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5/30/19

B ME 331

Project 3

Given:

Below is a diagram of a thin-walled tube, which must heat water from 15°C to 35°C. It is heated by using hot gases in cross flow over the tube. The water has a mass flow rate of 0.2 kg/s.

D = 20, 30, or 40 mm

L = 3, 4, or 6 m

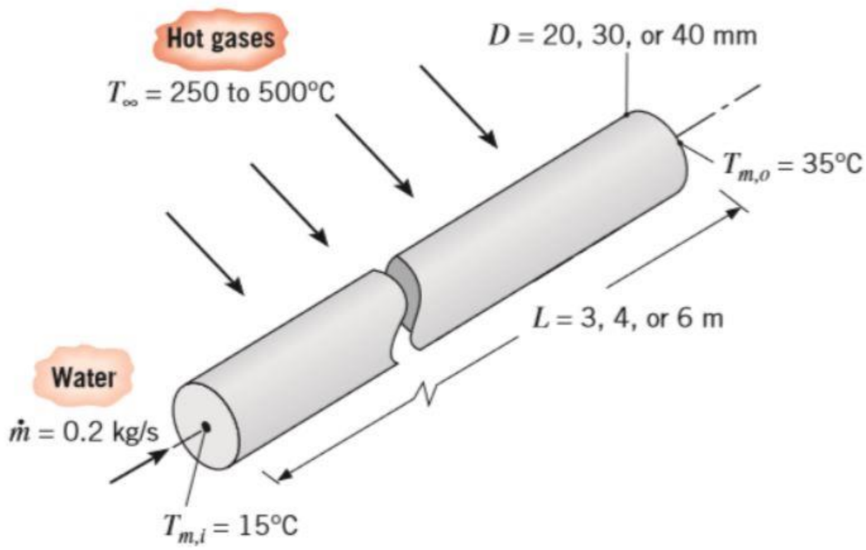
T_∞ = 250, 375, or 500°C

20 m/s $\leq V \leq$ 40 m/s

Find:

The goal is to use MATLAB to create several design graphs which will demonstrate what dimensions of the thin-walled tube are acceptable, but also determine what hot gas conditions will satisfy those acceptable requirements. Be sure to include a brief report of your work to include all assumptions made, a brief report of the problem i.e. assumptions, steps taken, results, MATLAB code (.m file only) and all graphs created.

Diagram:



Assumptions:

1. Steady State Conditions
2. Hot gas is air
3. Fully developed flow and thermal conditions for internal flow

Process:

The process I took was to find the convection coefficients for external and internal flow and then using those values, with the temperatures given, to calculate the length of the tube. The point is to see at what T-infinite temperature gives the designer the most flexibility for what velocity, diameter, and length they want when designing this tube so that the water will be heated from 15°C to 35°C.

Calculation:

(Note: calculation is for when T-infinite is 375 °C, the diameter is 20 mm, and the velocity is 30 m/s. The point of just one calculation is to show my process of how I got to my goal. The code will calculate all the various combinations with velocity, T-infinite, and diameter.)

(1) For Internal Flow: $\bar{T}_m = \frac{15+35}{2} = 25° \approx 300K$

• $\mu = 855 \times 10^{-6}\ N \cdot s/m^2$ • $C_p = 4179\ J/kg \cdot K$ • $k_i = 613 \times 10^{-3}\ W/m \cdot K$
• $Pr = 5.83$

(2) For $D = 20mm$: $Re_{Di} = 4\dot{m}/\pi D\mu = \frac{4(0.2\ kg/s)}{\pi(0.02m)(855\times10^{-6}\ N \cdot s/m^2)} = 14892$

Flow is turbulant!

(3) $(T_\infty - T_{m,o})/(T_\infty - T_{mi}) = \exp[(-\pi DL/\dot{m}c_p)\bar{U}] \rightarrow \bar{U} = \left(\frac{1}{\bar{h}_i} + \frac{1}{\bar{h}_o}\right)^{-1}$

(4) Assuming flow is turbulent and fully developed, we can use the dittus-Boelter Correlation to find $\bar{h}_i$

$$\bullet\ \bar{N}_{uD} = \bar{h}_i D/k_i = 0.023 Re_{Di}^{4/5} Pr^{0.4} \rightarrow \bar{h}_i = \frac{k_i}{D}(0.023 Re_{Di}^{4/5} Pr^{0.4})$$

