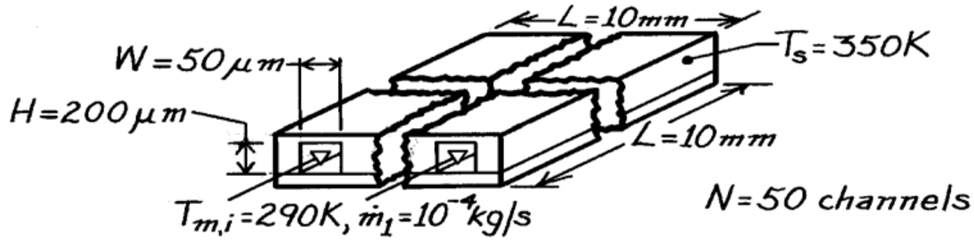
PROBLEM 8.107

KNOWN: Chip and cooling channel dimensions. Channel flowrate and inlet temperature. Chip temperature.

FIND: Water outlet temperature and chip power.

SCHEMATIC:



ASSUMPTIONS: (1) Incompressible liquid with negligible viscous dissipation, (2) Uniform channel surface temperature, (3) $\overline{T}_m$ = 300 K, (4) Fully developed flow.

PROPERTIES: *Table A-6*, Water ($\overline{T}_m$ = 300 K): c_p = 4179 J/kg·K, μ = 855 × 10^{-6} kg/s·m, k = 0.613 W/m·K, Pr = 5.83.

ANALYSIS: Using the hydraulic diameter, find the Reynolds number,

$$D_h = \frac{4(H \times W)}{2(H+W)} = \frac{2(50 \times 200)\,\mu m^2}{250\ \mu m} 10^{-6}\ m/\mu m = 8 \times 10^{-5}\ m$$

$$Re_D = \frac{\rho\, u_m D_h}{\mu} = \frac{\dot{m}_1 D_h}{A_c \mu} = \frac{10^{-4}\ kg/s\left(8 \times 10^{-5}\ m\right)}{(50 \times 200)10^{-12}\ m^2\left(855 \times 10^{-6}\ kg/s \cdot m\right)} = 936.$$

Hence, the flow is laminar and, from Table 8.1, Nu_D = 4.44, so that

$$h = Nu_D \frac{k}{D_h} = \frac{4.44(0.613\ W/m \cdot K)}{8 \times 10^{-5}\ m} = 34,022\ W/m^2 \cdot K.$$

With P = 2(H + W) = 2(250 μm) 10^{-6} m/μm = 5 ×10^{-4} m, Eq. 8.41b yields

$$\frac{T_s - T_{m,o}}{T_s - T_{m,i}} = \frac{350K - T_{m,o}}{60\ K} = \exp\left(-\frac{PL}{\dot{m}_1\ c_p} h\right) = \exp\left(-\frac{5 \times 10^{-6}\ m^2 \times 34,022\ W/m^2 \cdot K}{10^{-4}\ kg/s \times 4179\ J/kg \cdot K}\right)$$

$$T_{m,o} = 350K - 60\ K\ \exp(-0.407) = 310\ K. \qquad <$$

Hence, from Eq. 8.34,

$$q = \dot{m}\ c_p\left(T_{m,o} - T_{m,i}\right) = N\dot{m}_1 c_p\left(T_{m,o} - T_{m,i}\right) = 50 \times 10^{-4}\ kg/s\left(4179\ J/kg \cdot K\right)\left(20\ K\right) = 418\ W. \qquad <$$

COMMENTS: (1) The chip heat flux of 418 W/cm^2 is extremely large and the method provides a very efficient means of heat removal from high power chips. However, clogging of the microchannels is a potential problem which could seriously compromise reliability. (2) L/D_h = 125 and 0.05 Re_DPr = 272. Hence, fully developed conditions are not realized and $\overline{h}$ > 34,022. The actual power dissipation is therefore greater than 418 W.