Kinematic viscosity of oi

$$\upsilon_{oil} := 45.5 \cdot 10^{-2}\ \mathrm{St} = 4.55 \cdot 10^{-5}\ \mathrm{s\ Gy}$$

Density of lube oil

$$\rho_{oil} := 869\ \frac{\mathrm{kg}}{\mathrm{m}^3}$$

Specific heat of lube oil

$$c_{oil} := 2.1413\ \frac{\mathrm{kJ}}{\mathrm{kg\ K}} = 2141.3\ \frac{\mathrm{Gy}}{\mathrm{K}}$$

Specific heat of water

$$c_{water} := 4.1868\ \frac{\mathrm{kJ}}{\mathrm{kg\ K}} = 4186.8\ \frac{\mathrm{Gy}}{\mathrm{K}}$$

Thermal coductivity of lube oil at 55 C

$$k_{oil} := 0.13\ \frac{\mathrm{W}}{\mathrm{m\ K}} = 0.13\ \frac{\mathrm{N}}{\mathrm{s\ K}}$$

Viscosity of lube oil

$$\mu_{oil} := 15 \cdot 10^{-3}\ \mathrm{Pa\ s} = 0.015\ \mathrm{s\ Pa}$$

Cooling water inlet

$$T_{wi} := 35\ {}^{\circ}\mathrm{C} = 308.15\ \mathrm{K}$$

Important

Cooling water outlet

$$T_{wo} := 39\ {}^{\circ}\mathrm{C} = 312.15\ \mathrm{K}$$

Assumed

Oil inlet temp

$$T_{oi} := 65\ {}^{\circ}\mathrm{C} = 338.15\ \mathrm{K}$$

Constants

Oil outlet temp

$$T_{oo} := 45\ {}^{\circ}\mathrm{C} = 318.15\ \mathrm{K}$$

Temp difference of oil

$$\Delta t_1 := T_{oi} - T_{oo} = -253.15\ {}^{\circ}\mathrm{C} \qquad \Delta T_1 := T_{oi} - T_{wo} = -247.15\ {}^{\circ}\mathrm{C}$$

Temp difference of water

$$\Delta t_2 := T_{wo} - T_{wi} = -269.15\ {}^{\circ}\mathrm{C} \qquad \Delta T_2 := T_{oo} - T_{wi} = -263.15\ {}^{\circ}\mathrm{C}$$

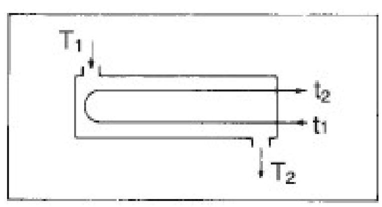
Volumetric flow rate of oil

$$Q_{oil} := 450\ \frac{\mathrm{L}}{\mathrm{min}}$$

$$m_{oil} := Q_{oil} \cdot \rho_{oil} = 6.5175\ \frac{\mathrm{kg}}{\mathrm{s}}$$

Heat duty

$$\phi_t := m_{oil} \cdot c_{oil} \cdot \Delta t_1 = 2.7912 \cdot 10^{5}\ \mathrm{W}$$



Heat balance

Mass flow of water

$$m_{water} := \frac{\phi_t}{c_{water} \cdot \Delta t_2} = 16.6666\ \frac{\mathrm{kg}}{\mathrm{s}}$$