(5) $\bar{h}_i = 3110.2\ W/m^2 \cdot K$

(6) For external flow: $\bar{T}_f = (\bar{T}_s + T_\infty)/2$, assuming $\bar{T}_s = 452K$

$$\bar{T}_f = (452K + (375+273)K)/2 = 550\ K$$

• $\nu = 46.3 \times 10^{-6}\ m^2/s$ • $k = 44.1 \times 10^{-3}\ W/m \cdot K$ • $Pr = 0.726$

(7) $Re_{Do} = \frac{VD}{\nu} = \frac{(30m/s)(0.02m)}{(46.3\times10^{-6}\ m^2/s)} = 12{,}959$

(8) Using Churchill-Bernstien correlation

$$\bullet\ Nu_{Do} = 0.3 + \frac{0.62 Re_{Do}^{1/2} Pr^{1/3}}{[1 + (0.4/Pr)^{2/3}]^{1/4}}\left[1 + \left(\frac{Re_{Do}}{282{,}000}\right)^{5/8}\right]^{4/5}$$

$Nu_{Do} = 62.5 \rightarrow \bar{h}_o = Nu_{Do}\frac{k}{D} = 62.5(44.1\times10^{-3}/0.02m) = 137.8\ W/m^2 \cdot K$

$$L = \frac{-\ln\left(\frac{T_\infty - T_{mo}}{T_\infty - T_{mi}}\right)\dot{m}c_p}{\pi D\bar{U}} = \frac{-\ln\left(\frac{375-35}{375-15}\right)(0.2)(4179)}{\pi(0.02)\left(\frac{1}{137.8} + \frac{1}{3110.2}\right)^{-1}} = \boxed{5.76\ m}$$

• Repeat process for $20 m/s < V < 40\ m/s$, $d = 0.03m, 0.04m$ and $T_\infty = 250°C, 500°C$

Other Info:

(Note: values used for when T-infinite is 250°C and 500°C)

For $T_\infty = 250\,C = 523\,K$, Assume $\bar{T}_s = 477\,K$

so $\bar{T}_f = 500\,k$

$\nu = 39.4 \times 10^{-6}\ m^2/s$

$k = 41.2 \times 10^{-3}\ W/m \cdot K$

$Pr = .716$

For $T_\infty = 500\,C = 773\,K$, Assume $\bar{T}_s = 427\,K \rightarrow \bar{T}_f = 600\,K$

$\nu = 53.59 \times 10^{-6}\ m^2/s$

$k = 47.3 \times 10^{-3}\ W/m \cdot k$

$Pr = 0.729$

Code:

My code starts off inputting values for internal flow since that wont change. I then start a for loop to go through each T-infinite and choose the correct values for each temperature. Inside that for loop is another for loop that goes through each diameter to calculate the Reynolds number and internal flow coefficient. There is another for loop inside that for loop that goes through velocity to then calculate the external flow coefficient and length L. The length L is then graphed to its respective velocity. There are three total graphs produced as shown on the next page.

