Problem 1.2-22

You are designing a cubical case that contains electronic components that drive remotely located instruments. You have been asked to estimate the maximum and minimum operating temperature limits that should be used to specify the components within the case. The case is W = 8 inch on a side. The emissivity of the paint used on the case is $\varepsilon = 0.85$. The operation of the electronic components within the case generates between $\dot{q} = 5$ and $\dot{q} = 10$ W due to ohmic heating, depending on the intensity of the operation. The top surface of the case is exposed to a solar flux $\dot{q}''$. All of the surfaces of the case convect (with average heat transfer coefficient $\overline{h}$) and radiate to surroundings at T_∞. The case will be deployed in a variety of climates, ranging from very hot ($T_{\infty,max}$ = 110°F) to very cold ($T_{\infty,max}$ = -40°F), very sunny ($\dot{q}''_{max}$ = 850 W/m^2) to night ($\dot{q}''_{min}$ = 0 W/m^2), and very windy ($\overline{h}_{max}$ = 100 W/m^2-K) to still ($\overline{h}_{min}$ = 5 W/m^2-K). For the following questions, assume that the case is at a single, uniform temperature and at steady state.

a.) Come up with an estimate for the maximum operating temperature limit.

The case temperature will be highest when the case generation is maximum, the ambient temperature is maximum, the solar flux is maximum, and the heat transfer coefficient is minimum. These inputs are entered in EES:

```
$UnitSystem SI MASS RAD PA K J
$Tabstops 0.2 0.4 0.6 3.5 in

"Inputs"
W=8 [inch]*convert(inch,m)                          "side dimension"
e=0.85 [-]                                          "emissivity"
q_dot=10 [W]                                        "dissipation in case"
q``=850 [W/m^2]                                     "solar flux"
h_bar=5 [W/m^2-K]                                   "heat transfer coefficient"
T_infinity=converttemp(F,K,120 [F])                 "ambient temperature"
```

The surface area of the case is:

$$A_s = 6W^2 \tag{1}$$

The resistance to convection from the case is:

$$R_{conv} = \frac{1}{\overline{h}\, A_s} \tag{2}$$

```
A_s=6*W^2                                           "surface area"
R_conv=1/(h_bar*A_s)                                "convection resistance"
```

The radiation resistance cannot be calculated without knowing the surface temperature of the case, T. Therefore, a reasonable value of the surface temperature is assumed. The radiation resistance is:

$$R_{rad} = \frac{1}{\varepsilon \sigma A_s \left(T^2 + T_\infty^2\right)\left(T + T_\infty\right)} \tag{3}$$

```
T=350 [K]                                                   "guess for the case temperature"
R_rad=1/(e*A_s*sigma#*(T^2+T_infinity^2)*(T+T_infinity))    "radiation resistance"
```

The guess values are updated and the assumed value of the case temperature is commented out. An energy balance on the case leads to:

$$\dot{q}_s + \dot{q} = \frac{\left(T - T_\infty\right)}{R_{conv}} + \frac{\left(T - T_\infty\right)}{R_{rad}} \tag{4}$$

where $\dot{q}_s$ is the absorbed solar irradiation.

$$\dot{q}_s = W^2 q'' \tag{5}$$

```
{T=350 [K]}                                               "guess for the case temperature"
q``*W^2+q_dot=(T-T_infinity)/R_conv+(T-T_infinity)/R_rad   "energy balance on case"
T_F=converttemp(K,F,T)                                    "case temperature in F"
```

which leads to a maximum operating temperature limit of T = 147.5°F.

b.) Plot the maximum operating temperature as a function of the case size, W. Explain the shape of your plot (why does the temperature go up or down with W? if there is an asymptotic limit, explain why it exists).

The value of W is commented out and a parametric table is generated that includes W and T. Figure 1 illustrates the maximum operating temperature as a function of the size of the enclosure. As the size of the enclosure is reduced, the maximum operating temperature increases because the 10 W of dissipation must be rejected but the area available for convection and radiation is reduced. As the size is increased, the maximum operating temperature reaches an asymptote. The limiting value of T is higher than T_∞ because the absorbed solar irradiation and the surface area for convection and radiation both increase in proportion to W^2; therefore the limit is consistent with the situation where the solar flux is exactly balanced by the heat flux associated with radiation and convection (the dissipation becomes insignificant relative to the solar flux).

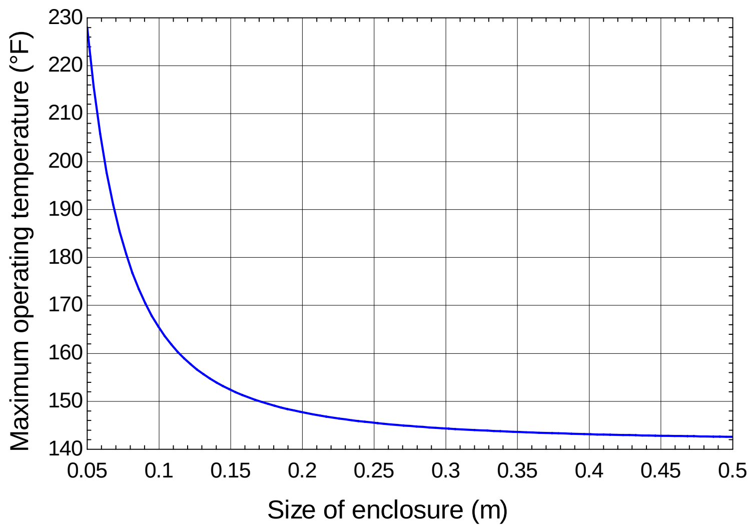

Figure 1: Maximum operating temperature as a function of the size of the enclosure.

c.) Come up with an estimate for the minimum operating temperature limit (with W = 8 inch).

The case temperature will be lowest when the case generation is minimum, the ambient temperature is minimum, the solar flux is minimum, and the heat transfer coefficient is maximum. These inputs are entered in EES:

```
q_dot=5 [W]                                  "dissipation in case"
q``=0 [W/m^2]                                "solar flux"
h_bar=100 [W/m^2-K]                          "heat transfer coefficient"
T_infinity=converttemp(F,K,-40 [F])          "ambient temperature"
```

The solution is run again at the predicted temperature is T= -39.7°F

d.) Do you feel that the emissivity of the case surface is very important for determining the minimum operating temperature? Justify your answer.

The emissivity is not important because radiation is not important. To see this, look at the resistance to convection, R_{conv}= 0.040 K/W, and the resistance to radiation, R_{rad}= 1.65 K/W. These two heat transfer mechanisms occur in parallel; the largest resistance in a parallel network is not important - therefore, radiation is much less important than convection.