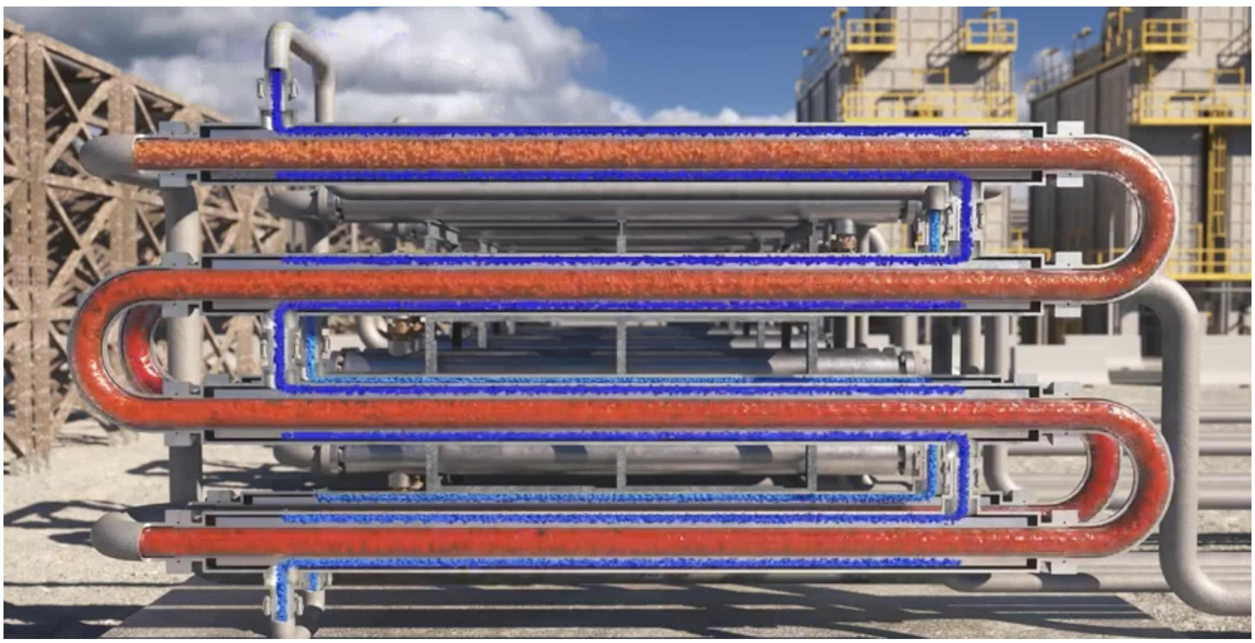
Double Pipe Heat Exchanger



Group-29
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19CH30018

Problem Statement

Z kg/hr of 57^{0}API gasoline is cooled from T_{in} °C to T_{out} °C by heating 42^{0}API kerosene from 30 °C to 45 °C. The allowable pressure drop is 0.7 bar for both tube and shell sides. A minimum dirt factor of 0.004 $m^2 \cdot K/W$ may be assumed.

Design a double pipe heat exchanger with the hairpin arrangement and present the drawings in a form that can be sent to the fabricator.

Given, Z=750 kg/hr, T_{in}=68^{0}C, T_{out}=42^{0}C

DOUBLE PIPE HEAT EXCHANGER DATA SHEET

UNITS OF MEASUREMENT : (SI)

1	Service Of Unit:			No Of Units:	2	Item No:	
2	Site:	Chemical Engineering Department, IIT Kharapur		Manufacturer	Group 29		
3	Size 1'x1/2'	Type	Arrangement Shell Parallel Yes	Series:	Tube	Parallel: Yes	Series
4	Surface/Unit (Eff.)		m^2	Section/Unit		Surface/Section (Eff.)	m^2
5	PERFORMANCE OF ONE UNIT						
6	Fluid Allocation			SHELL SIDE		TUBE SIDE	
7	Fluid Name			Gasoline		Kerosene'	
8	Fluid Quantity, Total		Kg/hr	750		1010.53	
9		Vapor (In/Out)	Kg/hr				
10		Liquid	Kg/hr	750	750	1010.53	1010.53
11		Steam	Kg/hr				
12		Water	Kg/hr				
13		Non-Condensate (Mw)	Kg/hr				
14	Temperature		°C	68	42	30	45
15	Density (Vapor/Liquid)		Kg/m^3	820	820	760	760
16	Viscosity (Vapor/Liquid)		cP	0.45	0.45	1.4	1.4
17	Molecular Weight		Kg/Kmol				
18	Specific Heat (Vapor/Liquid)		Kj/Kg°C	2.219	2.219	2.0097	2.0097
19	Thermal Coductivity (Vapor/Liquid)		W/m°C	0.0126	0.0126	0.011	0.011
20	Surface Tension		Dyn/cm				
21	Boiling Point		°C				
22	Latent Heat		Kj/Kg				
23	Inlet Pressure		barg				
24	Velocity		m/s	1.2695		1.883	
25	Pressure Drop, Allowable/Calculated		bar	007/0.601		0.7/0.207	
26	Fouling Resistance (Min.)		m^2 °C/W	0.004		0.004	
27	Heat Exchanged	0.01202	MW	MTD (Corrected) (Weighted)		21.54	°C
28	Transfer Rate	232.809	W/m^2 °C				
29	CONSTRUCTION OF ONE SHELL						
30			SHELL SIDE	TUBE SIDE	Sketch		
31	Design Pressure	barg	0.601	0.207			
32	Design Temperature Max/Min	°C	68/42	45/30			
33	Corrosion Allowance	mm					
34	Insulation THK. In/Out	mm					
35	Connections	In					
36	Size &	Out					
37	Rating						
38	Tube No. O.D. 15.79 (mm);	Thk. mm (Ave/Min)	Length 9753.6 mm;	Pitch mm ;	Flow Angle Deg		
39	Tube Type	Double Pipe	Material	40ST(Stainless Steel)			
40	Fins: No. Height mm;	Thk. mm	Type	Material			
41	Shell O.D. 26.64 mm;	Thk. 5.304 mm	Material	40ST (Stainless Steel)			
42	Tube Sheet - Stationary		Impingement Protection				
43	Baffles-Cross	Type %Cut	Spacing:c/c mm;	Inlet mm			
44	Shell Return Bend - Housing Material		Cover Material				
45	Tube Side Closure - Type			Material			
46	External Return Bend: OD mm;	Thk. mm;		Material			
47	Gasket - Shell Side		Tube Side				
48	Code Requirements	IPS	Stamp NO				
49	Double Pipe Type?	Yes	Multi Tube Type?				
50	Remarks:						
51							
52							
53							

