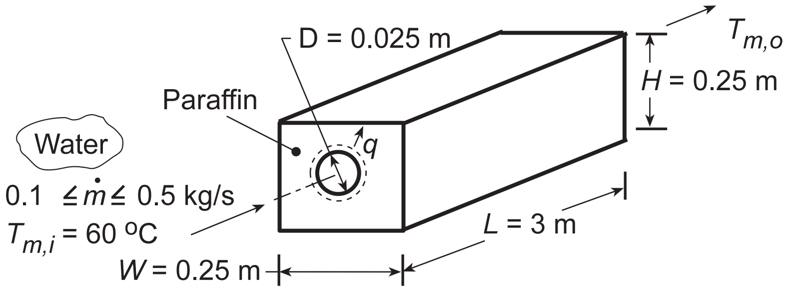
# PROBLEM 8.47

**KNOWN:** Length and diameter of tube submerged in paraffin of prescribed dimensions. Inlet temperature and flow rate of water flowing through tube.

**FIND:** (a) Outlet temperature, heat rate, and time required for complete melting, and (b) Effect of flowrate on operating conditions.

**SCHEMATIC:**




**ASSUMPTIONS:** (1) Negligible KE/PE and flow work changes for water, (2) Constant water properties, (3) Negligible tube wall conduction resistance, (4) Negligible convection resistance in melt ($T_s = T_\infty = T_{mp}$), (5) Fully developed flow, (6) No heat loss to the surroundings.

**PROPERTIES:** Water (given): $c_p$ = 4.185 kJ/kg·K, k = 0.653 W/m·K, $\mu = 467 \times 10^{-6}$ kg/s·m, Pr = 2.99; Paraffin (given): $T_{mp}$ = 27.4°C, $h_{sf}$ = 244 kJ/kg, $\rho$ = 770 kg/m$^3$.

**ANALYSIS:** (a) From Eq. 8.41b, $\dfrac{T_\infty - T_{m,o}}{T_\infty - T_{m,i}} = \exp\left(-\dfrac{\pi D L \bar{h}}{\dot{m} c_p}\right)$. With $Re_D = \dfrac{4\dot{m}}{\pi D \mu}$ = $\dfrac{4 \times 0.1\,\text{kg/s}}{\pi \times 0.025\,\text{m} \times 467 \times 10^{-6}\,\text{kg/s}\cdot\text{m}}$ = 10,906, the flow is turbulent. Assuming fully developed conditions,

$$h = \frac{Nu_D k}{D} = \frac{k}{D} 0.023 Re_D^{4/5} Pr^{0.3} = \frac{0.653\,\text{W/m}\cdot\text{K}}{0.025\,\text{m}} 0.023(10,906)^{4/5}(2.99)^{0.3} = 1418\,\text{W/m}^2\cdot\text{K}$$

$$T_{m,o} = 27.4^\circ\text{C} - (27.4 - 60)^\circ\text{C}\exp\left(-\frac{\pi \times 0.025\,\text{m} \times 3\,\text{m}}{0.1\,\text{kg/s} \times 4185\,\text{J/kg}\cdot\text{K}} 1418\,\text{W/m}^2\cdot\text{K}\right) = 42.17^\circ\text{C} \quad <$$

From the overall energy balance,

$$q = \dot{m} c_p (T_{m,i} - T_{m,o}) = 0.1\,\text{kg/s} \times 4185\,\text{J/kg}\cdot\text{K}(60 - 42.17)^\circ\text{C} = 7500\,\text{W} \quad <$$

Applying an energy balance to a control volume about the paraffin, $E_{in} = \Delta E_{st}$, the time $t_m$ required to melt the paraffin is

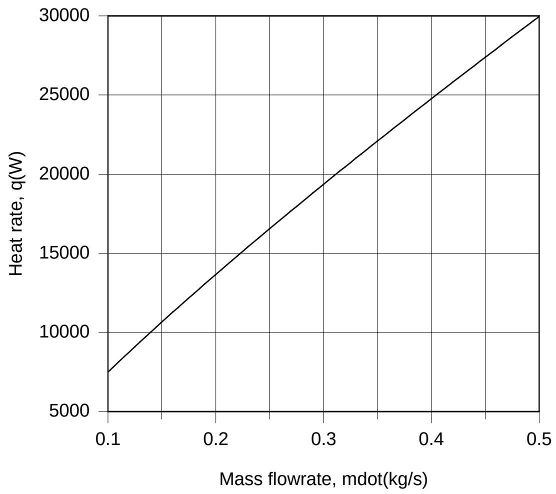
$$q t_m = \rho V h_{sf} = \rho L\left(WH - \pi D^2/4\right)h_{sf}$$

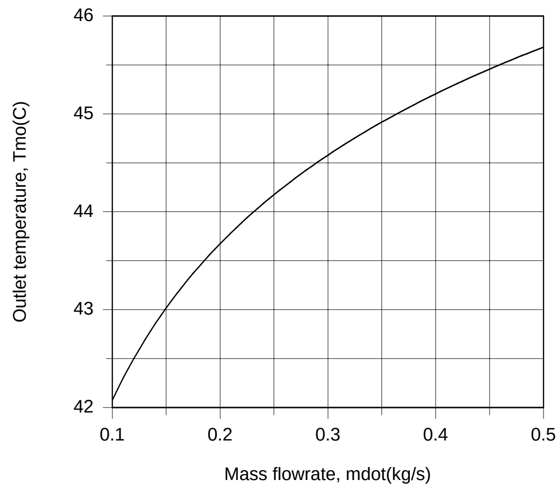
$$t_m = \frac{770\,\text{kg/m}^3 \times 3\,\text{m}\left(0.25 \times 0.25\,\text{m}^2 - \pi(0.025\,\text{m})^2/4\right)}{7500\,\text{W}} 2.44 \times 10^5\,\text{J/kg} = 4660\,\text{s} = 1.29\,\text{h} \quad <$$

Continued...

# PROBLEM 8.47 (Cont.)

(b) The effect of $\dot{m}$ on q and $T_{m,o}$ was determined by accessing the *Correlations* Toolpad of IHT, and the results are plotted as follows.




Although q increases with increasing $\dot{m}$ due to the attendant increase in $Re_D$, and therefore $\bar{h}$, the increase is not linearly proportional to the change in $\dot{m}$. Hence, from the overall energy balance, $q = \dot{m} c_p(T_{m,i} - T_{m,o})$, there is a reduction in $(T_{m,i} - T_{m,o})$, which corresponds to an increase in $T_{m,o}$. With the increase in q, there is a reduction in $t_m$, and for $\dot{m} = 0.5$ kg/s,

$$t_m = 1167\,\text{s} = 0.324\,\text{h} \qquad <$$

**COMMENTS:** Heat transfer from the water to the paraffin is also affected by free convection in the melt region around the tube. The effect is to decrease U, increase $T_s$, and decrease q with increasing time. The actual time to achieve complete melting would exceed values computed in the foregoing analysis.