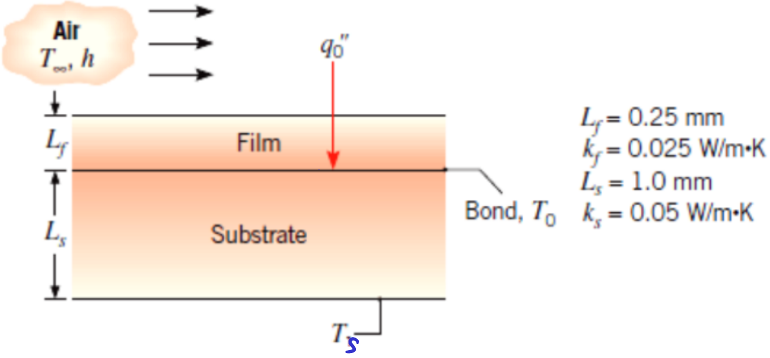
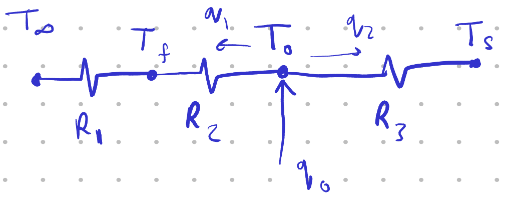
Plates

2

1. In a manufacturing process, a transparent film is being bonded to a substrate as shown in the figure. To achieve the bond at a temperature T_o, a radiant source is used to provide a radiation heat flux q_o (W/m^2), all of which is absorbed at the bonded surface. The back of the surface is maintained at T_s, while the free surface of the film is exposed to air at T_∞ and convection coefficient h. show the thermal circuit representing the steady-state heat transfer and calculate the value of q_o required to maintain the bonded surface at T_o=60°C and T_s=30°C. Take L_f=0.25mm, L_s=10mm, k_f=0.025, k_s=0.05W/m^2.°K, T_∞=20°C and h=50 W/m^2.K. Also calculate and T_f.





$R_1 = \frac{1}{hA}$

$R_2 = \frac{L_f}{k_f A_f}$

$R_3 = \frac{L_s}{k_s A}$

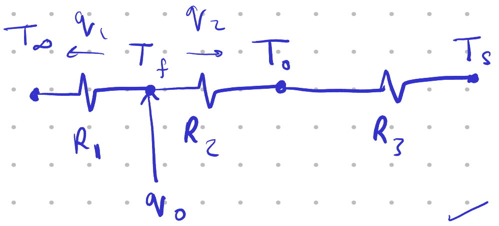
$q_1 = \frac{T_o - T_\infty}{R_1 + R_2}$

$q_2 = \frac{T_o - T_s}{R_3}$

$q_1 = \frac{T_f - T_\infty}{R_1} \longrightarrow T_f = \checkmark$

$q_o = q_1 + q_2 = \checkmark$

If the film layer is not transparent and all the radiation heat flux is absorbed at its upper surface, determine the radiation heat flux required to achieve bonding.

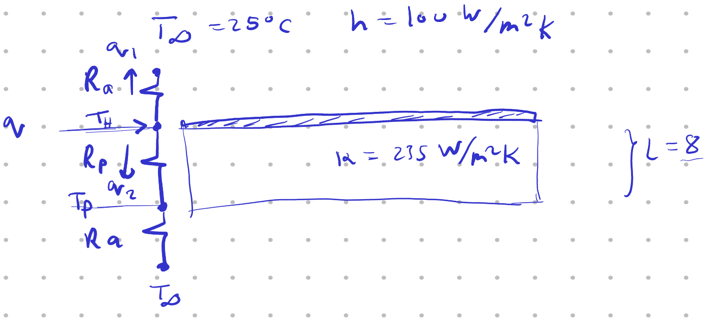


$q_2 = \frac{\overset{\checkmark}{T_f} - T_o}{R_2}$

$q_1 = \frac{\overset{\checkmark}{T_f} - T_\infty}{R_1} = \frac{T_o - T_s}{R_3}$

$q = q_1 + q_2$

2. A thin plate heater is attached to higher surface of 8 mm thickness aluminum horizontal plate which has k=235 W/m^2.K, this surface and the other lower surface of the aluminum plate are exposed to air stream of temperature 25°C and convective coefficient 100 W/m^2.K, for both surfaces. If the heater dissipates 10kW/m^2, what is the heater and lower plate surface temperature? ***[Ans. T_{heater}=75.09°C and T_{Lower}=74.92°C]***