Rev.	Date	Description	App.1	App.2	App.3

Given, mass flow rate of 57°API (z) = 750 kg/hr
= 1653.47 lb/hr

For 57°API Gasoline given, T_{in} = 68°C = 154.4°F
T_{out} = 42°C = 107.6°F

At, $T_{av} = \frac{154.4 + 107.6}{2} = 131°F$, Cp_g = 0.53 BtU/lb-°F

For 42°API Kerosene given, T'_{in} = 30°C = 86°F
T'_{out} = 45°C = 113°F

At, $T'_{av} = \frac{113 + 86}{2} = 99.5°F$, Cp_k = 0.48 BtU/lb-°F

Heat Balance :

$$\dot{m}_{gasoline} \cdot Cp_{(gasoline)} (T_{in} - T_{out}) = \dot{m}_{kerosene} \, Cp_{(kerosene)} (T'_{out} - T'_{in})$$

$$\therefore \dot{m}_{kerosene} = \frac{1653.47 \times (154.4 - 107.6) \times 0.53}{(113 - 86) \times 0.48}$$

$$= 2227.843 \text{ lb/hr}$$

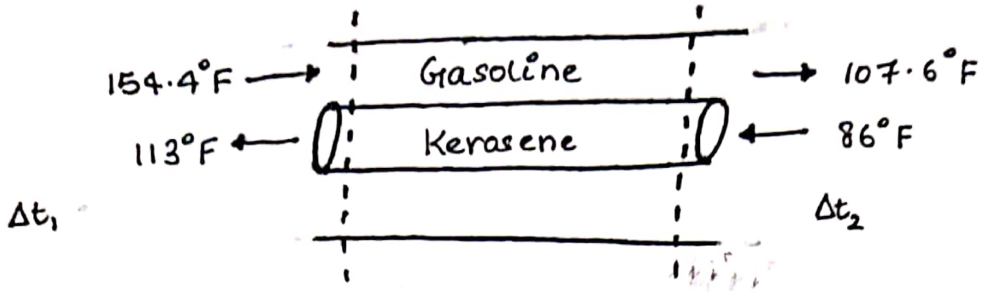
Heat duty : $Q = 1653.47 \times (154.4 - 107.6) \times 0.53$
$= 41012.66988$ BtU/hr

We consider the cold fluid (kerosene) in the inner tube and gasoline (hot fluid) in the outer tube; For the following reasons

- Larger flow rate stream in annulus
- Viscosity of kerosene is greater than viscosity of gasoline
- However, one drawback of considering this, radiative heat losses to the environment, but it is negligible compared to heat transfer happening

We use the 40ST, 40S pipe for this case

② Calculation of LMTD



$$LMTD = \frac{\Delta t_1 - \Delta t_2}{\ln\left(\frac{\Delta t_1}{\Delta t_2}\right)} = 70.77°F$$

③ Caloric Temperature : A check of both streams will show that neither is viscous at cold terminal and temp. ranges and temp. difference are moderate.

$$T_{av} = \frac{1}{2}(154.4 + 107.6) = 131°F$$

$$t_{av} = \frac{1}{2}(113 + 86) = 99.5°F$$

Double pipe used in 1' by 1/2' IPS

Pipe Parameters:

Outer Tube (1')

Outer diameter $(D_2) = 1.049/12$
$= 0.0874$ ft

Inner diameter $(D_1) = 0.84/12$
$= 0.07$ ft

Inner Tube (1/2')

Inner Diameter $(D) = 0.622/12$
$= 0.0518$ ft

As mentioned earier, we consider gasoline on the annulus side and kerosene in the pipe side.

