Chapter 5 Name: ____________________

Single Phase Systems Date: ______________

Thus far, you have been given either mass or molar quantities (and mass or mole fractions) to describe stream flows in material balance problems. In Chapter 5, you encounter more realistic problem descriptions in which stream flows are specified in terms of volumetric quantities or flow rates, and your task is then to determine the density of the stream material and use this value to calculate the mass or molar quantity or flow rate of the stream. The mass or molar quantities, in turn, are used in material balance calculations. When the materials involved are solids and liquids, the densities can normally be assumed independent of temperature and pressure and looked up in published tables (e.g., Table B.1 in your text). When the streams are gases, however, density depends strongly on temperature and pressure, and an equation of state (EOS) must be used to relate molar and volumetric quantities. The simplest EOS is the ideal gas equation of state, which works well at high temperatures and low pressures. At other conditions, a more complex EOS must be used.

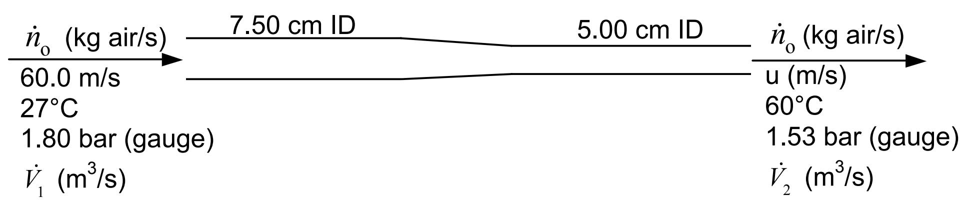
Be sure to read Chapter 5 in your text and work through the example problems before tackling the problems in the workbook. The text explains the concepts; we will work problems without as much explanation.

PROBLEM 5.10

A stream of air enters a 7.50 cm pipe at a velocity of 60.0 m/s at 27°C and 1.80 bar (gauge). At a point downstream, the air flows through a 5.00 cm ID pipe at 60°C and 1.53 bar (gauge). What is the velocity of the gas at this point?

Strategy

The problem statement doesn't ask for it, but it is always advisable to draw and label a flowchart first. The air is flowing at steady-state so the mass flow rate in each pipe must be the same and, since there is no chemical reaction, the molar flow rate must be the same as well.



We have built the mole balance into the flowchart by using $\dot{n}_o$ for both inlet and outlet flow rates.

To solve the problem, we need to recognize the need for two relationships. The first relates the velocity of the gas (which we know at the inlet) to its volumetric flow rate at that point, $\dot{V} = uA_x$ where A_x is the cross-sectional area of the pipe. Also, we need an equation to relate the volumetric flow, temperature, and pressure of the gas to its molar flow rate. We can use the ideal gas equation of state (EOS) for the second relationship, but we should test its validity for the stated conditions of the gas.

We will carry out the calculation in several steps:

(1) Determine whether the air can be assumed to behave as an ideal gas at the conditions in the 7.50 cm ID and the 5.00 cm ID pipes.
(2) Calculate the volumetric flow rate of the gas in the 7.50 cm ID pipe.
(3) If the air behaves as an ideal gas in the 7.50 cm ID pipe, calculate the molar flow rate, $\dot{n}_o$.
(4) If the air behaves as an ideal gas in the 5.00 cm ID pipe, calculate the volumetric flow rate of the air in the 5.00 cm ID pipe from the molar flow rate.
(5) Calculate the velocity of the air in the 5.00 cm ID pipe from the volumetric flow rate and the cross-sectional area.