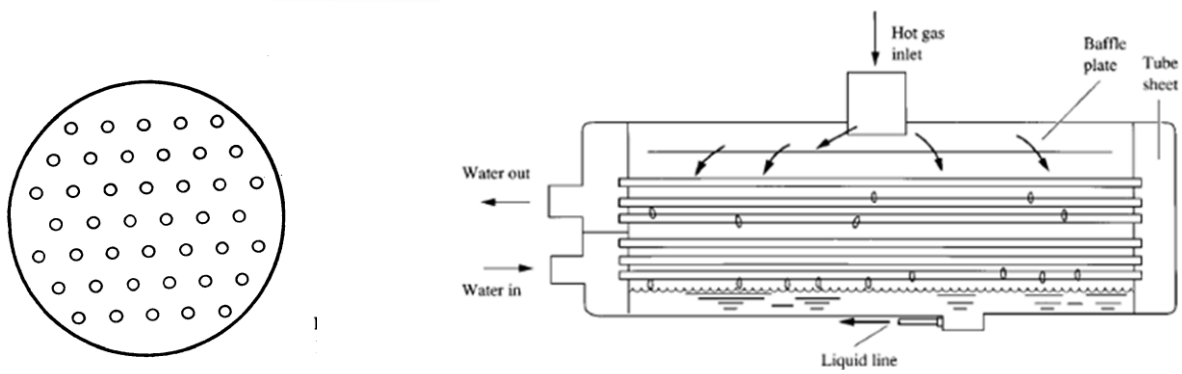
Example 12-3 The condensing area is to be specified for a refrigerant 22 condenser of a refrigerating system that provides a capacity of 80 kW for air conditioning. The evaporating temperature is 5°C, and the condensing temperature is 45°C at design conditions. Water from a cooling tower enters the condenser at 30°C and leaves at 35°C.

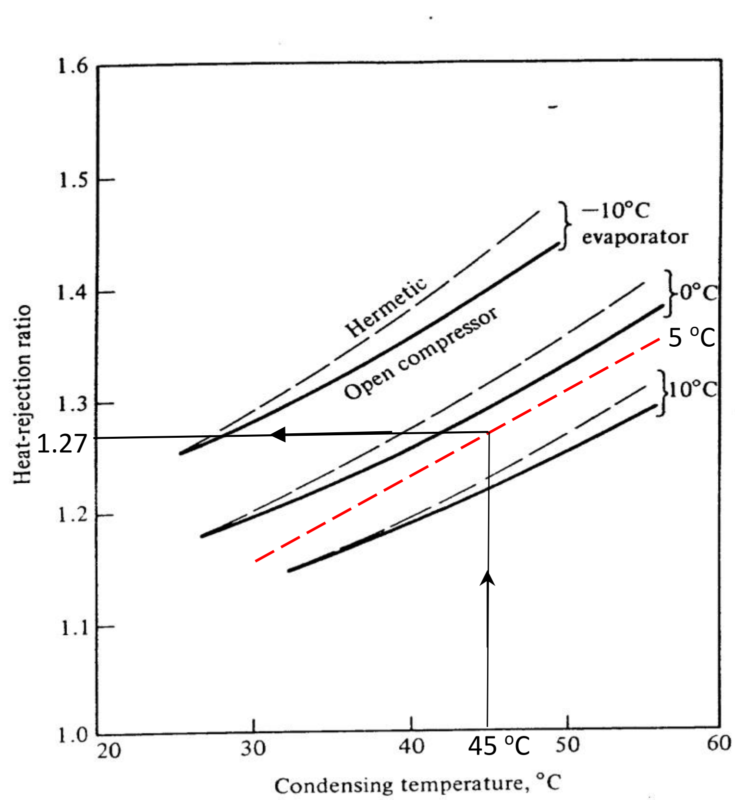
A two-pass condenser with 42 tubes, arranged as shown in Fig. 12-15, will be used, and the length of tubes is to be specified to provide the necessary area. The tubes are copper and are 14 mm ID and 16 mm OD.



