1. (20 points) What is the Reynolds number \( \text{Re} \equiv \rho \langle v \rangle D/\mu \) for 25°C water flowing in 200.0 meters of smooth horizontal copper tubing at 5.6 gpm? The tubing has the following characteristics: inner diameter 0.454 in; wall thickness, 0.040 in, outside diameter, 0.625 in.

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<table>
<thead>
<tr>
<th>Problem</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>20</td>
</tr>
<tr>
<td>2.</td>
<td>20</td>
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<tr>
<td>3.</td>
<td>20</td>
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<tr>
<td>4.</td>
<td>25</td>
</tr>
<tr>
<td>5.</td>
<td>15</td>
</tr>
</tbody>
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2. (20 points) We seek to model the contraction flow shown below with the microscopic momentum balance (steady state, incompressible fluid, Newtonian fluid). Answer the following questions for this flow (note the coordinate system chosen):

a. Which components of the velocity vector $\mathbf{v}$ can we reasonably assume to be zero?

b. In the Navier-Stokes equation, the velocity derivatives shown below appear. Which velocity derivatives can we reasonably assume are zero for this flow? Please indicate your reasons.

\[
\begin{align*}
\frac{\partial v_x}{\partial x} & \quad \frac{\partial v_y}{\partial x} & \quad \frac{\partial v_z}{\partial x} \\
\frac{\partial v_x}{\partial y} & \quad \frac{\partial v_y}{\partial y} & \quad \frac{\partial v_z}{\partial y} \\
\frac{\partial v_x}{\partial z} & \quad \frac{\partial v_y}{\partial z} & \quad \frac{\partial v_z}{\partial z}
\end{align*}
\]
3. (20 points) Answer the questions below for 25°C water flowing in 200.0 meters of smooth horizontal copper duct at a Reynolds number of $2.2 \times 10^4$. The duct has the following characteristics: rectangular cross section, duct height = 0.454 in; duct width = 0.900 in.

a. What is the hydraulic diameter \( D_H = \frac{4 A_{xs}}{\rho} \) for this flow?

b. Compared to a circular tube with inner diameter equal to the duct’s hydraulic diameter, what is the Fanning friction factor for this flow? Explain your answer.

4. (25 points) What is the flow-direction force on the walls for 25°C water flowing in 200.0 meters of smooth horizontal copper tubing at a Reynolds number of $2.2 \times 10^4$? The tubing has the following characteristics: circular cross-section, inner diameter 0.454 in; wall thickness, 0.040 in, outside diameter, 0.625 in. Please give your answer in Newtons.
5. (15 points) What is the y-direction force on 25°C water flowing in steady, turbulent flow in a horizontal return bend constructed from a length $L$ of smooth horizontal copper tubing? (see figure below; the device is in the x-y plane, which is horizontal) The inlet pressure is $p_{in}$ and the outlet pressure is $p_{out}$ and the average velocity is $\langle v \rangle$ throughout. The tubing has the following characteristics: circular cross-section, inner diameter $D$; wall thickness, $\delta D$, outside diameter, $D + 2\delta d$. Note the coordinate system defined in the figure.