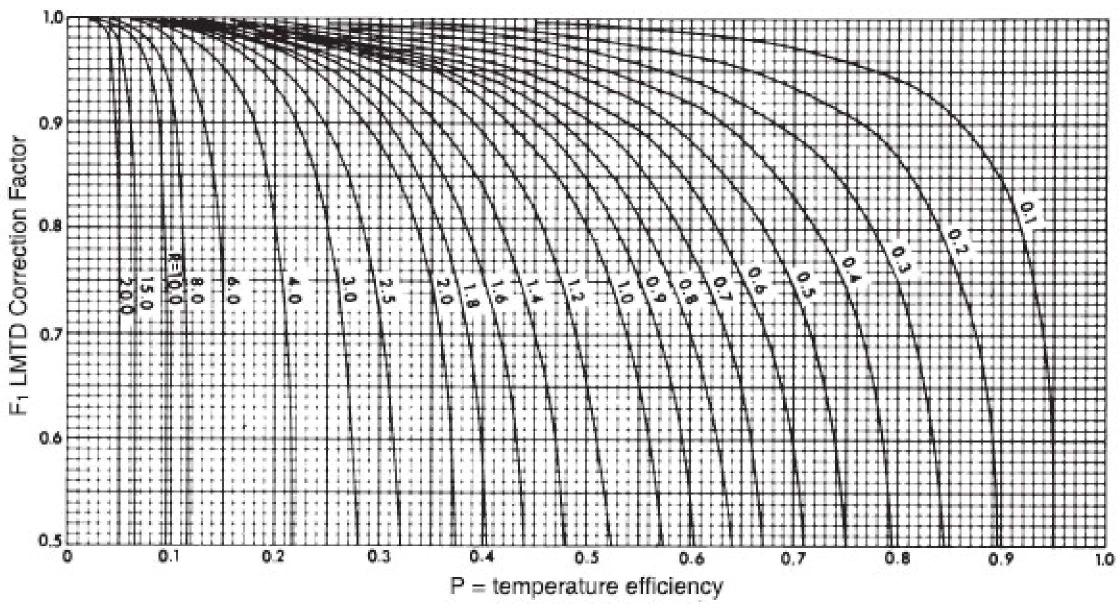
$$\Delta T_{ln} := \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} = 16.745\ \mathrm{K}$$

For first trial lets take

Number of tube side pass

$$N_p := 4$$

$$R := \frac{T_{oi} - T_{oo}}{T_{wo} - T_{wi}} = 5 \qquad S := \frac{T_{wo} - T_{wi}}{T_{oi} - T_{wi}} = 0.1333$$



From fig

If Ft is < 0.8 then selected config of HE is not appropiate

$$F_t := 0.95$$

Mean temp difference

$$\Delta T_m := F_t \cdot \Delta T_{ln} = 15.9077\ \text{K}$$

Assume overall heat transfer coeff

$$U := 400 \frac{\text{W}}{\text{m}^2\ \text{K}} = 400 \frac{\text{kg}}{\text{s}^3\ \text{K}}$$

Provisional area for heat transfer area for first trial cal

$$A := \frac{\phi_t}{U \cdot \Delta T_m} = 43.8653\ \text{m}^2$$

Assume tube diameter

$$d_o := 15.875\ \text{mm} \qquad L := 3.048\ \text{m}$$

Number of tubes

$$N_t := \frac{A}{\pi \cdot d_o \cdot L} = 288.5641$$

Table 6.7 Typical Overcell Coefficients for Shell and Tube Heat Exchangers

	Shell side	Tube side	U, W/(m² · °C)
	[A] Heat exchangers		
1.	Water	Water	800–1400
2.	Organic solvent	Water	300–850
3.	Organic solvent	Brine	200–500
4.	Light oil	Water	350–900
5.	Heavy oil	Water	60–300
6.	Water	Brine	600–1200
7.	Gas	Brine	15–250
8.	Gas	Gas	10–50
9.	Gas	Water	20–300
10.	Naphtha	Water	300–400
11.	Lube oil	Water	150–500
12.	Gasoline	Water	350–550
13.	Kerosene	Water	150–300
14.	Water	10 to 30% Caustic soda solution	500–1250
	[B] Condensers		
1.	Organic vapour	Water	700–1000
2.	Organic vapour + Gas	Water or Brine	100–300
3.	Low boiling hydrocarbons vapour mixture	Water	450–1100
4.	Naphtha vapour	Water	300–425
5.	Steam	Water	2000–5000
6.	Alcohol vapour	Water	500–1000
7.	Saturated Organic vapour	Water or Brine	280–680
	[C] Vaporizers/Reboilers		
1.	Light organics	Steam	800–1200
2.	Heavy organics	Steam	600–900
3.	Aqueous solution	Steam	1000–1500
4.	Chlorine	Steam	700–1500
5.	Ammonia	Steam	700–1500
6.	Water	Steam	1250–2000
7.	Refrigerants	Water	425–850

