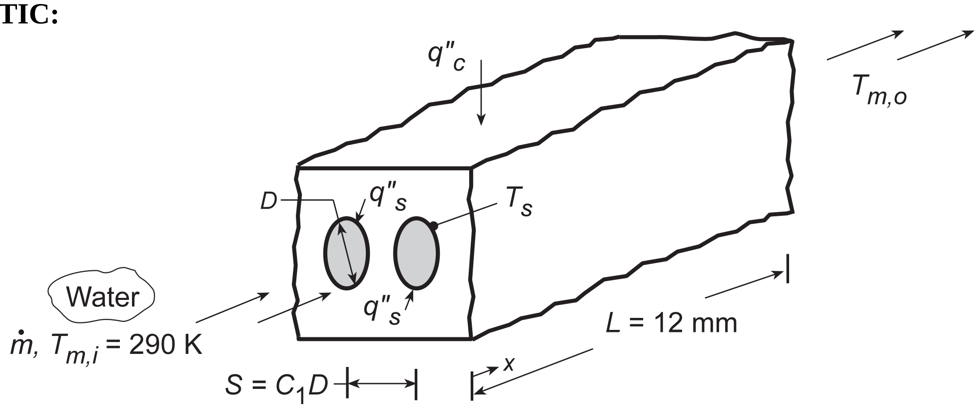
PROBLEM 8.55

KNOWN: Configuration of microchannel heat sink.

FIND: (a) Expressions for longitudinal distributions of fluid mean and surface temperatures, (b) Coolant and channel surface temperature distributions for prescribed conditions, (c) Effect of heat sink design and operating conditions on the chip heat flux for a prescribed maximum allowable surface temperature.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state, (2)Incompressible liquid with negligible viscous dissipation, (3) All of the chip power dissipation is transferred to the coolant, with a uniform surface heat flux, q''_s, (4) Laminar, fully developed flow, (5) Constant properties.

PROPERTIES: *Table A.6*, Water (assume $\overline{T}_m = T_{m,i}$ = 290 K): c_p = 4184 J/kg·K, $\mu = 1080 \times 10^{-6}$ N·s/m^2, k = 0.598 W/m·K, Pr = 7.56.

ANALYSIS: (a) The number of channels passing through the heat sink is N = L/S = L/C_1D, and conservation of energy dictates that

$$q''_c L^2 = N(\pi DL)q''_s = \pi L^2 q''_s / C_1$$

which yields

$$q''_s = \frac{C_1 q''_c}{\pi} \tag{1}$$

With the mass flowrate per channel designated as $\dot{m}_1 = \dot{m}/N$, Eqs. 8.40 and 8.27 yield

$$T_m(x) = T_{m,i} + \frac{q''_s \pi D}{\dot{m}_1 c_p} x = T_{m,i} + \frac{L q''_c}{\dot{m} c_p} x \tag{2} <$$

$$T_s(x) = T_m(x) + \frac{q''_s}{h} = T_m(x) + \frac{C_1 q''_c}{\pi h} \tag{3} <$$

where, for laminar, fully developed flow with uniform q''_s, Eq. 8.53 yields h = 4.36 k/D.

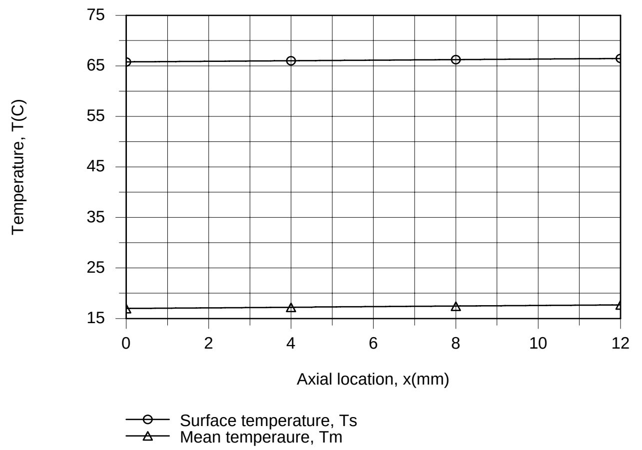
(b) With L = 12 mm, D = 1 mm, C_1 = 2 and $\dot{m}$ = 0.01 kg/s, it follows that S = 2 mm, N = 6 and Re_D = $4\dot{m}_1/\pi D\mu = 4(0.01\,\text{kg/s})/6\pi(0.001\,\text{m})1.08\times10^{-3}\,\text{N}\cdot\text{s/m}^2$ = 1965. Hence, the flow is laminar, as assumed, and h = 4.36(0.598 W/m·K/0.001 m) = 2607 W/m^2·K. From Eqs. (2) and (3) the outlet mean and surface temperatures are