Heat Transfer Analysis:

Hot Fluid : Annulus , Gasoline

Flow Area,

$$a_g = \frac{\pi (D_1^2 - D_2^2)}{4}$$

$$= 0.00215\ ft^2$$

Equivalent Diameter,

$$D_{eq} = \frac{D_1^2 - D_2^2}{D_2} = 0.0392\ ft$$

Mass velocity,

$$G_g = \frac{\dot{m}_{gasoline}}{a_g}$$

$$= 767566.343\ lb/hr\text{-}ft^2$$

Flow velocity,

$$v_g = \frac{\dot{m}_g}{\rho_g a_g} = 1.2695\ m/s$$

$$(\rho_g = 820\ kg/m^3)$$

Viscosity,

At $T = 131°F$, $\mu_g = 0.45\ cp$

$$\mu_g = 1.094\ lb/ft\text{-}hr$$

Reynold's Number,

$$Re_g = \frac{D_{eq} G_g}{\mu_g}$$

$$\therefore Re_g = \frac{0.0392 \times 767566.343}{1.094}$$

$$= 27503.291$$

Cold Fluid : Inner Pipe , Kerosene

Flow Area,

$$a_k = \frac{\pi}{4} D^2$$

$$= 0.00211\ ft^2$$

Equivalent Diameter,

$$d_{eq} = 0.0518\ ft$$

Mass velocity,

$$G_k = \frac{\dot{m}_{kerosene}}{a_k}$$

$$= 1055849.763\ lb/hr\text{-}ft^2$$

Flow velocity,

$$V_k = \frac{\dot{m}_k}{\rho_k a_k} = 1.883\ m/s$$

$$(\rho_k = 760\ kg/m^3)$$

Viscosity,

At $t = 99.5°F$, $\mu = 1.4\ cp$

$$\therefore \mu = 3.388\ lb/ft\text{-}hr$$

Reynold's Number,

$$Re_k = \frac{d_{eq} \times G_k}{\mu_k}$$

$$\therefore Re_k = \frac{0.0518 \times 1055849.763}{3.388}$$

$$= 16143.158$$

$C_p = 0.53$ BtU/lb-°F

$k_g = 0.087$ BtU/hr-ft-°F

Prandtl Number,

$$Pr = \frac{C_p \mu}{k}$$

$$\therefore Pr = \frac{0.53 \times 1.094}{0.087} = 6.665$$

Since, $Re \geq 10^4$, $Nu = 0.023\, Re^{0.8} Pr^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$

Nusselt Number,

$$\frac{h_g D_{eq}}{k_g \cdot \phi_g} = 0.023 \times (27503.29)^{0.8} \times (6.665)^{1/3}$$

$$\therefore \frac{h_g}{\phi_g} = \frac{154.112 \times 0.087}{0.0392}$$

$$= 342.034 \text{ BtU/hr-ft}^2\text{°F}$$

$$t_w = t_k + \frac{h_g/\phi_g}{h_k'/\phi_k + h_g/\phi_g}(T_g - t_k)$$

$$= 120.79 \text{ °F}$$

At $t_w = 120.79$°F, $\mu_{w_g} = 0.48$ cp

$$\therefore h_g = \frac{h_g}{\phi_g} \times \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

$$= 342.034 \times \left(\frac{0.45}{0.48}\right)^{0.14}$$

$$\therefore h_g = 338.96 \text{ BtU/hr-ft}^2\text{°F}$$

$C_{p_k} = 0.48$ BtU/lb-°F

$k_k = 0.078$ BtU/hr-ft°F

Prandtl Number,

$$Pr = \frac{C_p \mu}{k}$$

$$\therefore Pr = \frac{0.48 \times 3.388}{0.078} = 20.849$$

Nusselt Number,

$$\frac{h_k d_{eq}}{\phi_k k_k} = 0.023 \times (16143.158)^{0.8} \times (20.849)^{1/3}$$

$$\therefore \frac{h_k}{\phi_k} = \frac{147.168 \times 0.078}{0.0518}$$

$$= 221.61 \text{ BtU/hr-ft}^2\text{°F}$$

$$\frac{h_k'}{\phi_k} = \frac{h_k}{\phi_k} \times \frac{ID}{OD}$$

$$= 221.61 \times \frac{0.622}{0.84}$$

$$= 164.093 \text{ BtU/hr-ft}^2\text{°F}$$

At $t_w = 120.79$°F, $\mu_w = 1.2$ cp

$$\therefore h_k = \frac{h_k'}{\phi_k} \times \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

$$= 164.093 \times \left(\frac{1.4}{1.2}\right)^{0.14}$$

$$\therefore h_k = 167.67 \text{ BtU/hr-ft}^2\text{°F}$$

Clean overall co-efficient (U_c)

$$U_c = \frac{h_{io} \times h_g}{h_{io} + h_g} = \frac{338.96 \times 167.67}{338.96 + 167.67}$$

