ME 552 Measurements in fluid mechanics and heat transfer

Lab 1: Calibration of volumetric flow measurement devices (individual assignment using data collected in your group)

Due: February 2nd, 3rd, or 6th at the start of your respective laboratory time. Please turn in on the shelf at the entrance of Rogers 334.

The purpose of this laboratory assignment is to familiarize you with common sensors and methods used in measuring and calibrating volumetric flow rates of gases and liquids. The first objective is to calibrate orifice plates and a rotameter. These measurements will be calibrated using a dry-test meter. The second objective is to perform a catch-and-weigh measurement to calibrate liquid flow from a pressure vessel. The third objective is to use a bubble Gilibrator (Sensidyne) to calibrate flow rates of air through the MKS (thermal) flow controller.

First objective: Air flow rates for a flame (which you will study later in the term) need to be calibrated. Air initially enters an anhydrous filter to eliminate moisture. The flow is separated at a 'T' fitting and the stagnation temperature and pressure are measured prior to traveling through a pair of orifices. Only one orifice plates will be calibrated, so verify that the secondary flow path is closed. You will calibrate the orifice plate at incompressible and compressible flow conditions. Consequently, you will need to measure the pressure up and downstream of the orifice plate and consider which regime you are collecting data.

Recall that for incompressible flows: $Q = CEAY\sqrt{\frac{2\Delta p}{\rho_1}}$, where Q is the volumetric flow rate, C is the discharge coefficient, A is the area, Δp is the pressure drop across the orifice, ρ_1 is the upstream density, Y is a compressibility constant, and $E = \frac{1}{[1-(A_0/A_1)^2]^{1/2}}$. The subscripts 0 and 1 indicate the diameters in and upstream of the orifice.

Under chocked conditions (i.e., the flow is sonic) the mass flow rate (kg/s) can be determined using the stagnation pressure and temperature. Reference the equation below to determine the mass flow rate through a sonic nozzle. Further information regarding choked flows can be found in a gas dynamics textbook. Note that *k* is the ratio of specific heats.

$$\dot{m}_{choked} = C\frac{P_o A_t}{\sqrt{RT_o}}\sqrt{\frac{2k}{k+1}\left(\frac{2}{k+1}\right)^{2/(k-1)}}$$

Following the orifice plate, air enters a rotameter which allows for visual inspection of the flow rate. It is important to note that a rotameter's reading changes as the flow becomes compressible. This is suggested by the relationship:

$$Q_{actual} = C(Pressure_{downstream})Q_{observed}.$$

Here C is a calibration constant which depends on the downstream pressure. Following the rotameter, the air travels through a dry test meter (calibration standard). The volume which passes through the dry test meter is determined by measuring the volume of fluid which passes through the meter over a period of time. The plumbing and instrumentation diagram is below.

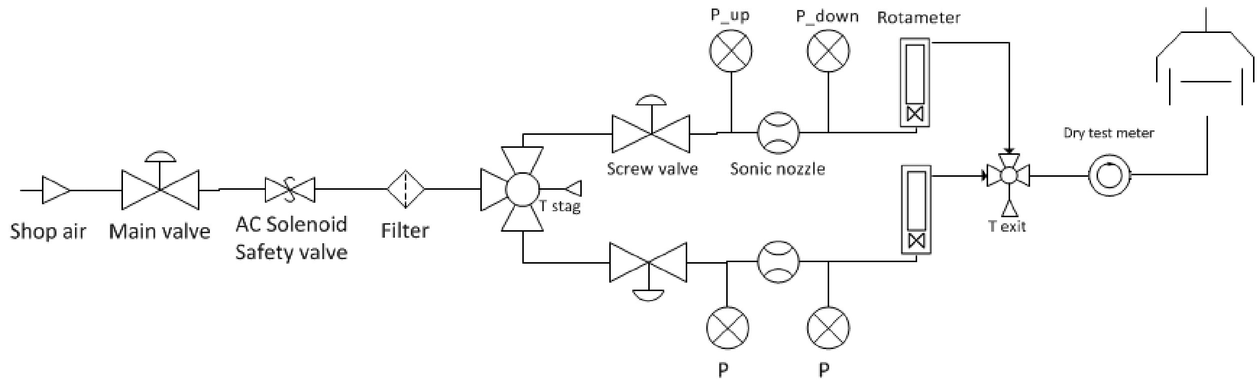

Figure 1. Plumbing and instrumentation diagram for calibration of orifice plate and rotameters.

Pressure and temperature measurements are recorded using a standalone DAQ. Temperature measurements reference a built-in cold-junction compensator within the device. Inputs are recorded by the LabVIEW program and are saved as Excel files in a designated directory. **Be sure to verify that files are saved and change the file name during each measurement.**

Procedures for calibrating the orifice plates and rotameters:

