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Hot fluid : Gasoline :-

$\dot{m}_{gasoline} = 8000$ lb/hr

Final temp. = 130°F, Initial temp. = 150°F

Specific heat = 0.55 Btu/lb°F

Cold fluid : Kerosene :-

$\dot{m}_{kerosene} = ?$

Final temp. = 100°F, Initial temp. = 70°F

Specific heat = 0.48 Btu/lb°F

Heat duty = $Q = 8000 \times 0.55 \times (150-130) = 88000$ Btu/hr

$$\dot{m}_{kerosene} = \frac{88000}{(100-70)\,48/100} = 6111 \text{ lb/hr}$$

$$LMTD = \frac{(150-70)-(130-100)}{\ln\left(\frac{150-70}{130-100}\right)} = \frac{50}{\ln\left(\frac{8}{3}\right)} = 51°F$$

$\mu_{gasoline} < 1$ but $\mu_{kerosene} > 1$ at avg. temperature

$\therefore$ To calculate caloric temperatures, we need K_c and F_c.

From the plot of F_c v/s temperature given for different API,

$K_c = 0.09$. For this K_c, $F_c = 0.526$.

T_c (gasoline) $= 130 + 0.526(150-130) = 140.52°F$

t_c (kerosene) $= 70 + 0.526(100-70) = 85.78°F$

Hot fluid (gasoline)

$D_2 = 2.469/12 = 0.206$ ft

$D_1 = 1.66/12 = 0.138$ ft

$$D_e = \frac{0.206^2 - 0.138^2}{0.138}$$

$= 0.170$ ft

$$\text{Mass velocity} = \frac{8000}{\frac{\pi}{4}(0.206^2 - 0.138^2)}$$

$= 435444$ lb/hr ft^2

at $140.52°F$, $\mu = 0.42$ cp

$= 0.42 \times 2.42 = 1.016$ lb/ft hr

$$Re = \frac{0.17 \times 435444}{1.016}$$

$= 72860$

$j_H = 180$

$k = 0.088$ Btu/°F ft hr

$$\left(\frac{c\mu}{k}\right)^{1/3} = \left(\frac{0.55 \times 1.016}{0.088}\right)^{1/3}$$

$= 1.852$

$$h_o = j_H \cdot \frac{k}{D_e} \cdot \left(\frac{c\mu}{k}\right)^{1/3} \cdot \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

$$= 180 \times \frac{0.088}{0.17} \times 1.852 \times 1^{0.14}$$

$= 172.56$ Btu/hr ft^2 °F

Cold fluid (kerosene).

$D = 1.38/12 = 0.115$ ft

$$\text{Flow area} = \pi \times \frac{0.115^2}{4}$$

$= 0.0104$ ft^2

$$\text{Mass velocity} = \frac{6111}{0.0104}$$

$= 587596$ lb/hr ft^2

at $85.78°F$, $\mu = 1.6$ cp

$= 1.6 \times 2.42 = 3.872$ lb/ft hr

$$Re = \frac{0.115 \times 587596}{3.872}$$

$= 17452$

$j_H = 64$

$k = 0.082$ Btu/°F ft hr

$$\left(\frac{c\mu}{k}\right)^{1/3} = \left(\frac{0.48 \times 3.872}{0.082}\right)^{1/3}$$

$= 2.830$

$$h_i = 64 \times \frac{0.082}{0.115} \times 2.83 \times 1$$

$= 129.15$ Btu/hr ft^2 °F

$$h_{io} = 129.15 \times \frac{1.38}{1.66}$$

$= 107.36$ Btu/hr ft^2 °F

Clean overall co-efficient $(U_c) = \frac{172.56 \times 107.36}{172.56+107.36}$

$= 66.18$ Btu/hr ft^2 °F

Dirty overall co-efficient (U_D) :-

$\frac{1}{U_D} = \frac{1}{66.18} + 0.004$ → dirt factor

$\Rightarrow U_D = 52.33$ Btu/hr ft^2 °F

Area $= \frac{Q}{U_D \Delta t_{LMTD}} = \frac{88000}{52.33 \times 51} = 33$ ft^2

Area per unit length $= 0.435$ ft^2

Length needed $= \frac{33}{0.435} = 75.86$ ft

$\therefore$ 2 hairpins will be required (20×4)

Surface applied $= 20 \times 40 \times 0.435 = 34.8$ ft^2.

U_D(actual) $= \frac{88000}{34.8 \times 51} = 49.58$ Btu/hr ft^2 °F

$R_d = \frac{66.18 - 49.58}{66.18 \times 49.58} = 0.0051$ (dirt factor).

Pressure Drop calculations :-

Gasoline	Kerosene
$D_e' = D_2 - D_1$	$Re' = 17452$
$= 0.206 - 0.138$	
$= 0.068$ ft	$f = 0.0035 + \frac{0.264}{17452^{0.42}}$
$Re' = \frac{0.068 \times 435444}{1.016}$	
	$= 0.0079$
$= 29144$	

$$f = 0.0035 + \frac{0.264}{Re^{0.42}}$$

$$= 0.0035 + \frac{0.264}{(29144)^{0.42}}$$

$$= 0.007$$

specific gravity $= 0.71$

$$\rho_{gasoline} = 0.71 \times 62.5$$

$$= 44.38 \text{ lb/ft}^3$$

$$\Delta f_{gasoline} = \frac{4fG^2L}{2g\rho^2 De'}$$

$$= \frac{4 \times 0.007 \times 435444^2 \times 80}{2 \times 4.18 \times 10^8 \times \cancel{50.31}^2 \times \cancel{0.115}}$$

