Physical Properties :-

Tube side fluid : Water	Shell side fluid : Kerosene ~~Kerosene~~
API : 10°	API : 42°
Inlet temperature = $33^\circ C$	Inlet temperature = $110^\circ C$
Outlet temperature = $45^\circ C$	Outlet temperature = $40^\circ C$
Mean temperature = $39^\circ C$	Mean temperature = $75^\circ C$
Density = $993\ kg/m^3$	Density = $775\ kg/m^3$
Absolute viscosity = 0.7 cp	Absolute viscosity = 1 cp
Specific heat capacity = 4179 ~~k~~J/kg°C	Specific heat capacity = 2155 ~~k~~J/kg°C
Thermal conductivity = 0.64 W/m°C	Thermal conductivity = 0.138 W/m°C
Fouling resistance = $0.00024\ m^2\,^\circ C/W$	Fouling resistance = $0.0002\ m^2\,^\circ C/W$
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 :-

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

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

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

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/cm² (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.

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

For given pair of liquids,

Overall heat transfer co-efficient = $U_{o,assm}$ = 550 W/m²°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 $= \frac{\pi}{4} \times 0.856^2$

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

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).

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

$$d_e = \frac{1.1}{1 \times 25.4}(1.25^2 - 0.917 \times 1^2)\, 25.4^2 \times 10^{-3}$$
$$= 0.01804\ m.$$

$$u_s = \frac{15500}{3600} \times \frac{1}{0.02704} \times \frac{1}{775}$$
$$= 0.205\ m/s.$$

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

$K_{shell} = 0.138 \ W/m°C$

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

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

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

$$= 604.21 \ W/m^2 °C.$$

Overall co-efficient :-

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

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

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

$h_{od} = (0.0002)^{-1} \ W/m^2°C$.

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

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

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

$\therefore U_o$ 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