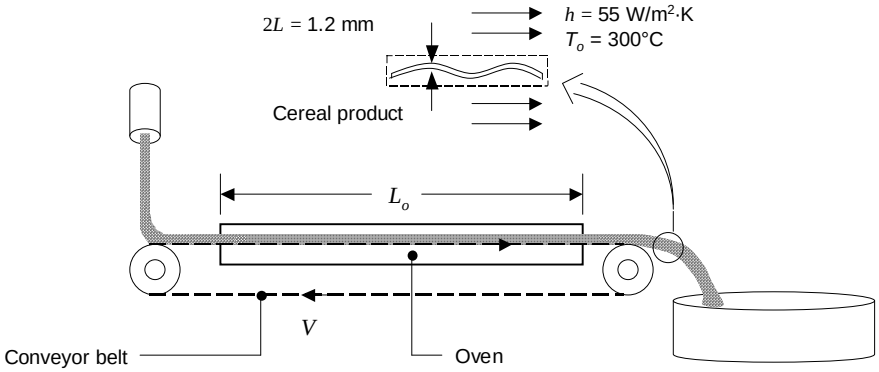
## PROBLEM 5.10

**KNOWN:** Thickness and properties of flaked food product. Conveyor length. Initial flake temperature. Ambient temperature and convection heat transfer coefficient. Final product temperature.

**FIND:** Required conveyor velocities for thick and thin flakes.

**SCHEMATIC**:




**ASSUMPTIONS**: (1) Constant properties. (2) Lumped capacitance behavior. (3) Negligible radiation heat transfer. (4) Negligible moisture evaporation from product. (5) Negligible conduction between flake and conveyor belt.

**PROPERTIES:** Flake: $\rho = 700$ kg/m$^3$, $c_p = 2400$ J/kg·K, and $k = 0.34$ W/m·K.

**ANALYSIS:** The Biot number is

$$Bi = \frac{hL}{k} = \frac{55\ \text{W/m}^2\cdot\text{K} \times 0.6\times10^{-3}\ \text{m}}{0.34\ \text{W/m}\cdot\text{K}} = 0.098$$

Hence the lumped capacitance assumption is valid. The required heating time is

$$t = \frac{\rho Vc}{hA_s}\ln\frac{\theta_i}{\theta} = \frac{\rho Lc}{h}\ln\frac{\theta_i}{\theta} = \frac{700\ \text{kg/m}^3 \times 0.6\times10^{-3}\ \text{m} \times 2400\ \text{J/kg}\cdot\text{K}}{55\ \text{W/m}^2\cdot\text{K}}\ln\frac{(20-300)}{(220-300)} = 23\ \text{s}$$

Therefore the required conveyor velocity is $V = L_o/t = 3\text{m}/23\text{s} = 0.13$ m/s . <

If the flake thickness is reduced to $2L = 1$ mm, the lumped capacitance approximation remains valid and the heating time is 19 s. The associated conveyor velocity is 0.16 m/s. <

**COMMENTS**: (1) Assuming large surroundings, a representative value of the radiation heat transfer coefficient is $h_r = \sigma(T_i + T_o)\left(T_i^2 + T_o^2\right) = 5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\,(293+573)\left(293^2+573^2\right)\text{K}^4 = 20.3$ W/m$^2$·K. Radiation heat transfer would be significant and would serve to increase the product heating rate, increasing the allowable conveyor belt speed. (2) The food product is likely to enter the oven in a moist state. Additional thermal energy would be required to remove the moisture during heating, reducing the rate at which the product temperature increases. (3) The effects noted in Comments 1 and 2 would tend to offset each other. A detailed analysis would be required to assess the impact of radiation and evaporation on the required conveyor velocity.