$$\therefore \quad U_c = 112.18 \ BtU/hr\text{-}ft^2 {}^\circ F$$

Design overall co-efficient (U_D)

$$\frac{1}{U_D} = \frac{1}{U_c} + R_d$$

$$R_d = 2 \times 0.004 = 0.008$$

$$\frac{1}{U_D} = \frac{1}{112.18} + 0.008$$

$$\therefore \quad U_D = 59.12 \ BtU/hr ft^2 {}^\circ F$$

WKT,

$$A = \frac{Q}{U_D(LMTD)} = \frac{41012.6698}{59.12 \times 70.77} = 9.8024 \ ft^2$$

$$\therefore \quad A = 9.8024 \ ft^2$$

For a 1/2' IPS standard pipe there is $0.222 \ ft^2$ external surface area per foot length

$$\therefore \text{ Required length} = \frac{9.8024}{0.22} = 44.56 \ ft$$

This is equivalent to considering 2 hairpins of 16 ft long connected in parallel

Corrected U_D :

$$U_D = \frac{Q}{A \ LMTD} = \frac{41012.6698}{64 \times 0.22 \times 70.77} = 41.159 \ BtU/hr ft^2 {}^\circ F$$

Corrected Dirt Factor :

$$R_d = \frac{1}{U_D} - \frac{1}{U_c} = \frac{1}{41.159} - \frac{1}{112.18}$$

$$\therefore \quad R_d = 0.0154$$

Pressure Drop Analysis

$D_e' = D_2 - D_1$

$= 0.0174$ ft

$Re' = D_e' G / \mu$

$= \dfrac{767566.34 \times 0.0174}{1.094}$

$\therefore Re' = 12208.094$

$f_g = 0.0035 + \dfrac{0.264}{(12208.094)^{0.42}}$

$\therefore f_g = 0.00857$

$S = 0.82, \; \rho_g = 0.82 \times 92.1$

$= 75.52$

$\Delta F_{g_1} = \dfrac{4 f_g G_g^2 L_g}{2 g \rho_g^2 D_{eq}^2}$

$= \dfrac{4 \times 0.00857 \times 767566^2 \times 64}{2 \times 4.18 \times 10^8 \times 75.52^2 \times 0.0174}$

$\therefore \Delta F_{g_1} = 15.1769$ ft

$V = \dfrac{G_g}{3600 \rho} = \dfrac{767566}{3600 \times 75.52} = 2.82$ fps

$F_{g_2} = N_{hp} \left(\dfrac{V^2}{2g'} \right) = 2 \times \dfrac{2.82^2}{2 \times 32.2}$

$= 0.495$ ft

$\Delta P_g = \dfrac{(15.1769 + 0.495) \times 80.127}{144}$

$= 8.72$ psi (≈ 0.601 bar)

For $Re = 16143.158$,

$f_k = 0.0035 + \dfrac{0.264}{Re^{0.42}}$

$= 0.0035 + \dfrac{0.264}{16143.158^{0.42}}$

$\therefore f_k = 0.00801$

$S = 0.76, \; \rho_k = 0.76 \times 92.1$

$= 69.996$

Halves of the fluid will flow through only ~~four~~ exchanger

$\Delta F_k = \dfrac{4 f_k G_k^2 L_k}{2 g \rho_k^2 D_{eq}^2}$

$= \dfrac{4 \times 0.00801 \times 1055849^2 \times \cancel{64}}{2 \times 4.18 \times 10^8 \times 69.996^2 \times 0.0518}$