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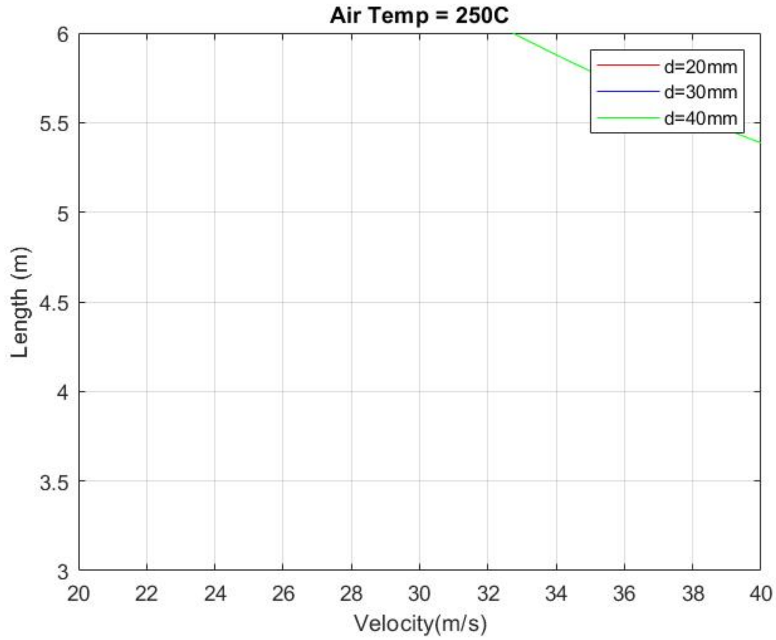
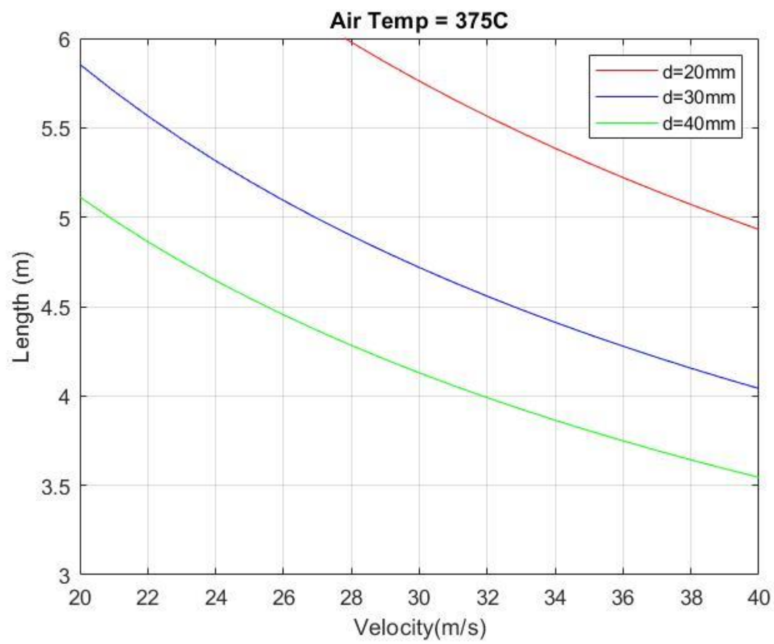
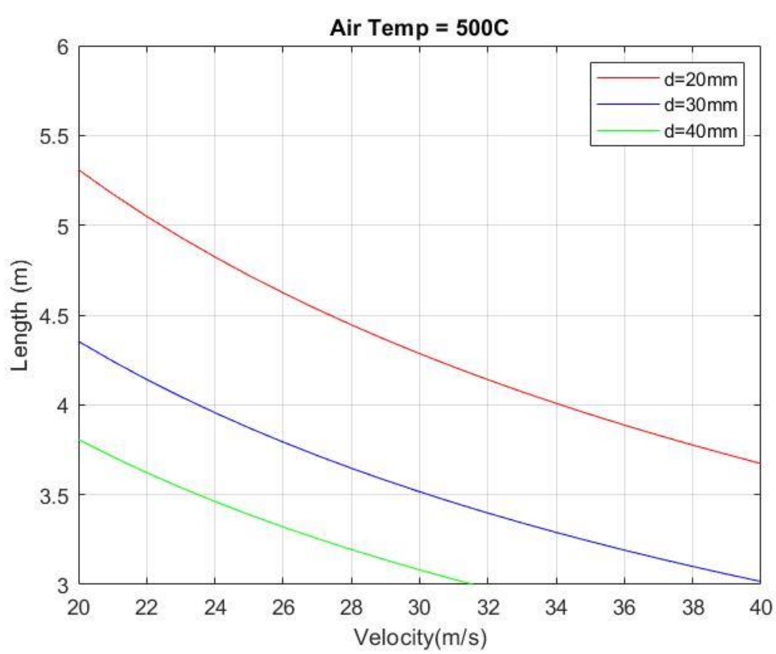

Air Temp = 250C
Length (m)
Velocity(m/s)
d=20mm
d=30mm
d=40mm


Air Temp = 375C
Length (m)
Velocity(m/s)
d=20mm
d=30mm
d=40mm


Air Temp = 500C
Length (m)
Velocity(m/s)
d=20mm
d=30mm
d=40mm

Analysis:

Looking at the first graph where the T-infinite is 250°C it is seen that only a diameter of 40 mm would work for a length of 6 meters and a velocity at 33 meters per second. This doesn't give any flexibility to design the tube.

For the second graph where the T-infinite is 375°C, we see there are three variations to choose from that could be:

- d = 20mm
  - L = 6 m and V = 28 m/s
- d = 30 mm
  - L = 4 m and V = 40 m/s
- d = 40 mm
  - L = 4 m and V = 32 m/s

Finally, for the third graph where the T-infinite is 500°C, there are four different variations available that could be:

- d = 20mm
  - L = 4 m and V = 34 m/s
- d = 30 mm
  - L = 4 m and V = 23.5 m/s
  - L = 3 m and V = 40 m/s
- d = 40 mm
  - L = 3 m and V = 31.5 m/s

Based off all these graphs, we can conclude that the best T-infinite to pick would be 375°C because there are 4 different variations to pick from to design the tube compared to the other two temperatures.