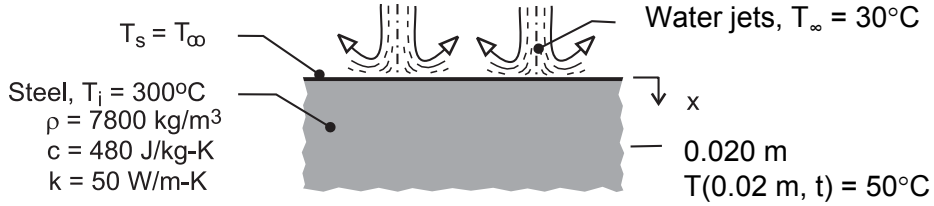
PROBLEM 5.86

KNOWN: Thermophysical properties and initial temperature of thick steel plate. Temperature of water jets used for convection cooling at one surface.

FIND: Time required to cool prescribed interior location to a prescribed temperature.

SCHEMATIC:



ASSUMPTIONS: (1) One-dimensional conduction in slab, (2) Validity of semi-infinite medium approximation, (3) Negligible thermal resistance between water jets and slab surface ($T_s = T_\infty$), (4) Constant properties.

ANALYSIS: The desired cooling time may be obtained from Eq. (5.60). With T(0.020m, t) = 50°C,

$$\frac{T(x,t)-T_s}{T_i-T_s}=\frac{(50-30)°C}{(300-30)°C}=0.0741=\text{erf}\left(\frac{x}{2\sqrt{\alpha t}}\right)$$

$$\frac{x}{2\sqrt{\alpha t}}=0.0657$$

$$t=\frac{x^2}{(0.0657)^2\,4\alpha}=\frac{(0.02m)^2}{0.0261\left(1.34\times10^{-5}m^2/s\right)}=1729s \quad <$$

where $\alpha = k/\rho c = 50\ W/m\cdot K/(7800\ kg/m^3 \times 480\ J/kg\cdot K) = 1.34 \times 10^{-5}\ m^2/s$.

COMMENTS: (1) Large values of the convection coefficient ($h \sim 10^4\ W/m^2\cdot K$) are associated with water jet impingement, and it is reasonable to assume that the surface is immediately quenched to the temperature of the water. (2) The surface heat flux may be determined from Eq. (5.61). In principle, the flux is infinite at t = 0 and decays as $t^{1/2}$.