$\therefore \Delta F_k = 5.387$ ft

$\Delta P_k = \dfrac{5.387 \times 80.127}{144}$

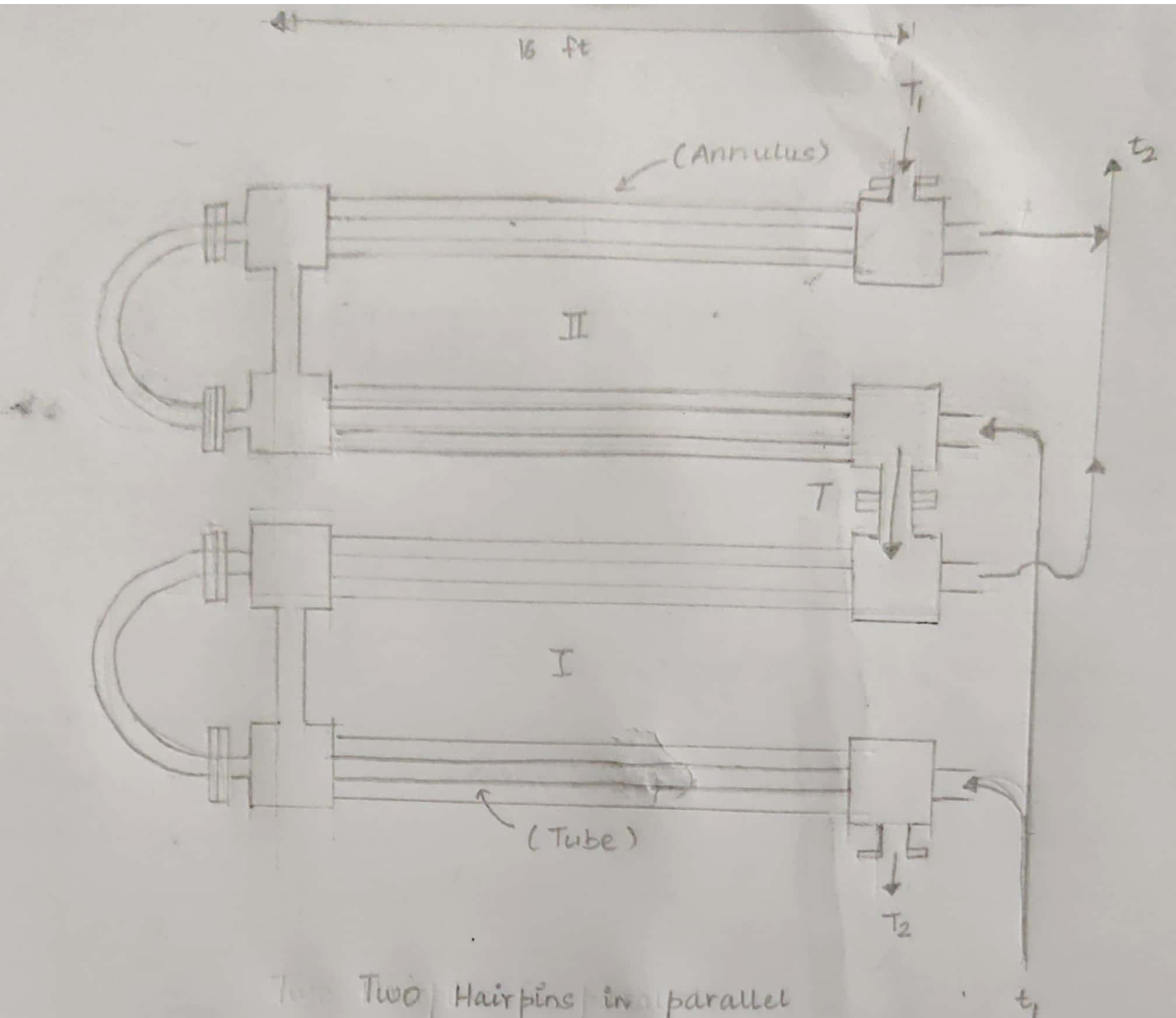
$= 2.998$ psi (≈ 0.207 bar)

$\Delta P_k = 0.207 \text{ bar} < 0.7 \text{ bar}$

$\Delta P_g = 0.601 \text{ bar} < 0.7 \text{ bar}$

Thus, the pressure drop is in the range for both annulus and pipe side.

$\therefore$ The design is safe



Two Hairpins in parallel
(1" by ½" IPS)