Table 6.2 Constants for Eq. (6.1)

A. For $P_t/d_o = 1.25$, Triangular Pitch

No. of tube side passes	1	2	4	6	8
k_1	0.319	0.249	0.175	0.0743	0.0365
n_1	2.142	2.207	2.285	2.499	2.675

Table 6.3 Constants for Eq. (6.1)

B. For $P_t/d_o = 1.25$, Square Pitch

No. of tube side passes	1	2	4	6	8
k_1	0.215	0.156	0.158	0.0402	0.0331
n_1	2.207	2.291	2.263	2.617	2.643

selecting BEM type heat exchanger and triangular pitch

$$P_t := 1.25 \qquad k_1 := 0.175$$

$$d_o = 15.875\ \text{mm} \qquad n_1 := 2.285$$

Tube bundle diameter

$$D_b := d_o \cdot \left(\frac{N_t}{k_1}\right)^{\frac{1}{n_1}} = 406.1445\ \text{mm}$$

Let the diameter clearane between shell ID and Db be

$$C := 12\ \text{mm}$$

Shell ID

$$D_i := D_b + C = 418.1445\ \text{mm}$$

Evaluation of hi

Tube side flow area

$$d_i := 13.3858\ \text{mm}$$

$$a_t := \left(\frac{480}{N_p}\right) \cdot \frac{\pi}{4} \cdot d_i^{\,2} = 0.016887\ \text{m}^2$$

Tube side mass velocity

$$G_t := \frac{m_{water}}{a_t} = 986.9305\ \frac{\text{kg}}{\text{m}^2\ \text{s}}$$

$$\mu_{water} := 0.73 \cdot 10^{-3}\ \text{Pa s}$$

$$k_{water} := 0.628\ \frac{\text{W}}{\text{m K}}$$

Reynolds number in tubes

$$Re_t := \frac{d_i \cdot G_t}{\mu_{water}} = 18097.06$$

Prandtl number cal

$$Pr_{oil} := \frac{c_{oil} \cdot \mu_{oil}}{k_{oil}} = 247.0731$$

$$Pr_{water} := \frac{c_{water} \cdot \mu_{water}}{k_{water}} = 4.8668$$

Using sieder tate equation

$$Nu_{sieder} := 1.86 \cdot \left(Re_t \cdot Pr_{oil} \cdot \frac{d_i}{L} \right)^{0.33} \cdot \left(\frac{\mu_{oil}}{\mu_{water}} \right)^{0.14} = 74.1329$$

$$h_{isieder} := Nu_{sieder} \cdot \frac{k_{oil}}{d_i} = 719.9632 \ \frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{K}}$$

Using dittus bolter equation

$$Nu_{dittus} := 0.023 \cdot Re_t^{\ 0.8} \cdot Pr_{water}^{\ 0.33} \cdot \left(\frac{\mu_{oil}}{\mu_{water}} \right)^{0.14} = 150.797$$

$$h_{idittus} := Nu_{dittus} \cdot \frac{k_{water}}{d_i} = 7074.7018 \ \frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{K}}$$

Evaluation of ho

Shell Side flow area

$$x := 1.25 \qquad B_s := \frac{D_i}{5} = 83.6289 \ \mathrm{mm}$$

$$P_1 := x \cdot d_o$$

$$A_s := \left(\frac{P_1 - d_o}{P_1} \right) \cdot D_i \cdot B_s = 0.00699 \ \mathrm{m}^2$$

Shell side mass velocity

$$G_s := \frac{m_{oil}}{A_s} = 931.8977 \ \frac{\mathrm{kg}}{\mathrm{m}^2\ \mathrm{s}}$$

