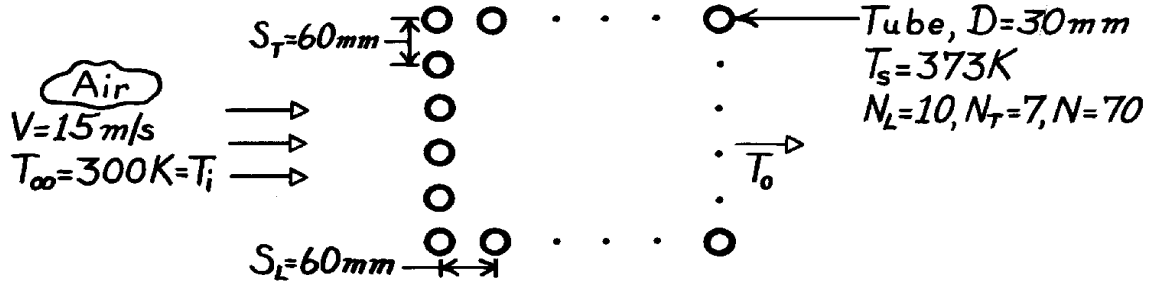


PROBLEM 03

KNOWN: Surface temperature and geometry of a tube bank. Velocity and temperature of air in cross-flow.

FIND: (a) Air outlet temperature, (b) Pressure drop and fan power requirements.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Negligible radiation, (3) Air pressure is approximately one atmosphere, (4) Uniform surface temperature.

PROPERTIES: Table A-4, Air (300 K, 1 atm): $\rho = 1.1614 \text{ kg/m}^3$, $c_p = 1007 \text{ J/kg}\cdot\text{K}$, $\nu = 15.89 \times 10^{-6} \text{ m}^2/\text{s}$, $k = 0.0263 \text{ W/m}\cdot\text{K}$, $\text{Pr} = 0.707$; (373 K): $\text{Pr} = 0.695$.

ANALYSIS: (a) The air temperature increases exponentially, with

$$T_o = T_s - (T_s - T_i) \exp\left(-\frac{\pi D N \bar{h}}{\rho V N_T S_T c_p}\right).$$

$$\text{With } V_{\max} = \frac{S_T}{S_T - D} V = \frac{60}{30} 15 \frac{\text{m}}{\text{s}} = 30 \frac{\text{m}}{\text{s}}; \text{Re}_{D,\max} = \frac{30 \text{ m/s} \times 0.03 \text{ m}}{15.89 \times 10^{-6} \text{ m}^2/\text{s}} = 56,639.$$

Tables 7.5 and 7.6 give $C_1 = 0.27$, $m = 0.63$ and $C_2 = 0.97$. Hence from the Zukauskas correlation,

$$\bar{\text{Nu}}_D = 0.27(0.97)(56,639)^{0.63}(0.707)^{0.36}(0.707/0.695)^{1/4} = 229$$

$$\bar{h} = \bar{\text{Nu}}_D k/D = 229 \times 0.0263 \text{ W/m}\cdot\text{K}/0.03 \text{ m} = 201 \text{ W/m}^2\cdot\text{K}.$$

Hence,

$$T_o = 373\text{K} - (373 - 300)\text{K} \exp\left(-\frac{\pi \times 0.03 \text{ m} \times 70 \times 201 \text{ W/m}^2\cdot\text{K}}{1.1614 \text{ kg/m}^3 \times 15 \text{ m/s} \times 7 \times 0.06 \text{ m} \times 1007 \text{ J/kg}\cdot\text{K}}\right)$$

$$T_o = 373\text{K} - 73\text{K} \times 0.835 = 312\text{K} = 39^\circ\text{C}.$$

(b) With $\text{Re}_{D,\max} = 5.66 \times 10^4$, $P_L = 2$, $(P_T - 1)/(P_L - 1) = 1$, Fig. 7.14 yields $f \approx 0.19$ and $\chi = 1$. Hence,

$$\Delta p = N_L \chi \left(\frac{\rho V_{\max}^2}{2} \right) f = 10 \left(\frac{1.1614 \text{ kg/m}^3 \times (30 \text{ m/s})^2}{2} \right) 0.19 = 993 \text{ N/m}^2 = 0.00993 \text{ bar}.$$

The fan power requirement is

$$P = \dot{m}_a \Delta p / \rho = \rho V N_T S_T L \Delta p / \rho = 15 \text{ m/s} \times 7 \times 0.06 \text{ m} \times 1 \text{ m} \times 993 \text{ N/m}^2 = 6.26 \text{ kW}.$$

COMMENTS: The heat rate is

$$q = \dot{m}_a c_p (T_o - T_i) = \rho V N_T S_T L c_p (T_o - T_i)$$

$$q = 1.1614 \text{ kg/m}^3 \times 15 \text{ m/s} \times 7 \times 0.06 \text{ m} \times 1 \text{ m} \times 1007 \text{ J/kg}\cdot\text{K} (312 - 300)\text{K} = 88.4 \text{ kW}.$$