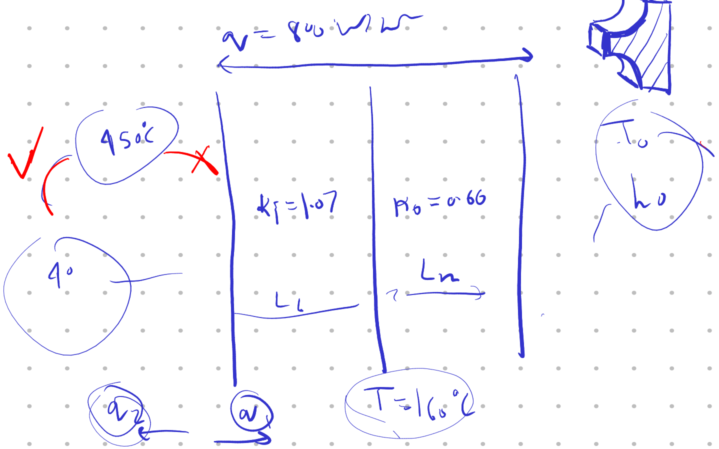
$\frac{KA}{L}$ (OT)

$$q_1 = \frac{T_H - T_\infty}{R_a} \qquad q_2 = \frac{T_H - T_\infty}{R_a + R_p} = \frac{T_H - T_p}{R_p}$$

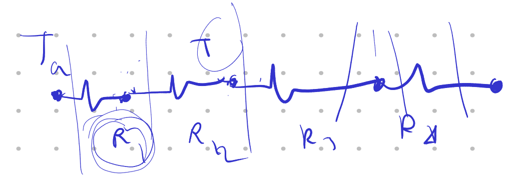
$q = q_1 + q_2 \rightarrow T_H \rightarrow T_p$ ✓

3. A furnace wall has an inner layer of silica brick (k_i=1.07 W/m.K) and an outer layer of masonry brick (k_o=0.66 W/m.K). The furnace gas conditions are T_i=450°C and h_i=40 W/m^2.K and T_o=25°C and h_o=28 W/m^2.K. If desired that the interface temperature be 160°C. Calculate the thickness of both layers, if a heat loss is not exceeded than 800 W/m^2. ***[Ans. L_{brick}=361mm and $L_{masonry}$=88mm]***

$-q_2 \cancel{=} q_1$



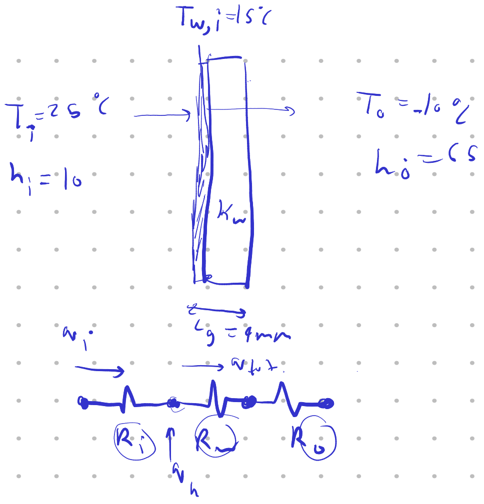
$\frac{1}{h}$ $\frac{L}{K}$



$$\frac{T_a - T_i}{R_1 + R_2 -}$$ ✓

4. The rear window of an automobile is defogged by attaching a thin, transparent film-type heating element to its inner surface. By electrically heating this element, a uniform heat flux may be established at the inner surface. What is the electric power that must be provided per unit window area to maintain an inner surface temperature of 15°C? The interior air temperature and convection coefficient are 25°C and 10 W/m^2. K, respectively, and the exterior air temperature and convection coefficient are -10°C and 65 W/m^2.K respectively. The glass is 4mm thick and has a thermal conductivity of 1.4W/m.K.