Solution:- Given (Water cooled refrigeration condenser, Refrigerant 22, Qe = 80 kW, Te = 5 °C, Tc = 45 °C, Cooling water T_{in} = 30 °C and T_{out} = 35 °C , Two-pass 42 Tubes, copper tubes ID= 14 mm , OD = 16 mm, Hermetic compressor, ($1/h_{ff}$ = 0.000176 m^2 .K/W) Find condenser area and tube length.

$$Heat\ rejection\ ratio = \frac{Q_c}{Q_e}$$

Q_C = Heat rejection ratio X Q_e



Q_C = 1.27 X 80 = 101.6 kW

$Q_C = U_o A_o$ LMTD

$$\frac{1}{U_0 A_o} = \frac{1}{h_0 A_o} + \frac{x}{k A_m} + \frac{1}{h_{ff} A_i} + \frac{1}{h_i A_i}$$

$$\frac{1}{U_0} = \frac{A_o}{h_0 A_o} + \frac{x\, A_o}{k A_m} + \frac{A_o}{h_{ff} A_i} + \frac{A_o}{h_i A_i}$$

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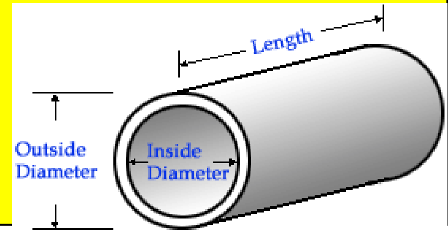
$$\frac{1}{U_0} = \frac{1}{h_0} + \frac{x\,A_o}{kA_m} + \frac{A_o}{h_{ff}A_i} + \frac{A_o}{h_iA_i}$$

$A_o = \pi \times OD \times L$ (Outside surface area)

$A_i = \pi \times ID \times L$ (Inside surface area)

$A_m = \frac{A_o + A_i}{2}$ (Mean area)

$x = \frac{OD - ID}{2}$ (Wall thickness)



$$\text{LMTD} = \frac{(t_c - t_i) - (t_c - t_o)}{\ln\left[(t_c - t_i)/(t_c - t_o)\right]}$$

Finding h_o

Condensing coefficient From Eq. (12-24)

$$h_{\text{cond}} = 0.725\left(\frac{g\rho^2 h_{fg} k^3}{\mu\,\Delta t\,ND}\right)^{1/4}$$

g = Gravity acceleration 9.81 m/s^2

h_{fg}= Latent heat of vaporization ($h_g - h_f$) J/kg , R-22 table of properties at 45 °C

h_{fg} = (417.308 – 256.396)= 160.912 kJ/kg = 160912 J/kg

ρ = Refrigerant density ($1/v_f$) kg/m^3

ρ = (1/ (0.90203 x 10^{-3})) = 1108.6 kg/m^3

k = Refrigerant thermal conductivity W/m.K (from table 15-5 by interpolation)

40	0.0805
45	k
60	0.0704

$$\left[\frac{k - 0.0805}{45 - 40} = \frac{0.0704 - 0.0805}{60 - 40}, k = 0.0779\ {}^{W}\!/_{m.K}\right]$$

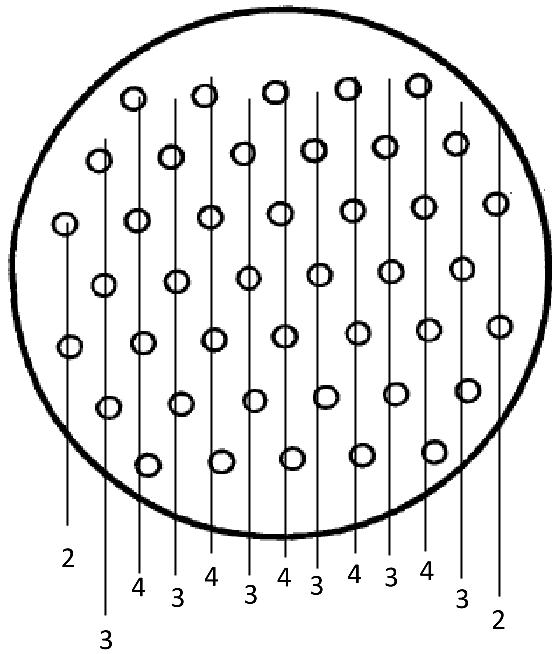
μ = Refrigerant viscosity (liquid viscosity) Pa.s

40	0.000182
45	μ
60	0.000162

$$\left[\frac{\mu - 0.000182}{45 - 40} = \frac{0.000162 - 0.000182}{60 - 40}, \mu = 0.000177\ Pa.s\right]$$

Δt = Temperature difference between refrigerant vapor and outer surface of tube. K (Δt = 5 K)

D= Outside diameter of tube (OD) m.   (OD = 0.016 m)