- Record time, laboratory temperature & pressure.
- Become familiar with the test layout and physical flow path for the air.
- Ensure all valves are closed.
- Turn on DAQ CPU, and open LabVIEW program.
- Turn on MKS module (warm up).
- Open wall air valve.
- Only use one nozzle flow path for your testing procedures.
- Begin to open screw valve upstream of the sonic nozzle, bringing pressure to 60 PSI.
- Open rotameter to a desired flow rate between 1-8 LPM.
- Measure the pressures on either side of the orifice plates. Adjust flow rates in non sequential order to limit hysteresis. You should collect data at 4 conditions between 1 and 4 LPM and 5 conditions between 4 and 8 LPM.
- Ensure that the dry-test meter is moving as intended.
- Perform snoop check on all fittings to look for the sign of leaks.
- When ready to perform calibration:
    - Record initial measurement of dry test meter and start stop watch
    - Record pressure and temperature data from the DAQ for 1 minute
    - Create new files names for each test
    - Let the flow occur for 4+ minutes and record the time and the value on the dry test meter
    - Use pressure and temperature data from equation 1 to measure mass flow rate through the sonic nozzle using a spreadsheet.
- Determine the volumetric flow rate and mass flow rate from the dry test meter for each condition. This will be used to calibrate the orifice plate and the rotameter.
- Be sure to record the make and model of the instrumentation used for the calibration. You will need this information to determine the design stage uncertainty.

- When complete with this phase of the assignment, turn off control box and close the air valve at the wall.

To Include in Report:

Plots of the calibration for both the orifice plates and the rotameters. **For the rotameter calibration, plot** the calibrated flow rate and compare to the value reported on the dial. Be sure to show uncertainty bars (design stage uncertainty) on the measured and dependent variables in the plot. **For the orifice calibration, plot** flow rates reported on the rotameter and determine using the dry-test meter for the different pressure drops. Include both subsonic and sonic conditions.

Answer the following questions:

1) How does the discharge coefficient compared to that reported for the orifice plate. http://www.okcc.com/PDF/NPT%20connections.pdf (Type H orifice with a 0.125" diameter throat)? Is the discharge coefficient constant for compressible and incompressible flows?
2) Are compressibility effects a concern for the rotameter over the range that you studied? Justify your answer.

<u>**Second Objective:**</u> You will calibrate the volumetric flow rate of fluid (water) delivered from an Isco-pump. An Isco-pump is a syringe type of pump that is used to deliver fuel to the burner. You will vary the volumetric flow rate and determine the difference between the value reported by Isco and what you measure.

Procedures for calibrating the volumetric flow rate:

- Using a calibrated scale, tare a container used as the catching device for fluid.
- Setting a constant discharge rate from the pump start and stop the timer as flow is discharged into a container. Weigh the container and compute the volume of the fluid.
- Divide the weight (by the fill time to measure the mass flow rates.
- Perform the calibration for at least 6 flow rates.
- Be sure to record the make and model of the instrumentation used for the calibration. You will need this information to determine the design stage uncertainty.

To Include in Report:

Plot the value reported by the Isco-pumps as the independent variable and the calibrated flow rate as the dependent variable. Be sure to show uncertainty bars (design stage uncertainty) for <u>both</u> the independent and dependent variables.

Answer the following questions:

1) Are the values reported by the Isco-pumps appropriate to use, or does a calibration need to be applied to the values reported for the Isco-pumps. Consider if values fall within the uncertainty bounds.

<u>**Third Objective:**</u> In the flame which you will study later in this term a pilot flame is used to ignite and stabilize the premixed fuel and air. It is important to know the equivalence ratio (i.e., the ratio of fuel and air) and energy released by the pilot flame. The pilot fuel flow rate is measured using a MKS thermal mass flow controller. You will

calibrate the MKS controller using a bubble Gilibrator device. During this calibration air will used instead of methane to preserve fuel. The air passes through the small rotameter prior to entering into the MKS controller at the user interface on the server rack. Air then passes from the MKS through the Gilibrator. Inside the Gilibrator, air passes through a bubbly solution from the bottom and exits through the top into an exhaust hood. When the action button is depressed and released, a ring is mechanically dipped into the liquid solution where a bubble may be created by the flowing gas. The bubble rises vertically through the transparent cylinder. The velocity of the bubble (and hence volumetric flow rate) is measured by computing the time the bubble takes to pass through two fixed locations within the device. Input values into the MKS controller will be calibrated based on the readings from the Gilibrator.

It is necessary to take numerous quality bubble measurements (>10) per flow rate.

Procedures for Calibrating the MKS thermal flow controller:

- Open small rotameter fully open.
- Input desired flow rate into MKS controller and ensure flow rate is 'on'.
- Air should be flowing though the Gilibrator at this point.
- Depress the action button on Gilibrator to create a single bubble.
- Only count single bubbles, and discard broken bubbles or double bubbles as this may give inaccurate readings.
- Record at least 10 bubble readings for each flow rate through the Gilibrator.
- Include at least 6 MKS flow settings in the calibration.

To Include in Report:

Plot data for MKS inputs to actual flow rates determined by Gilibrator. Be sure to show uncertainty bars (design stage uncertainty) on the measured and dependent variables.

Answer the following questions:

1) Discuss why the calibrated and MKS reported values are linearly related or not.

You may work with your group to record the data and determine instrument uncertainty. Is up to each individual to process the data, create the plots, and determine the design state uncertainty. You may compare results, but it must be your work.

Report:
Present a brief introduction, describe the methodology used, and any assumptions for the measurements. Respond to the questions posed in the handout and include the required plots with uncertainty bars. Conclude by describing what you learned from this laboratory. **Ensure that the final report is professional.** It is anticipated that no more than two pages of text is required to complete the report. Include in the Appendix documentation about how the design stage uncertainty was determined, <u>your uncertainty trees</u>, and anything that is needed to support your discussion.