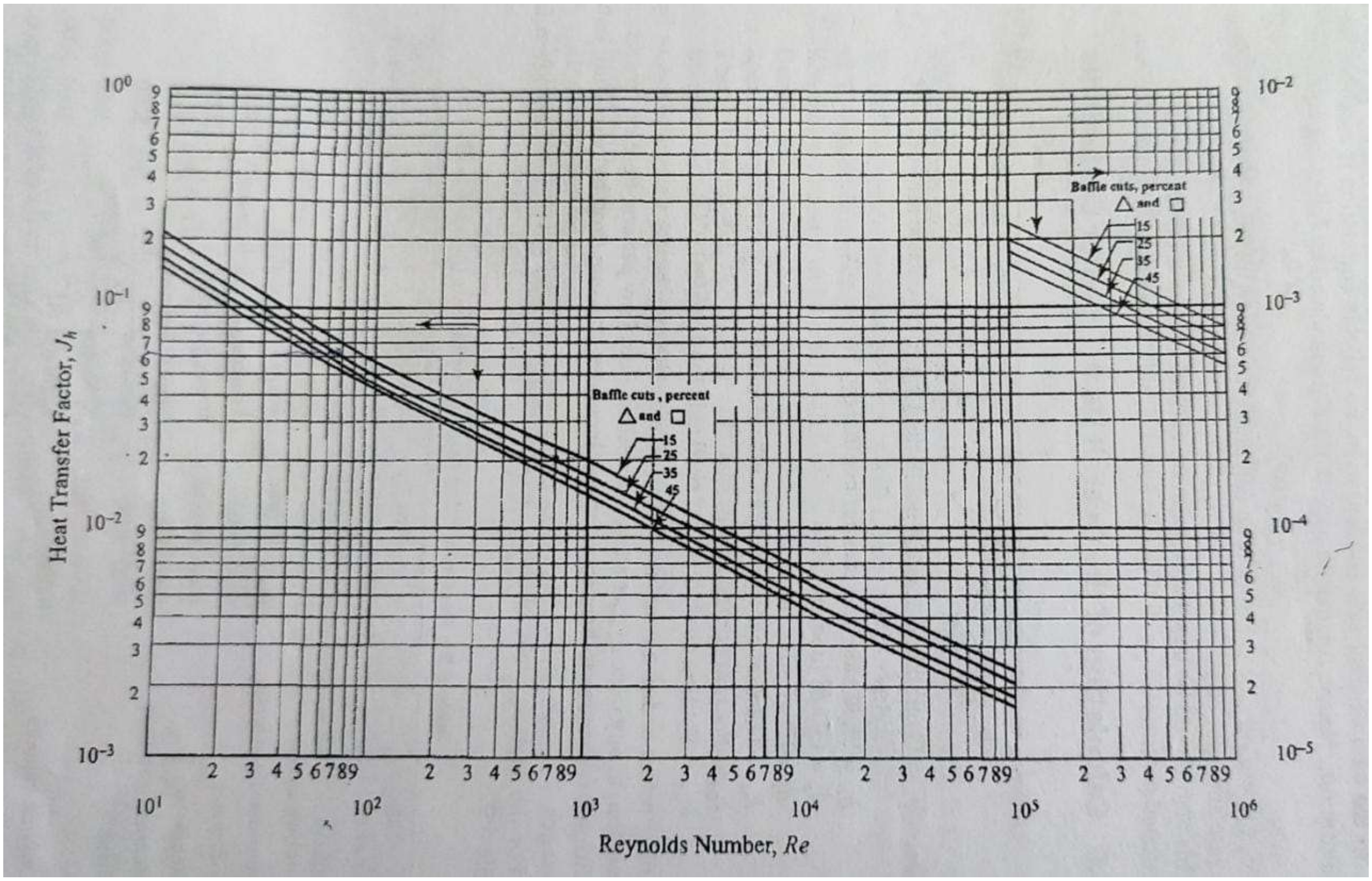
$$u_s := \frac{G_s}{\rho_{oil}} = 1.0724 \ \frac{\mathrm{m}}{\mathrm{s}}$$

Shell side equivalent diameter for triagular pitch

$$d_e := \frac{1.1}{d_o} \cdot \left(P_1^{\ 2} - \left(0.907 \cdot d_o^{\ 2} \right) \right) = 11.4467 \ \mathrm{mm}$$