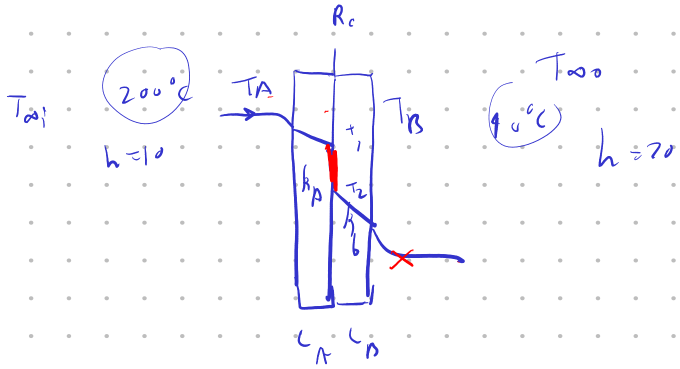
[Ans. Q_{heater}=1270.5W/m^2]



$$q_i + q_h = \frac{T_{w,i} - T_o}{R_w + R_o}$$

$$q_i = \frac{T_i - T_{w,i}}{R_i}$$

5. Consider a plane composite wall is composed of two materials (A &B) of thermal conductivity k_A=0.1 W/m.K and k_B=0.04 W/m.K and thickness L_A=10mm and L_B=20mm. The contact resistance at the interface between the two materials is known to be 0.3m^2.K/W. Material A adjoins a fluid at 200°C for which h=10 W/m^2.K, while material B adjoins a fluid at 40°C for which h=20 W/m^2.K; sketch the temperature distribution and calculate the heat transfer rate through the wall if it is 2.5m long &2m wide. Also calculate the outer surface temperature for material A&B and the drop in temperature across the interface. ***[Ans. Q_{tr}=762W, T_A=184.8°C, T_B=47.6°C and $\Delta T_{interface}$=45.7°C]***



$A = 2.5 \times 2$

$$\frac{R''_c}{A} = R_c$$

$$R_{A,B} = \frac{L_{A,B}}{k_{A,B} A}$$

$$R_{\infty i,o} = \frac{1}{h_{i,o} A}$$

$$q = \frac{T_{\infty i} - T_{\infty o}}{R_i + R_A + R_B + R_o + \boxed{R_c}}$$

$$q = \frac{T_A - T_1}{R_A} \checkmark$$

$$q = \frac{T_2 - T_B}{R_B} \checkmark$$

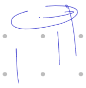
Cylinders

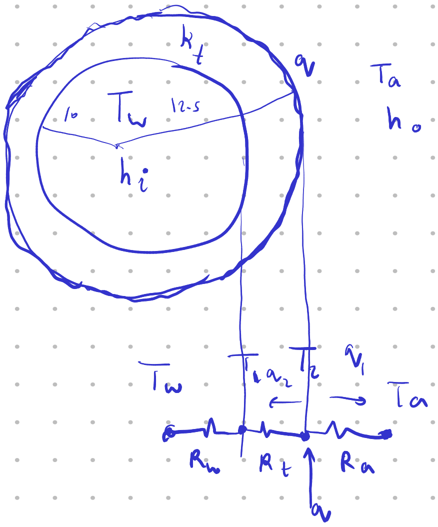
6. Water at an average temperature of 320K flows inside a Teflon tube (k=0.17W/m.K) with inside connective coefficient h_i=200W/m^2.K. The inner and outer diameters of the tube are 20mm and 25mm respectively. A thin electric heating tape is wounded around the tube. The tape provides a uniform heat flux of 2kW/m^2, and ambient air at temperature of 300K, maintains an outside convective coefficient of 12W/m^2.K. Calculate:

i- The outer surface temperature of the Teflon tube.

ii- The percentage of heat flux transferred to the water.

[Ans. i- T_h=351.4K and ii.69.3%].





$$q_1 = \frac{T_2 - T_a}{R_a}$$

$$q_2 = \frac{T_2 - T_w}{R_t + R_w} = \frac{T_2 - T_1}{R_t}$$

$$q = q_1 + q_2 \longrightarrow T_2 = ✓$$

$$\frac{q_2}{q} \times 100$$

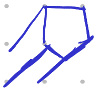
$$A = 2\pi r H \to h$$

$$R_h = \frac{1}{hA}$$

$$R_k = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi k H}$$

If we need benefit insulation around the electric heating tape in the previous problem to increase the percentage of heat that transferred to water, determine the maximum value of $k_{in,max}$ and repeat calculation of items i and ii when use 30 mm thickness for that insulation with the same heater capacity (2 kW/m^2).

