10^{-3}} \Rightarrow 5043.65$$

$$Pr = \frac{2155 \times 10^{-3}}{0.138} \Rightarrow 15.62$$

$$j_H = 0.008$$

$$h_o = \frac{0.138}{0.0164} \times 0.008 \times 5043.65 \times (15.62)^{1/3}$$

$$= 848.71 \ \frac{W}{m^2 \, °C}$$

$$\left.\begin{aligned} h_{id} &= (0.00024)^{-1} \\ h_{od} &= (0.0002)^{-1} \end{aligned}\right\} \frac{W}{m^2 \, °C}$$

$(K_w = 109)$ material thermal conductivity

$$\frac{1}{U_{o\,cal}} = \frac{1}{848.71} + 0.0002 + \frac{1}{0.856}\left(\frac{1}{5468.86} + 0.00024\right) + \frac{1 \times 0.0254 \ln\left(\frac{1}{0.856}\right)}{2 \times 109}$$

Notes:

$U_o\,cal = 528.99 \quad \frac{W}{m^2\cdot C}$

$\text{Mean absolute error} = \left| \frac{528.99 - 550}{550} \right|$

$= 3.82\ \%$ Within Range of error

Pressure drop calculations :-

$j_f\ (\text{Tube}) = 3.8 \times 10^{-3}$.

$\Delta P_{tube} = 4\left(8 \times 3.8 \times 10^{-3} \times (224.3) + 2.5\right) \times \left(\frac{819.2 \times 819.2}{2 \times 993}\right)$

3

Sunday

ρ ~~kerosene~~ water at $102\ ^\circ F = 993 \left(\frac{Kg}{m3}\right)$

$\Delta P_{tube} = 12444.1\ Pa.$

$U_{tube} = \frac{819.2}{993} \Rightarrow 0.82\ m/s.$

Notes:

$\Delta P_{shell} = ?$ ($\cancel{\rho \text{ kerosene at } 167°F} = 775 \frac{kg}{m^3}$)

$$u_{shell} = \frac{307.54}{775}$$

$$= 0.39 \left(\frac{m}{s}\right) \quad \{ j_f = 4.8 \times 10^{-2} \}$$

$$\Delta P_{shell} = (8 \times 4.8 \times 10^{-2}) \times \left(\frac{0.573}{0.0164}\right) \left(\frac{16 \times 12 \times 0.0254}{0.1146}\right) \times 775 \times \frac{(0.39)^2}{2}$$

$$= 33650.63 \text{ Pa.}$$

$$\simeq 0.3 \frac{kg}{cm^2}$$

Pressure drop are within limit. Hence our data is feasible.

Summary:

- Description: 1-4 Shell & Tube Heat Exchanger
- Shells per Pass: 1
- Surface area: 59.8 m^2

Operating Data for One Unit				
Units		Shell Side	Tube Side
Description of fluids		Kerosene	Cooling Water
Liquid Flow Rate	kg/h	15500	46625.49
Density	kg/m^3	775	993
Absolute Viscosity	cp	1	0.7
Specific Heat	J/kg °C	2155	4179
Thermal Conductivity	W/m °C	0.138	0.64
Temperature	°C	Inlet-110 Outlet-40	Inlet-33 Outlet-45
Maximum Pressure Drop	kg/cm^2	0.7	0.7
Operating Pressure Drop	kg/cm^2	0.13	0.3
Number of Passes		1	4
Velocity	m/s	0.82	0.39
Fouling Resistance	m^2 °C/W	0.0002	0.00024

- Overall Heat Transfer Coefficient: 550 W/m^2 °C (assumed), 530 W/m^2 °C (estimated)
- Material: Brass
- Tube OD: 1 inch, Length: 16 feet, Pitch: 1.25 inch (triangular)
- Shell ID: 0.573 m

- Baffle Spacing: 0.1146 mm, Baffle Cut: 25%
- Shell Head Cover: Split-ring floating head
- Thermal Conductivity: 109 W/m °C
- No. of tubes: 170
- Corrosion Allowance: 3 mm