Q.1 A refrigeration suction line having outer diameter 30 mm is required to be thermally insulated. The outside air convective heat transfer coefficient is 12 W/m^2 °C. The thermal conductivity of the insulating material is 0.3 W/m °C. Determine:

(i) Whether the insulation will be effective

(ii) Estimate the maximum value of thermal conductivity of insulating material to reduce heat transfer

(iii) The thickness of cork insulation to reduce the heat transfer to 20% (k=0.04 W/m °C)

$d = 30 mm$

$r = 15 mm$

$= 0.015 m$

$h = 12 \ W/m^2 °C$

$K_{in} = 0.3 \ W/m °C$

i)

Critical Radius $r_c = \frac{K_{insulation}}{h_{air}}$

$= \frac{0.3 \ W/m°C}{12 \ W/m^2 °C}$

$= 0.025 m$

$= 25 mm$

$r_2 = 15mm$

$r_2 < r_c$

insulation wouldbe ineffective

ii) for effective insulation

$$r_o \geq r_c \left(= \frac{k}{h}\right)$$

$$0.015 \geq \frac{k_{in}}{12}$$

$$k_{in} \leq (0.015 \times 12)$$

$$= 0.18 \ \text{W/m°C}$$

iii) for bare pipe

$$Q = h_o A \Delta T$$

$$= h_o \times 2\pi r l \Delta T$$

$l = 1$

$$= h_o \times 2\pi r_o \times \Delta T$$

for pipe with cork insulation

$$q_{ci} = \frac{\Delta T}{\frac{1}{2\pi k l}\ln(r_c/r_o) + \frac{1}{2\pi r_c l}\frac{1}{h_o}}$$

$l = 1\,m$

$$= \frac{\Delta T}{\frac{1}{2\pi k}\ln(r_c/r_o) + \frac{1}{2\pi r_c}\frac{1}{h_o}}$$

$$q_{ci} = 0.20 \times q.$$

$$\frac{\Delta T}{\frac{\ln(r_c/r_o)}{2\pi k_c} + \frac{1}{2\pi r_c h_o}} = 0.20 \times h_o \times 2\pi r_o \times 1 \times \Delta T$$

$$\frac{\ln(r_c/r_o)}{2\pi k_c} + \frac{1}{2\pi r_c h_o} = \frac{1}{0.20 \times h_o \times 2\pi r_o} = \frac{1}{0.20 \times 12 \times 0.015} = 25.25$$

$$\frac{\ln(r_c/r_o)}{K_{cl}} + \frac{1}{12 r_c} = 25.25$$

by Solving above eqn.

we get $r_c = 0.036\,m$

$r_c = 36\,mm$

Thickness of Cork insulation $= r_c - r_o$

$= 36 - 15$

$= 21\,mm$

Q.2 An electrical cable of 5 mm radius is applied a uniform sheathing of plastic insulation (k = 0.16 W/m-deg). The convective film coefficient on the surface of bare cable as well as insulated cable was estimated as 8 W/m^2-deg and a surface temperature of 70°C was noted when the cable was directly exposed to ambient air at 20°C. Calculate the most economical thickness and the corresponding increase in heat dissipation due to insulation. Also find out the increase in current carrying capacity of the cable by providing critical thickness of insulation.

$r = 5\,mm$

$K_{in} = 0.16\ W/m°C$

$h = 8\ W/m^2 c$

$T_s = 70°C$

$T_a = 20°C$

Case - I

for bare cable

$Q_{bare} = h_o A (T_s - T_a)$

$= h_o\, 2\pi r l (T_s - T_a)$

$= 8 \times 2\pi \times 0.005 \times (70 - 20) \quad (l = 1)$

$= 12.56\ W/\text{unit length}$

Case - II

wire with insulation

$$Q = \frac{\Delta T}{R_{th}} = \frac{(T_s - T_a)}{\frac{1}{h_o 2\pi r_o l} + \frac{\ln(r_o/r_i)}{2\pi K_{in} l}}$$

for economical value

$$r_o = r_c = K/h_o$$

$$q_{ins} = \frac{(T_s - T_a)}{\frac{1}{2\pi h_o l \times K/h_o} + \frac{1}{2\pi K l} \ln\left(\frac{K}{h_o} \cdot \frac{1}{r_i}\right)}$$

$$q_{in} = \frac{(T_s - T_a)}{\frac{1}{2\pi K l} + \frac{1}{2\pi K l} \ln\left(\frac{K}{h_o r_i}\right)}$$

$$= \frac{(70 - 20)}{\frac{1}{2\pi \times 0.16} + \frac{1}{2\pi \times 0.16} \ln\left(\frac{0.16}{8 \times 0.005}\right)} \quad (l = 1)$$

$= 21$ W/unit length

⇒ Percentage increase in heat Dissipation due to insulation.

$$\frac{Q_{in} - Q_{bare}}{Q_{bare}} = \frac{21 - 12.56}{12.56} = 0.6719 = 67.19\%$$

$$r_c = \frac{k}{h_o} = \frac{0.16}{8} = 0.02\,m = 20\,mm$$

thickness of insulation = 20 - 5 = 15 mm.