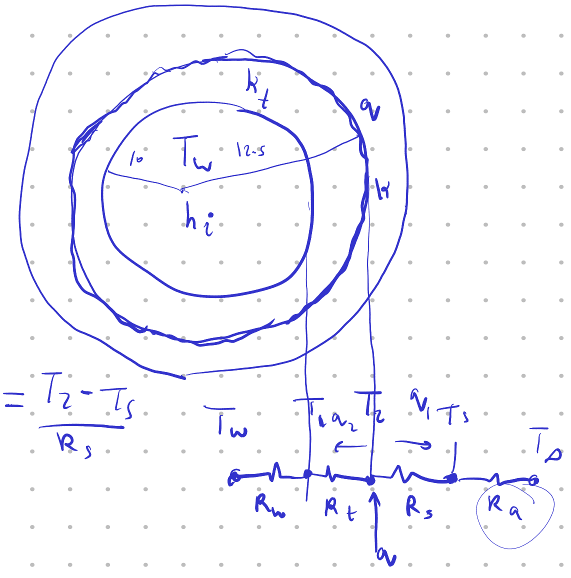
[Ans. $k_{in,max}$=0.15W/m.K, i-T_h= 355.4K and ii-78.3%]



$$R_s = \frac{\ln\left(\frac{42.5}{12.5}\right)}{2\pi k}$$

$$q_2 = \frac{T_2 - T_w}{R_w + R_t}$$

$$q_1 = \frac{T_2 - T_\infty}{R_s + R_a} = \frac{T_2 - T_s}{R_s}$$



$$\frac{h}{2\pi r_s}$$

T_a
h_o

$$\frac{T_2 - T_\infty}{R_s + R_a} =$$

$$\frac{h}{k} = r_{cr} \to q_{max} : r_{tube} = r_{cr} \to k$$

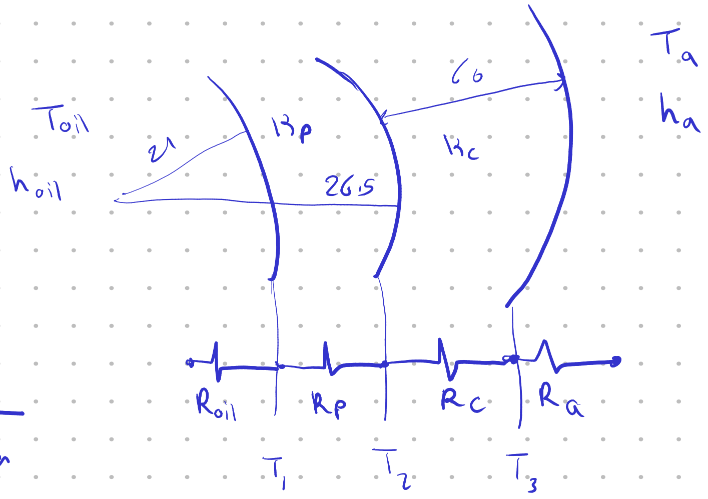
7. An oil pipe line D_i=42mm and D_o=56mm is covered with large concrete with thickness 60mm. the mean temperature and the convective coefficient for the oil filling the pipe are 140°C and 120 W/m^2.K respectively. The concrete layer is exposed to ambient air at 30°C with convective coefficient of 10 W/m^2.K. If the thermal conductivities of the pipe material and the concrete layer are 42 and 1.26 W/m.K respectively, Calculate:

i-The heat loss from bare pipe line in watt per meter length.

ii-The heat loss from the pipe line covered by the concrete layer in W/m length.

iii-What should be the magnitude of the thermal conductivity of the insulation $k_{in,max}$ to ensure a loss of heat from the pipe line covered with insulation with any thickness not exceed than the loss from the bare pipeline.

$$R = \frac{\ln(\frac{r_o}{r_i})}{2\pi k H}$$



$$q_1 = \frac{T_{oil} - T_a}{R_{oil} + R_p + R_a}$$

$$q_2 = \frac{T_{oil} - T_a}{R_{oil} + R_p + R_c + R_a}$$

$$\frac{k}{h} = r_o \longrightarrow k_{max}$$

8. Hot gases at 300°C flow inside a steel tube having D_i=100mm and D_o=110mm and k=50 W/m.K. it is required to cover the tube with two layers of insulation having equal thickness of 50mm. The outer surface of the insulation layer is exposed to air at 25°C. Two types of insulating materials are to be used: material ***A*** having k_A=0.06 W/m.K and material ***B*** having k_B=0.12W/m.K. The contact resistance between the two layers is 0.01 m^2.k/W. If the connective coefficient for gases and ambient air are 100W/m^2.K and 8 W/m^2.K respectively, Determine:

i- Which insulating material should be placed directly on the outer tube surface ***(A or B).***

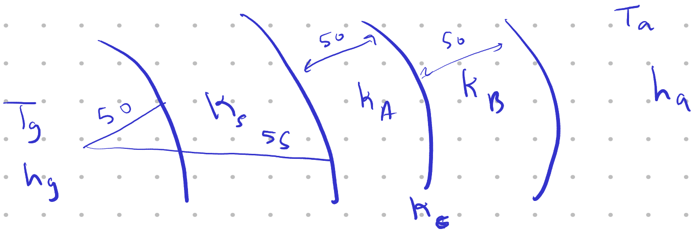
ii- For the chosen condition, calculate the heat loss from gases to the ambient air per meter length.

iii-Calculate the interface temperature and the outer temperature of the insulation.

