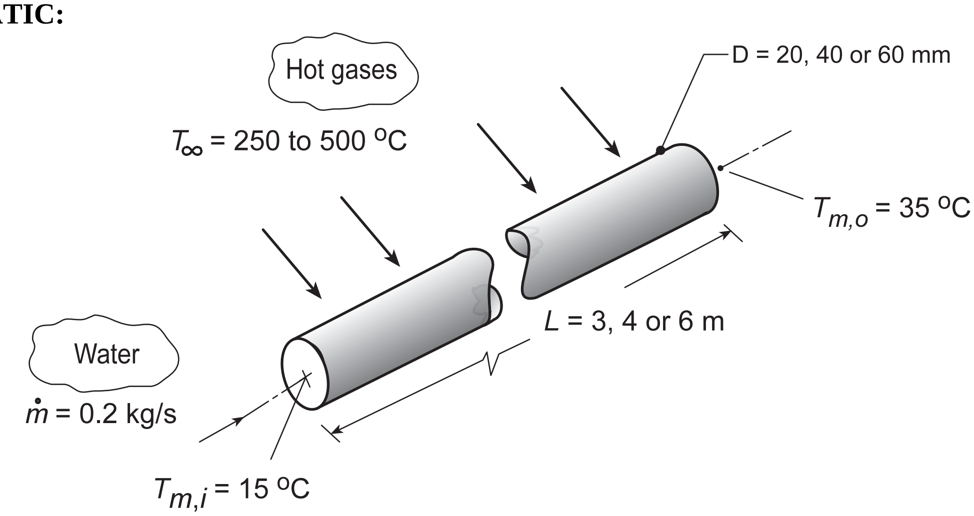
PROBLEM 8.69

KNOWN: Water flowing through a tube heated by cross flow of a hot gas. Required to heat water from 15 to 35°C with a flow rate of 0.2 kg/s.

FIND: Design graphs to demonstrate acceptable combinations of tube diameter (D = 20, 30 or 40 mm), tube length (L = 3, 4 or 6 m) and hot gas velocity ($20 \le V \le 40$ m/s) and temperature (T_∞ = 250, 375 or 500°C).

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2)Water is incompressible liquid with negligible viscous dissipation, (3) Fully developed flow and thermal conditions for internal flow, (4) Properties of the hot gas are those of atmospheric air, and (5) Negligible tube wall thermal resistance.

PROPERTIES: *Table A.6*, Water ($\overline{T}_m = (15+35)^\circ C/2 = 298K$); *Table A.4*, Air ($\overline{T}_f = \left(\overline{T}_s + T_\infty\right)/2$, 1 atm).

ANALYSIS: *Method of Analysis*: The tube having internal flow of water with cross flow of hot gas can be analyzed by the energy balance relation, Eq. 8.45a

$$\frac{T_\infty - T_{m,o}}{T_\infty - T_{m,i}} = \exp\left(-\frac{(\pi DL)}{\dot{m}c_p}\overline{U}\right) \tag{1}$$

where the overall coefficient $\overline{U}$ is

$$\overline{U} = \left(1/\overline{h}_i + 1/\overline{h}_o\right)^{-1} \tag{2}$$

Estimation of the internal flow coefficient, $\overline{h}_i$: Evaluating water properties at the average mean fluid temperature

$$\overline{T}_m = \left(T_{m,i} + T_{m,o}\right)/2, \tag{3}$$

characterize the flow with the Reynolds number,

$$Re_{D,i} = \frac{4\dot{m}}{(\pi D\mu)} \tag{4}$$

and assuming the flow to be both turbulent and fully developed (L/D > 3m/0.07m = 42), use the Dittus-Boelter correlation, Eq. 8.60, to evaluate $\overline{h}_i$,

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$$\overline{Nu}_{D,i} = \frac{\bar{h}_i D}{k_i} = 0.023 Re_{D,i}^{0.8} Pr^{0.4} \qquad (5)$$

Estimation of the external flow coefficient, $\bar{h}_o$: Evaluating gas (air) properties at the average film temperature

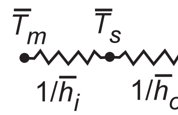
$$\bar{T}_f = \left(\bar{T}_s + T_\infty\right)/2 \qquad (6)$$

where $\bar{T}_s$ is the average tube wall temperature (see Eq. (9)), characterize the flow

$$Re_{D,o} = \frac{VD}{\nu} \qquad (7)$$

and use the Churchill-Bernstein correlation, Eq. 7.46, for cross-flow over a cylinder,

$$Nu_{D,o} = \frac{\bar{h}_o D}{k_o} = 0.3 + \frac{0.62 Re_{D,o}^{1/2} Pr_o^{1/3}}{\left[1+\left(0.4/Pr_o\right)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re_{D,o}}{282,000}\right)^{5/8}\right]^{4/5} \qquad (8)$$



The average tube wall temperature, $\bar{T}_s$, follows from the thermal circuit

$$\frac{\bar{T}_m - \bar{T}_s}{1/\bar{h}_i} = \frac{\bar{T}_s - \bar{T}_\infty}{1/\bar{h}_o} \qquad (9)$$

The IHT Workspace: Using the *Correlation Tools* for *Internal Flow* (*Turbulen*t flow), and *External Flow* (*Flow over a Cylinder*) and *Properties* for *Air* and *Water*, along with the appropriate energy balances and rate equations, the heater-tube system can be analyzed.

The Design Strategy: We have chosen to generate the design information in the following manner: for a specified gas temperature, T_∞, plot the required length L (limiting the scale to $3 \le L \le 6$m) as a function of gas velocity V ($20 \le V \le 40$ m/s) for tube diameters of D = 20, 30 and 40 mm. Three design graphs corresponding to T_∞ = 250, 375 and 500°C were generated and are shown on the next page.

COMMENTS: (1) The collection of design graphs will allow the contractor to select appropriate combinations of tube D and L and gas stream parameters (T_∞ and V) to achieve the required water heating.

(2) Note from the design graphs that with T_∞ = 250°C, the required heating of the water can be achieved only with a 40-mm diameter by 6 m length tube with gas velocities greater than 32 m/s. This configuration represents a worst case condition of largest tube parameters and highest gas velocity.

(3) Which operating conditions, T_∞ = 375 or 500°C, provides the contractor with more options in selecting combinations of tube parameters and gas velocities? What are the trade-offs in operating at 375 or 500°C? Consider such features as tube life, tubing costs and fan requirements.

(4) The Reynolds numbers for the internal flow are approximately 7,100, 9,460 and 14,200 for the tube diameters of 20, 30 and 40 mm. For the larger tube sizes, the Reynolds numbers are below 10,000, the usual lower limit for turbulent flow. The Gnielinski correlation would be more accurate under these conditions.

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PROBLEM 8.69 (Cont.)