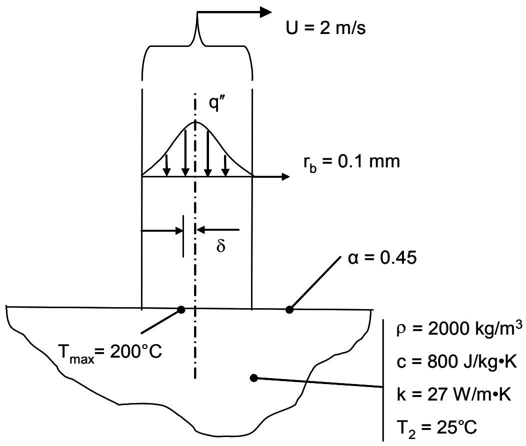
PROBLEM 4.21

KNOWN: Relation between maximum material temperature and its location, and scanning velocities.

FIND: (a) Required laser power to achieve a desired operating temperature for given material, beam size and velocity, (b) Lag distance separating the center of the beam and the location of maximum temperature, (c) Plot of the required laser power for velocities in the range $0 \le U \le 2$ m/s.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Constant properties, (3) Semi-infinite medium, (4) Negligible heat loss from the top surface.

ANALYSIS: The thermal diffusivity of the materials is

$$\alpha = k/\rho c = 27\ \text{W/m}\cdot\text{K} / (2000\ \text{kg/m}^3 \cdot 800\ \text{J/kg}\cdot\text{K}) = 16.9 \times 10^{-6}\ \text{m}^2/\text{s}$$

(a) The Peclet number is

$$Pe = Ur_b / \sqrt{2}\alpha = 2\ \text{m/s} \times 0.0001\ \text{m} / (\sqrt{2} \times 16.9 \times 10^{-6}\ \text{m}^2/\text{s}) = 8.38$$

Since this value of the Peclet number is within the range of the correlation provided in the problem statement, the maximum temperature corresponding to a stationary beam delivering the same power would be

$$T_{1,max,U=0} = (1 + 0.301Pe - 0.0108Pe^2)(T_{1,maxU\neq0} - T_2) + T_2$$
$$= (1 + 0.301 \times 8.37 - 0.0108 \times 8.37^2) \times (200 - 25)°C + 25°C$$
$$= 509°C.$$

From Eq. 4.20 and Problem 4.18 we know that (with the symbol $\hat{\alpha}$ now representing the absorptivity, since α is used for thermal diffusivity)

Continued…

PROBLEM 4.21 (Cont.)

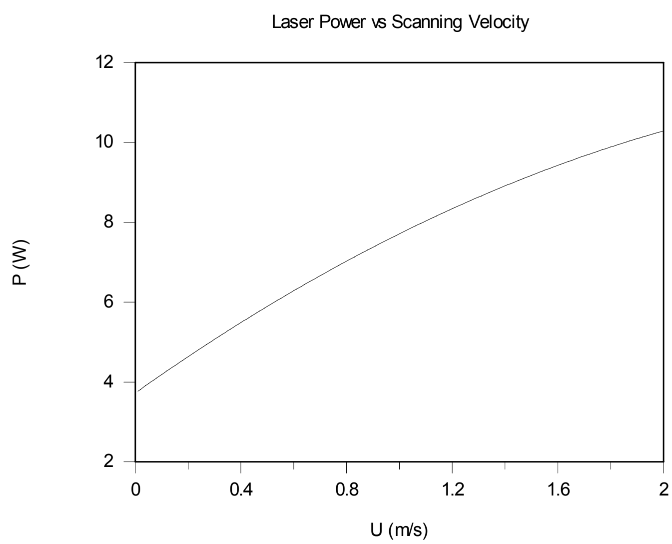
$$P = Sk\Delta T_{1\text{-}2}\ /\ \hat{\alpha} = 2\sqrt{\pi} r_b k \Delta T_{1\text{-}2}/\hat{\alpha} = 2\sqrt{\pi} \times 0.0001\ \text{m} \times 27\ \text{W/m}\cdot\text{K} \times (509 - 25)^\circ\text{C} / 0.45$$

$$= 10.3\ \text{W}$$ <

(b) The lag distance is

$$\delta = 0.944 \frac{\alpha}{U} Pe^{1.55} = 0.944 \times \frac{16.9 \times 10^{-6}\ \text{m}^2/\text{s}}{2\ \text{m/s}} \times 8.37^{1.55} = 0.21\ \text{mm}$$ <

(c) The plot of the required laser power versus scanning velocity is shown below.



COMMENTS: (1) The required laser power increases as the scanning velocity increases since more material must be heated at higher scanning velocities. (2) The relative motion between the laser beam and the heated material represents an advection process. Advective effects will be dealt with extensively in Chapters 6 through 9.