Exercise 2.1

The wall of a house is a composite structure consisting, from outside to inside, of a layer of wood ($L_w = 20mm$, $k_w = 0.12W/mK$), a fiberglass insulation ($L_f = 100mm$, $k_f = 0.038W/mK$, $\rho_f = 28kg/m^3$) and a plaster board($L_p = 10mm$, $k_p = 0.17W/mK$). On a winter day the air inside is at $T_{in} = 20°C$ while the air outside is at $T_{out} = -15°C$. Furthermore, due to the wind and internal ventilation the convection coefficients are $h_{out} = 60W/m^2K$ and $h_{in} = 30W/m^2K$. The wall has a total surface of $350m^2$.

a) Draw a sketch of the system indicating all the dimensions and material parameters of the problem (known and unknown). List all the assumptions.

b) Draw the equivalent electrical circuit and determine a symbolic expression for the total thermal resistance of the wall, including inside and outside convection effects.

c) Determine the total heat loss through the wall.

d) If the wind outside increases, raising h_{out} to $300W/m^2K$, determine the percentage increase in the heat loss

e) What is the controlling resistance that determines the amount of heat flux through the wall?

f) OPTIONAL QUESTION (Difficult) While the conditions inside remain unchanged, consider a varying external temperature of the form:

$$T_{\infty,o}(K) = 273 + 5sin(\frac{2\pi}{24}t)$$

for $0 \leq t \leq 12h$

$$T_{\infty,o}(K) = 273 + 11sin(\frac{2\pi}{24}t)$$

for $12 \leq t \leq 24h$.

The convection coefficient outside is always $h_{out} = 60W/m^2K$. Assume a quasi-steady condition for which changes in energy storage within the wall may be neglected. Can you estimate the daily heat-loss through the wall?

g) If the fuel to heat the room costs $0.1chf/kWh$, how much would be the daily bill to heat the room?

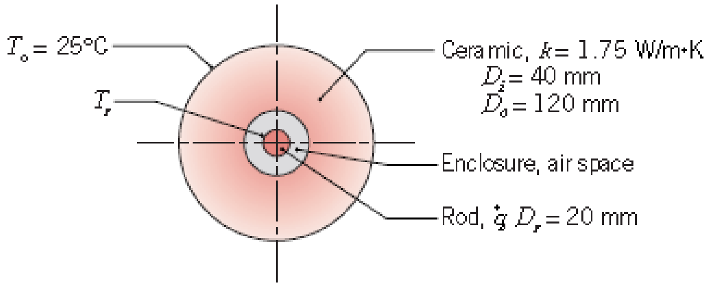
Exercise 2.2

An electric current flows through a long rod ($D_{rod} = 20mm$) generating thermal energy at a uniform volumetric rate $\dot{q} = 2 \cdot 10^6 W/m^3$. The rod is concentric with a hollow ceramic cylinder ($D_{cer,inner} = 40mm$, $D_{cer,outer} = 120mm$, $k_{cer} = 1.75W/mK$), thus creating an enclosure that is filled with air. The temperature of the outside surface of the ceramic cylinder is $T_o = 25°C$. The thermal resistance per unit length due to radiation between the enclosure surfaces is $R'_{rad} = 0.3mK/W$ and the natural convection coefficient in the enclosure is $h = 20W/m2K$.

a) Draw a schematic of the system including all dimensions and material parameters. List all of the assumptions.

b) Construct a thermal circuit that can be used to calculate the surface temperature of the rod, T_r. Label all temperatures, heat rates and thermal resistances and evaluate each thermal resistance.

c) Calculate the surface temperature of the rod for the prescribed conditions.



Exercise 2.3

Consider a plane composite wall that is composed of three materials (A,B and C from left to right) of thermal conductivities $k_A = 0.24W/mK$, $k_B = 0.13W/mK$, $k_C = 0.5W/mK$. The three layers have thicknesses of $L_A = 20mm$, $L_B = 13mm$ and $L_C = 20mm$. A contact resistance of $R_{cont} = 0.01m2K/W$ exists at the interface between materials A and B as well as at the interface of materials B and C. The left face of the composite wall is insulated while the right face is exposed to convection with $h = 10W/m^2K$ and $T_{air} = 20°C$. For Case 1, thermal energy is generated within material A at a rate ($q_A = 5000W/m^3$). For Case 2 thermal energy is generated within material C at the rate ($q_C = 5000W/m^3$).

a) Draw a schematic of the wall and indicate all dimensions and material parameters.

b) Determine the maximum temperature within the composite wall under steady state conditions for Case 1.

c) Sketch the steady state temperature distribution on T-x coordinates for Case 1.

d) Sketch the steady state temperature distribution for Case 2 on the same T-x coordinates used for Case 1.

Exercise 2.4 FOR REVISION

Superheated steam at $575°C$ has to be conveyed from the boiler to the turbine of an electric power plant. To do so, steel tubes are used ($k_{steel} = 35W/mK$, $D_1 = 300mm$ inner diameter and $30mm$ wall thickness). To reduce heat losses to the surroundings a layer of calcium silicate insulation ($k_{ins} = 0.1W/mK$) is applied to the tubes. Furthermore, a thin sheet of aluminum, having an emissivity of $\epsilon = 0.2$, is used to wrap the tubes. The air and wall temperatures of the power plant are $T_{sur} = 27°C$. Assume that the temperature of the inner surface of a steel tube corresponds to that of the steam and assume a convection coefficient outside the tube of $h_o = 6W/m^2K$.

a) Make a sketch of the system, indicating all the dimensions and material parameters. List the assumptions.

b) Draw the equivalent electrical circuit. HARD QUESTION What is the minimum insulation thickness needed to ensure that the temperature of the aluminum sheet does not exceed $T_{s,omax} = 50°C$? (Note: you will get a complex expression that can give you a numerical value only through iteration)

c) What is the corresponding heat loss per meter of tube length?

d) (Hard question) How would you expect the temperature of the aluminum sheet to change as a function of the thickness of the insulating layer?

Exercise 2.5 FOR REVISION

Steam flowing through a long, thin-walled pipe maintains the pipe wall at a uniform temperature of $T_w = 500K$. The pipe is covered with an inhomogeneous insulation blanket comprised of two different materials, A ($k_A = 2W/mK$) and B ($k_B = 0.25W/mK$). The interface between the two materials may be assumed to have an infinite contact resistance and the entire outer surface is exposed to air at $T_{air} = 300K$ such that the convection coefficient is $h = 25W/m^2K$.

a) Sketch the thermal circuit of the system. Label all pertinent nodes and resistances.

b) For the given conditions, what is the total heat loss from the pipe? What are the outer surfaces T_A and T_B?