[Ans i-Material A is direct contacted to tube surface, ii-Q_{Loss}=114.23W/m.l, iii-$T_{interface}$=100.4°C and $T_{in,o}$=98.7°C].

$$\frac{k_B}{h_a} = r_B \; ; \; r_B \le r_t + 50$$

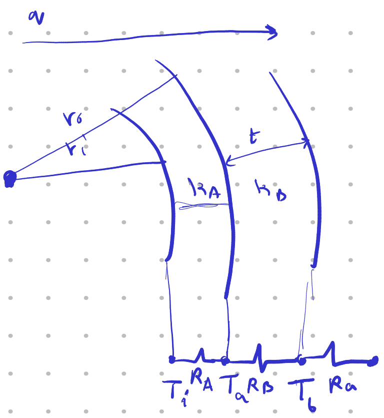
$$\frac{k_a}{h_a} = r_a \; ; \; r_a \le r_t + 50$$



$$r_b > r_a \longrightarrow r_b \text{ out} \quad \text{else } r_a \text{ out}$$

9. A hollow aluminum sphere, with an electric heater in the center, is use to test to determine the thermal conductivity of insulating materials. The inner and outer radii of the sphere are 0.15m and 0.18m, respectively and testing is done under steady state conditions. With the inner surface of the aluminum maintained at 250°C in a particular test, a spherical shell of insulation is cast on the outer surface of the sphere to a thickness of 0.12m. The system in a room for which the air temperature is 20°C with convective coefficient 30W/m^2.K. If 80 Watt is dissipate by the heater under steady-state conditions. What the thermal conductivity of the insulation? ***[Ans. k_{in}=0.0622W/m.K].***

$A = 4\pi r^2$



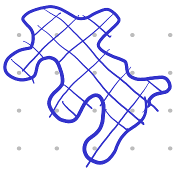
T_∞
h_o

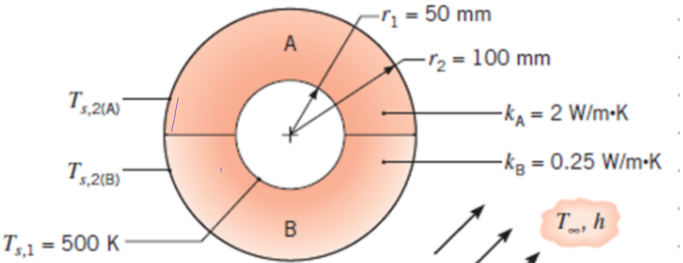
$$q = \frac{T_i - T_\infty}{\Sigma R}$$

$K_A \uparrow\uparrow \longrightarrow R_A \simeq 0$

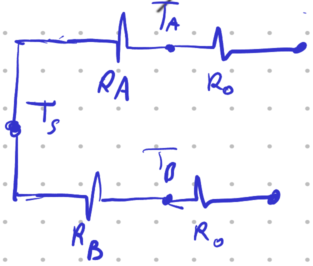
10. Air flowing through a long, thin-walled pipe maintaining the inner wall at a uniform temperature of 500K. The pipe is covered with an insulation blanket composed of two different materials ***A*** and ***B*** as shown in the figure. The interface between the two materials may be assumed to have an infinite contact resistance and the entire outer surface is exposed to air for which T_{air}=300K and h=25 W/m^2.K. What is the total heat loss from the pipe? Also calculate Temperature of $T_{s2,A}$ and $T_{s2,B}$.

[Ans. Q $_{Loss}$=1040W/m.L, $T_{s,A}$=407K and $T_{s,B}$=325K]





$R_A = 2\pi r/2\ H$



T_∞
h_o

$$q_1 = \frac{T_s - T_\infty}{R_A + R_o}$$

$$q_2 = \frac{T_s - T_\infty}{R_B + R_o}$$

$\oplus \rightarrow q$