$$44.38 \quad 0.068$$

$$= 3.8 \text{ ft}$$

$$\text{velocity} = \frac{435444}{44.375 \times 3600}$$

$$= 2.72 \text{ fps}$$

$$\Delta F_l = \frac{2 \times 2.72^2}{2 \times 32.2} = 0.23 \text{ ft}$$

$$\Delta P = \frac{(3.8 + 0.23)\,44.38}{144}$$

$$= 1.24 \text{ psi}$$

specific gravity $= 0.805$

$$\rho_{kerosene} = 0.805 \times 62.5$$

$$= 50.31 \text{ lb/ft}^3$$

$$\Delta f_{kerosene} = \frac{4fG^2L}{2g\rho^2 D}$$

$$= \frac{4 \times 0.0079 \times 587596^2 \times 80}{2 \times 4.18 \times 10^8 \times 50.31^2 \times 0.115}$$

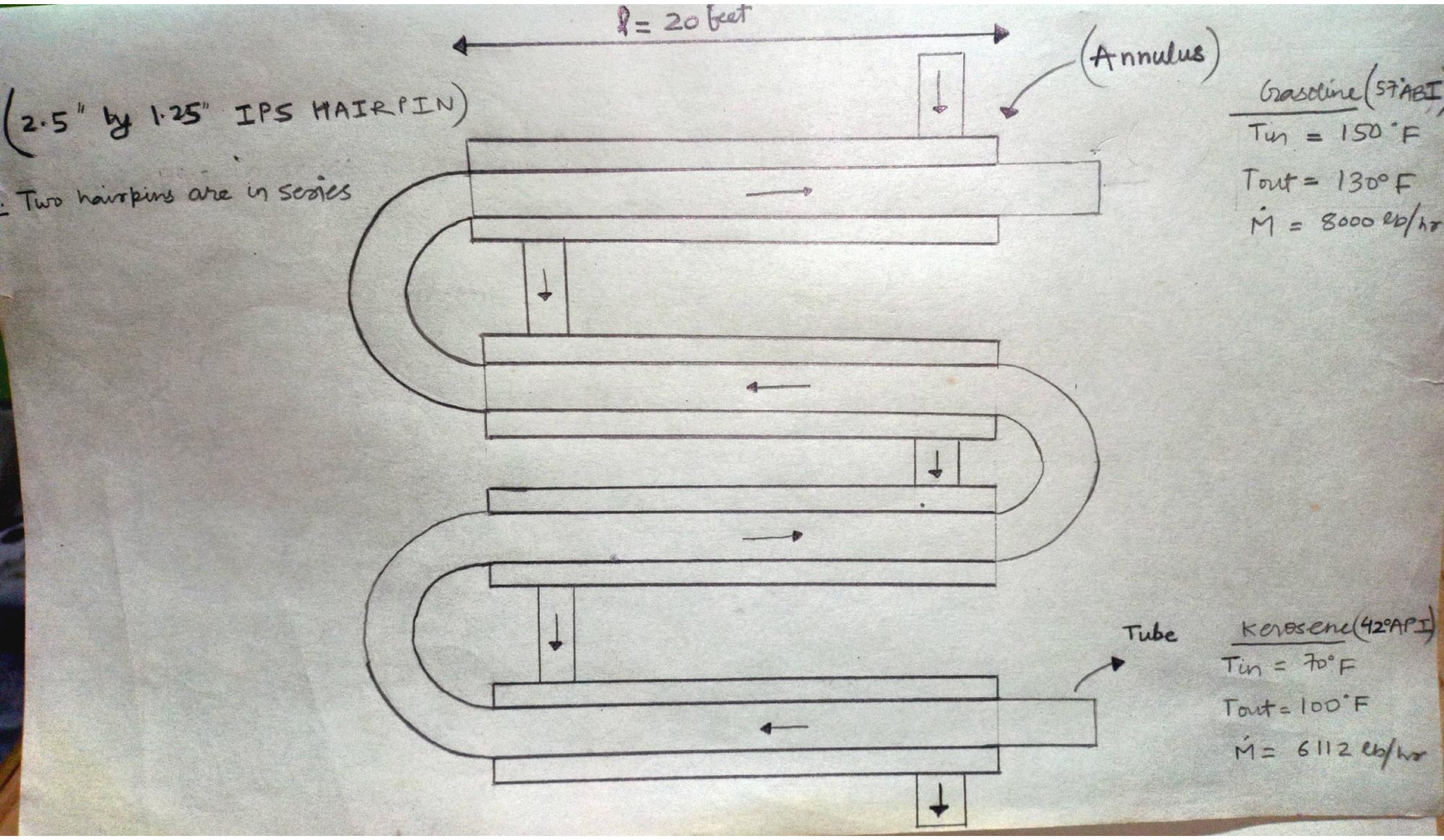
$$= 3.6 \text{ ft}$$

$$\Delta P = \frac{3.6 \times 50.31}{144}$$

$$= 1.26 \text{ psi}$$

$\because$ both pressure drops are lower than the allowable pressure drop, $\therefore$ the design is suitable.

Final Result :-
We need 2 hairpins to make this process happen
Both hairpins need to be connected in series
since the pressure drop across both is lower than
the allowable pressure drop.
The dirt factor obtained came out to be 0.0051.


ℓ = 20 feet
(2.5" by 1.25" IPS HAIRPIN)
Two hairpins are in series
(Annulus)
Gasoline (57°API)
Tin = 150°F
Tout = 130°F
Ṁ = 8000 lb/hr
Tube
Kerosene (42°API)
Tin = 70°F
Tout = 100°F
Ṁ = 6112 lb/hr