$$T_{m,o} = 290\,\text{K} + \frac{(0.012\,\text{m})^2\, 20\times10^4\,\text{W/m}^2}{0.01\,\text{kg/s}(4184\,\text{J/kg}\cdot\text{K})} = 290.7\,\text{K} = 17.7^\circ\text{C}$$

$$T_{s,o} = T_{m,o} + \frac{2}{\pi}\times\frac{20\times10^4\,\text{W/m}^2}{2607\,\text{W/m}^2\cdot\text{K}} = 339.5\,\text{K} = 66.5^\circ\text{C}$$

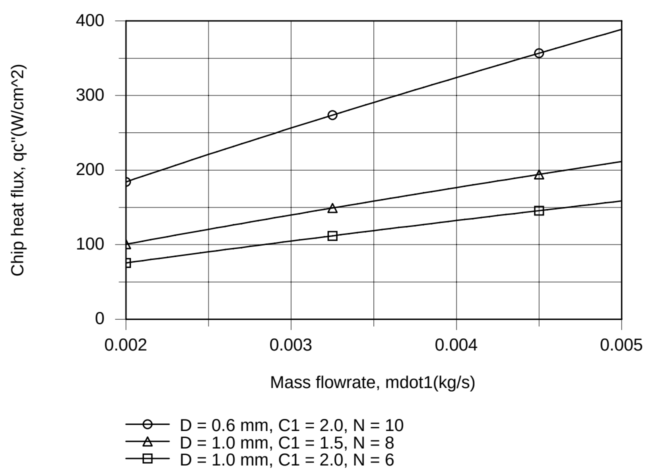
Continued...

The axial temperature distributions are as follows



The flowrate is sufficiently large (and the convection coefficient sufficiently low) to render the increase in T_m and T_s with increasing x extremely small.

(c) The desired constraint of $T_{s,max} \le 50°C$ is not met by the foregoing conditions. An obvious and logical approach to achieving improved performance would involve increasing $\dot{m}_1$ such that turbulent flow is maintained in each channel. A value of $\dot{m}_1$ > 0.002 kg/s would provide Re_D > 2300 for D = 0.001. Using Eq. 8.60 with n = 0.4 to evaluate Nu_D and accessing the Correlations Toolpad of IHT to explore the effect of variations in $\dot{m}_1$ for different combinations of D and C_1, the following results were obtained.



We first note that a significant increase in q''_c may be obtained by operating the channels in turbulent flow. In addition, there is an obvious advantage to reducing C_1, thereby increasing the number of channels for a fixed channel diameter. The biggest enhancement is associated with reducing the channel diameter, which significantly increases the convection coefficient, as well as the number of channels for fixed C_1. For $\dot{m}_1$ = 0.005 kg/s, h increases from 32,400 to 81,600 $W/m^2 \cdot K$ with decreasing D from 1.0 to 0.6 mm. However, for fixed $\dot{m}_1$, the mean velocity in a channel increases with decreasing D and care must be taken to maintain the flow pressure drop within acceptable limits.

COMMENTS: Although the distribution computed for $T_m(x)$ in part (b) is correct, the distribution for $T_s(x)$ represents an upper limit to actual conditions due to the assumption of fully developed flow throughout the channel.