Shell side reynolds number

$$Re_s := \frac{d_e \cdot G_s}{\mu_{oil}} = 711.14 \qquad Pr_{oil} = 247$$



From above fig for 25% baffle cut

$$J_h := 2 \cdot 10^{-2}$$

$$Nu := J_h \cdot Re_s \cdot Pr_{oil}^{\frac{1}{3}} \cdot \left(\frac{\mu_{oil}}{\mu_{water}}\right)^{0.14} = 136.2643$$

$$h_o := Nu \cdot \frac{k_{oil}}{d_e} = 1547.5561 \ \frac{W}{m^2\ K}$$

Calculation of overall heat transfer coeff

Shell side HTC $h_o = 1547.5561 \frac{W}{m^2 K}$

OD of tube $d_o = 15.875$ mm

ID of tube $d_i = 13.3858$ mm

Thermal conductivity of tube wall material $k_w := 50 \frac{W}{m K}$

Fouling coeff for tube side fluid $h_{id} := 5000 \frac{W}{m^2 K}$

Fouling coeff for shell side fluid $h_{od} := 3000 \frac{W}{m^2 K}$

Fluid	Fouling coefficient W/(m²·°C)	Fluid	Fouling coefficient W/(m²·°C)
Cooling water	3000–6000	Light Hydrocarbon	5000
Demineralized water	8000–10 000	Heavy Hydrocarbon	3000
Soft water	5000–8000	Aqueous Organic Solution	5000
Steam	4000–10 000	Vegetable oils	3000
Steam condensate	1500–5000	Caustic Solutions	5000
Brine	3000–5000	Gasoline	5000
Air	5000–10 000	Kerosene	3000–5000
Organic vapours	10 000	Light gas oil	3000–5000
Organic liquids	5000	Heavy gas oil	2000–3000
Heavy hydrocarbons	2000	Naphthas	5000
Aqueous salt solutions	3000–5000	Coal flue gas	1000

Overall HTC based on outside area of tubes

$$U_o := \frac{1}{\left(\frac{1}{h_o}\right) + \left(\frac{1}{h_{od}}\right) + \frac{d_o \cdot \ln\left(\frac{d_o}{d_i}\right)}{2 \cdot k_w} + \left(\frac{d_o}{d_i \cdot h_{id}}\right) + \left(\frac{d_o}{d_i \cdot h_{idittus}}\right)} = 708.5094 \frac{W}{m^2 K}$$

Heat transfer area required

$$A_r := \frac{\phi_t}{U_o \cdot \Delta T_m} = 24.7648\ \text{m}^2$$

% excess heat transfer area

$$Excess_{area} := \left(\frac{A}{A_r} - 1\right) = 77.1274\ \%$$

Shell side pressure drop

Shell side friction factor for the different value of baffle cut $J_f := 7.7 \cdot 10^{-2}$

shell inside diameter $D_s := 0.418\ \text{m}$

Density of shell fluid $\rho_{water} := 869\ \frac{\text{kg}}{\text{m}^3}$

$$\Delta P_s := 8 \cdot J_f \cdot \left(\frac{D_s}{d_e}\right) \cdot \left(\frac{L}{B_s}\right) \cdot \frac{\rho_{water} \cdot u_s^2}{2} \cdot \left(\frac{\mu_{oil}}{\mu_{water}}\right)^{-0.14} = 268.3092\ \text{kPa}$$

Tube side pressure drop

m = 0.25 for Re ≤ 2100 or m = 0.14 for Re > 2100

$$m := 0.14$$

$$u_t := \frac{G_t}{\rho_{water}} = 1.1357\ \frac{\text{m}}{\text{s}}$$

$$\Delta P_t := N_p \cdot \left(\left(8 \cdot J_f \cdot \left(\frac{L}{d_i}\right) \cdot \left(\frac{\mu_{oil}}{\mu_{water}}\right)\right)^{-m} + 2.5\right) \cdot \left(\frac{\rho_{water} \cdot u_t^2}{2}\right) = 6.3392\ \text{kPa}$$