The average number of tubes in a vertical row N is

$$N = \frac{2+3+4+3+4+3+4+3+4+3+4+3+2}{13} = 3.23$$

$$h_{cond} = 0.725 \left[\frac{9.81(1109^2)(160{,}900)(0.0779^3)}{0.000180(5)(3.23)(0.016)} \right]^{1/4}$$

$$= 1528 \text{ W/m}^2 \cdot \text{K}$$

$$\frac{1}{h_o} = \frac{1}{1528} = 6.544 \times 10^{-4}\ m^2.K/W$$

$$\frac{xA_o}{kA_m} = \frac{\frac{(OD-ID)}{2} \times (\pi \times OD \times L \times No.of\ tubes)}{k \times ((\pi \times OD \times L \times No.) + (\pi \times ID \times L \times No.))/2} = \frac{\frac{(OD-ID)}{2}}{k} \times \frac{OD}{\frac{(OD+ID)}{2}}$$

$$\therefore \frac{xA_o}{kA_m} = \frac{\frac{(0.016-0.014)}{2}}{390} \times \frac{0.016}{\frac{(0.016+0.014)}{2}} = 2.735 \times 10^{-6} = 0.000002735\ m^2.K/W$$

$$\frac{A_o}{h_{ff}A_i} = \frac{1}{h_{ff}} \times \frac{\pi \times OD \times L \times No.of\ tubes}{\pi \times ID \times L \times No.of\ tubes} = 0.000176 \times \frac{0.016}{0.014} = 2.0114 \times 10^{-4}\ m^2.K/W$$

Finding h_i

$$Nu = C\,Re^n\,Pr^m$$

$$\frac{hD}{k} = 0.023\left(\frac{VD\rho}{\mu}\right)^{0.8}\left(\frac{c_p\mu}{k}\right)^{0.4} \qquad (12\text{-}9)$$

$$Q_C = \dot{m}_w \times Cp_w \times (T_o - T_i)$$

$$101.6 = \dot{m}_w \times 4.19 \times (35-30)$$

$$\dot{m}_w = 4.85\ kg/s$$

$$V = \frac{\dot{m}_w}{\rho \times (21 \times \frac{\pi}{4} \times (0.014)^2}$$

$$V = \frac{4.85}{1000 \times (21 \times \frac{\pi}{4} \times (0.014)^2} = 1.5\ m/s$$

توضيحات

$$\dot{m} = \rho \times \dot{V}$$

$$\dot{m} = mass\ flow\ rate\ \frac{kg}{s}$$

$$\dot{V} = Volume\ flow\ rate\ \frac{m^3}{s} = (Tubes\ cross\ section\ area) \times Velocity$$

$$A = \frac{No.of\ Tubes}{Pass} \times Tube\ cross\ sectional\ area$$

$$\dot{V} = A \times V = (21 \times \frac{\pi}{4}\ (0.014)^2) \times V$$

$$\dot{m} = \rho \times \dot{V} = \rho \times (21 \times \frac{\pi}{4}\ (0.014)^2) \times V$$

Water properties at temperature average temperature (35+30)/2 = 32.5 °C

ρ_w= 995 kg/m^3, Cp_w =4190 J/kg.K , μ_w = 0.000773 Pa.s , k_w = 0.617 W/m.K

$$\frac{h_i \times ID}{k} = 0023\ (\frac{V \times ID \times \rho}{\mu})^{0.8} \times (\frac{\mu \times Cp}{k})^{0.4}$$

$$\frac{h_i \times 0014}{0.617} = 0023\ (\frac{1.5 \times 0.014 \times 995}{0.000773})^{0.8} \times (\frac{0.000773 \times 4190}{0.617})^{0.4}$$

h_i = 6910 W/m^2.K

$$\frac{A_o}{h_i \times A_i} = \frac{(\pi \times OD \times L \times No.of\ tubes)}{h_i \times (\pi \times ID \times L \times No.of\ tubes)} = \frac{0016}{6910 \times 0.014} = 1.653 \times 10^{-4} \quad m^2.K/W$$

$$\frac{1}{U_o} = 6.544 \times 10^{-4} + 2.735 \times 10^{-6} + 2.0114 \times 10^{-4} + 1.6539 \times 10^{-4} = 1.0236 \times 10^{-3}$$

$\therefore U_o = 976.88\ W/m^2.K$

The LMTD is

$$LMTD = \frac{(45 - 30) - (45 - 35)}{\ln \frac{(45 - 30)}{(45 - 35)}} = 12.33°C$$

$Q_C = U_o A_o$ LMTD

101.6 = 976.88 X A_o X 12.33

$$A_o = \frac{101{,}600\ W}{977(12.33)} = 8.43\ m^2$$

A_o = π X OD X L X No. of tubes

8.43 = π X 0.016 X L X 42

$$Length = \frac{8.43\ m^2}{(42\ tubes)\ (0.016\pi)} = 4.0\ m$$