Gasoline
$T_{in} = 68°C$
$T_{out} = 42°C$
$\dot{m} = 750$ kg/hr

Kerosene
$T_{in} = 30°C$
$T_{out} = 45°C$
$\dot{m} = 1010.53$ kg/hr

Plots, References, Reasons

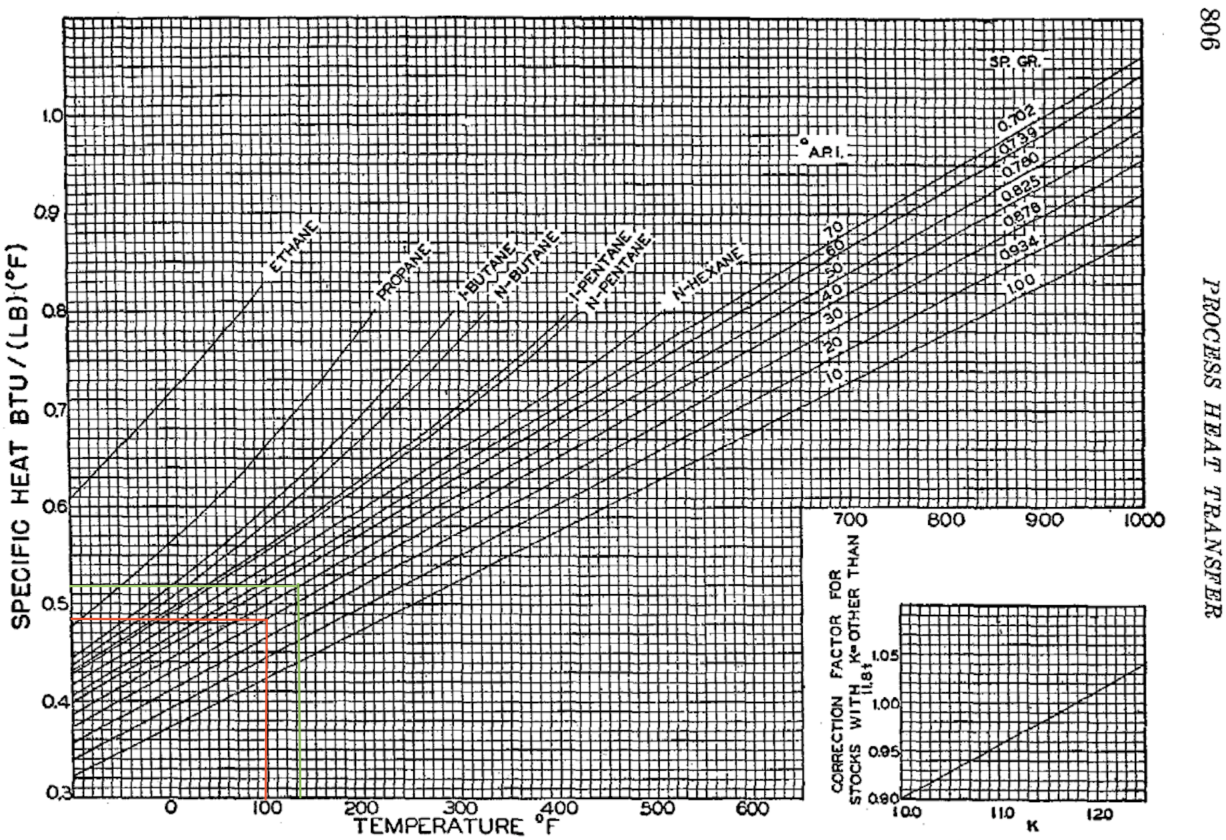


FIG. 4. Specific heats of hydrocarbon liquids. [*Holcomb and Brown, Ind. Eng. Chem.*, **34**, 595 (1942).]
† K = characterization factor.

------ Kerosene at t_c
------ Gasoline at T_c

Graph Plotting for finding out Specific Heat at various temperatures of Gasoline and Kerosene

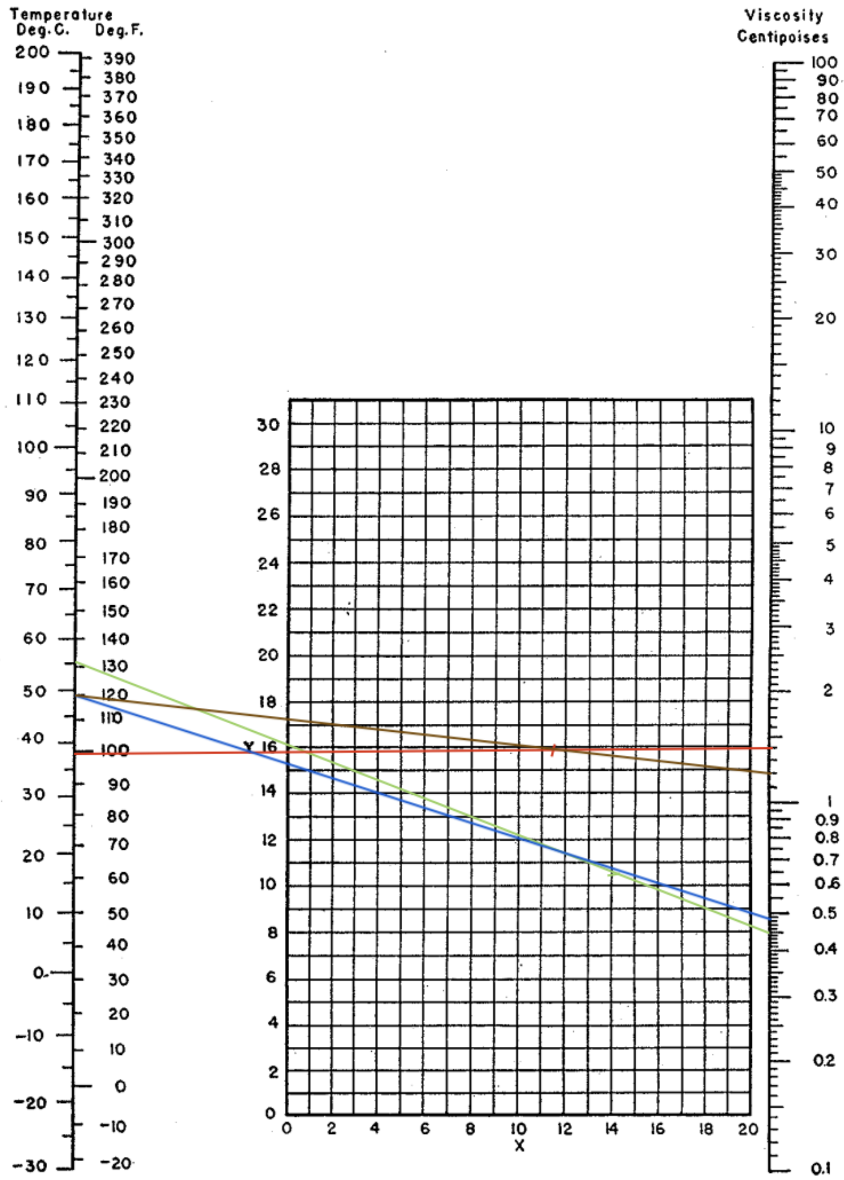


FIG. 14. Viscosities of liquids. (*Perry, "Chemical Engineers' Handbook," 3d ed., McGraw Hill Book Company, Inc., New York*, 1950.)

------ Kerosene at t_c

------ Kerosene at t_w

------ Gasoline at T_c

------ Gasoline at t_w

Graph Plotting for finding out Viscocity at various temperatures of Gasoline and Kerosene

Table A.15 *Thermal Conductivities of Liquids*

Liquid	T (°F)	k (Btu/h · ft · °F)
Acetic acid 100%	68	0.099
Acetic acid 50%	68	0.20
Acetone	86	0.102
	167	0.095
Allyl alcohol	77–86	0.104
Ammonia	5–86	0.29
Ammonia, aqueous 26%	68	0.261
	140	0.29
Amyl acetate	50	0.083
Amyl alcohol (*n*-)	86	0.094
	212	0.089
Amyl alcohol (iso-)	86	0.088
	167	0.087
Aniline	32–68	0.100
Benzene	86	0.092
	140	0.087
Bromobenzene	86	0.074
	212	0.070
Butyl acetate (*n*-)	77–86	0.085
Butyl alcohol (*n*-)	86	0.097
	167	0.095
Butyl alcohol (iso-)	50	0.091
Calcium chloride		
brine 30%	86	0.32
15%	86	0.34
Carbon disulfide	86	0.093
	167	0.088
Carbon tetrachloride	32	0.107
	154	0.094
Chlorobenzene	50	0.083
Chloroform	86	0.080
Cymene (para-)	86	0.078
	140	0.079
Decane (*n*-)	86	0.085
	140	0.083
Dichlorodi-fluoromethane	20	0.057
Ethyl alcohol 40%	68	0.224
Ethyl alcohol 20%	68	0.281
Ethyl alcohol 100%	122	0.087
Ethyl benzene	86	0.086
	140	0.082
Ethyl bromide	68	0.070
Ethyl ether	86	0.080
	167	0.078
Ethyl iodide	104	0.064
	167	0.063
Ethylene glycol	32	0.153
Gasoline	86	0.078
Glycerol 100%	68	0.164
Glycerol 80%	68	0.189
Glycerol 60%	68	0.220
Glycerol 40%	68	0.259
Glycerol 20%	68	0.278
Glycerol 100%	212	0.164
Heptane (*n*-)	86	0.081
	140	0.079
Hexane (*n*-)	86	0.080
	140	0.078
Heptyl alcohol (*n*-)	86	0.094
	167	0.091
Hexyl alcohol (*n*-)	86	0.093
	167	0.090
Kerosene	68	0.086
	167	0.081
Mercury	82	4.83
Methyl alcohol 100%	68	0.124
Methyl alcohol 80%	68	0.154
Methyl alcohol 60%	68	0.190
Methyl alcohol 40%	68	0.234
Methyl alcohol 20%	68	0.284
Methyl alcohol 100%	122	0.114
Methyl alcohol chloride	5	0.111
	[illegible]	[illegible]

For Kerosene,
We linearly interpolate to get our value,

$$k - 0.081 = \frac{0\cdot086 - 0.081}{167 - 68}(T - 68)$$

$$At, T = 99\cdot5^0F, k = 0\cdot078 BtU/hr ft^0 F$$

Reasons for various considerations

1) Kerosene in the inner tube and Gasoline in the outer tube

- A larger flow rate stream is taken in annulus side
- The viscosity of kerosene is greater than the viscosity of gasoline

2) Tube Dimensions: 1x1/2

- We have tried various dimensions, starting with 2x1.25, however, all conditions like velocity to be at least 1m/s-1.5m/s, allowable pressure should be less than 0.7 bar and hence after trying various pipes using the hit and trial method, we have come to this conclusion
- It is always preferable to flow in the turbulent region for lesser pressure drop and to avoid any errors

3) 40ST 40S Pipe

- Steel pipes are much more durable than pipes or tubes made out of other materials. Even without all the other benefits attached to using them, the strength of steel pipe makes it the best option for most flows, its strength enables it to withstand vibrations, shock and high pressure. Unlike other metals, steel will bend rather than break under extreme conditions, helping to prevent spills or leaks.
- Unlike other metals that rust or corrode easily, steel tubes are rust-proof and are resistant to other chemical reactions that can cause corrosion. This helps them to be more maintenance-free than other types of tubes and pipes, lasting for many years beyond installation.

4) Sider-Tate Equation

Since Re, > 10^4,

$$Nu = 0 \cdot 023\,(Re)^{0 \cdot 8}\,\mathrm{Pr}^{1/3}\left(\frac{\mu}{\mu_0}\right)^{0 \cdot 14}$$

References

1) Process Heat Transfer Principles and Applications by Robert. W. Sarat
2) Process Heat Transfer by D.Q.Kern
3) Python Code(attached below)

```python
def outer_pipe(d1,d2,m,u,d,isval=True):
  d1=d1/12
  d2=d2/12
  m1=m/2.20462
  a=22*(d1**2-d2**2)/(4*7)
  a1=a/10.764
  ed=(d1**2-d2**2)/d2
  v=m1/(d*a1*3600)
  g=m/a
  Re=g*ed/u
  return{"Area":a,"Equivalent Dia":ed,"Velocity":v,"Reynolds":Re,"Mass Velocity":g}
def inner_pipe(d1,m,u,d):
  d1=d1/12
  m1=m/2.20462
  a=22*(d1**2)/(4*7)
  a1=a/10.764
  v=m1/(d*a1*3600)
  g=m/a
  Re=g*d1/u
  return {"Area":a,"Velocity":v,"Reynolds":Re,"Mass Velocity":g}

def nusseltgasoline(cp,tc,u,d,k,re):
  return {"h/phi":0.023*(re**0.8)*((cp*u/k)**(1/3))*k/d}

def nusseltkerosene(cp,tc,u,d,k,re,id,od):
  return {"h/phi":0.023*(re**0.8)*((cp*u/k)**(1/3))*(k/d)*(id/od)}

def tw(h1,h2,t,T,id,od):
  return {"tw":t+((h1/(h2+h1))*(T-t))}

def phi(u,uw):
  return (u/uw)**0.14

def heatgasoline(h,p):
  return{"h":h*p}
```

```
def heatgasoline(h,p):
  return{"h":h*p}

def heatkerosene(h,p):
  return{"h":h*p}

def ud(h1,h2,rd):
  uc=(h1*h2)/(h1+h2)
  x=(1/uc)+(rd*2)
  y=1/x
  return {"Uc":uc,"Ud":y}

def allowedPressure1(re,ar,eqd,d,ar2,m,isval=True):
  if(isval):
    f=0.0035+(0.264/(re**0.42))
    delF=4*f*((m/ar2)**2)*ar/(2*(d**2)*eqd*4.18*(10**8))
    v=(m/ar2)/(3600*d)
    delF2=8*(v**2)/(2*32.2)
    delP=(delF2+delF)*48.4/144
    return {"Friction Factor":f,"delF":delF,"V":v,"delF2":delF2,"Pressure":delP}
def allowedPressure1(re,ar,eqd,d,ar2,m):
    f=0.0035+(0.264/(re**0.42))
    delF=4*f*((m/ar2)**2)*ar/(2*(d**2)*eqd*4.18*(10**8))
    delP=(delF2)*48.4/144
    return {"Friction Factor":f,"delF":delF,"Allowable Pressure":delP}
```

```python
print("Double pipe Heat Exchanger")
print("-"*100)
print("Hot Fluid: Gasoline")
print(outer_pipe(1.049,0.84,1653.47,1.094,820))
print(nusseltgasoline(0.521,131,1.094,0.034,0.087,27479.97340867542))
print(tw(391.8259082845798,151.97980969051227,99.5,131,0.84,0.622))
print(heatgasoline(391.8259082845798,phi(0.45,0.48)))
print(allowedPressure1(12302.8112,64,0.0175,72.52,0.00215,1653.47))
print("-"*100)
print("Overall and Design Co-efficient")
print(ud(342.034,164.093,0.0004))
print("-"*100)
print("Cold Fluid:Kerosene")
print(inner_pipe(0.622,1384.164333,3.388,760))
print(nusseltkerosene(0.485,99.5,3.388,0.0518,0.078,10031.605951089647))
print(heatkerosene(151.97980969051227,phi(1.4,1.2)))
print(allowedPressure2(16143.158,32,0.0518,69.996,0.00211,2227.843))
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Double pipe Heat Exchanger
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Hot Fluid: Gasoline
{'Area': 0.00215, 'Equivalent Dia': 0.0392, 'Velocity': 1.2695, 'Reynolds Number': 27503.291, 'Mass Velocity': 767566.343}
{'h/phi': 342.034}
{'tw': 120.791}
{'h': 388.30155317511895}
{'Friction Factor': 0.00857, 'delF': 15.1769, 'V': 2.821, 'delF2': 0.495, 'Pressure': 8.724}
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Overall and Design Co-efficient
{'Uc': 112.18, 'Ud': 59.12}
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Cold Fluid:Kerosene
{'Area': 0.00211, 'Velocity': 1.883, 'Reynolds': 16143.158, 'Mass Velocity': 1055849.763}
{'h/phi': 164.093}
{'h': 155.29534822296844}
{'Friction Factor': 0.00801, 'delF': 5.387, 'Pressure': 2.998}
```

Conclusion:

- Number of hairpins = 2
- Arrangement: Parallel
- The dirt factor is 0.00.0154 units
- Pressure drop is less than 0.7 bar

Drawbacks:

- There is radiative heat loss from the tube to the environment, however, it is very less compared to the heat transfer happening inside the tubes.
- We have considered the non-standard pipe 1x1/2, which might not be available in the market.
- We have increased the flow rate to 750 kg/hr, as the initial value didn't satisfy various conditions like velocity to be at least 1m/s-1.5m/s, also it is preferable to have the flow in a turbulent region and using the previous value, the flow was in the transition region and we don't have defined friction factors in this region, which might lead to further errors on the design. Hence the flow rate was increased.