Lab 1c
"Isentropic" Blow-down Process and Discharge Coefficient

OBJECTIVES

- To study the transient discharge of a rigid pressurized tank;
- To determine the discharge coefficients for several orifices and a long tube;
- To compare actual blow down processes with an isentropic processes for an ideal gas;
- To study the concept of choked flow

EQUIPMENT

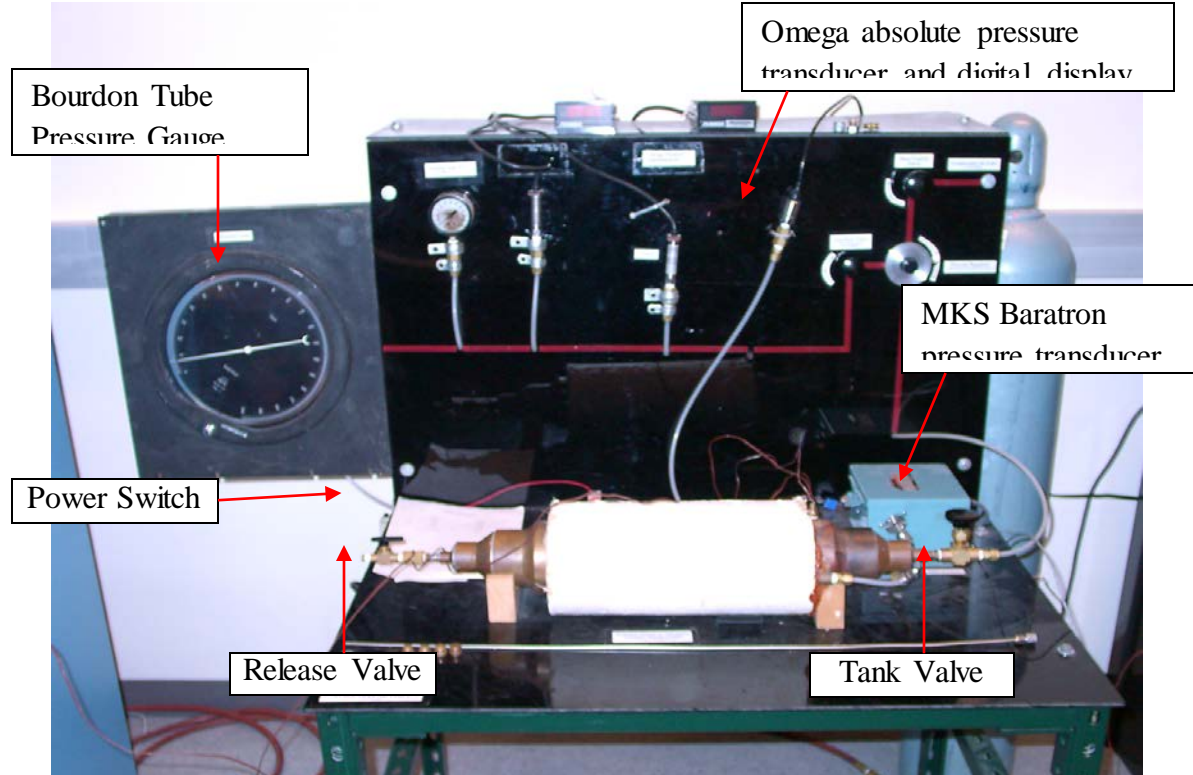| Name	Model	S/N
Thermistor	Omega HH804U	
Pressure Transducer	MKS Baratron	
Absolute Pressure Transducer	Omega Absolute	
Bourdon Tube Pressure Gage		
T-type Thermocouple		
Calibration Cell	Omega Ice Point Cell	
DAQ card	NI USB-9219	
Computer		
LabView VI		
Pressure Vessel		

Figure 1: "Isentropic" Blow-down Process and Discharge Coefficient Measurement

The "isentropic" blow down tank workstation includes a pressure vessel, pressure transducers, a pressure gauge, an internal thermocouple, and a computer-assisted data acquisition system (Omega OMB-DAQ-3001and LabView 2010 software). Figure 1 shows the main components of the experiment. You will use the Omega absolute pressure transducer with a digital display as a standard to calibrate the MKS Baratron pressure transducer which you will be using to acquire the pressure data. A T-type thermocouple and the MKS Baratron transducer are connected to the DAQ to record the data. The data acquisition is controlled by the software LabView VI available for download from the course website.

This lab was designed to be completed in 2 lab sessions. Data processing may take 1 or 2 more sessions. Data processing should be performed as data is taken, to guarantee good results.

REQUIRED READING

Read references [1, 2] for the theory and data reduction for this experiment.

PRE-LAB QUESTIONS (10% of the total grade of the lab, 2% each)

a) You measure the barometric (atmosphere) pressure in the lab to be 757.1 mm Hg. What is the pressure in units of pounds per square inch absolute (psia)?
b) What is choked flow?
c) How can you determine whether the system experiences choked flow?
d) What is the discharge coefficient?
e) Describe the isentropic blowdown process.

PROCEDURE

1. Write a detailed explanation of how the different components of the experiment work. Be sure to include information about:
    -   How to pressurize the tank?
    -   What channels of the DAQ should be connected to the pressure transducer and thermocouple? Make sure the channel and device numbers in the LabView program are correct in order to measure the signal properly.
2. The LabView program "lab1c.vi" will be used to control the measurement of this experiment with a National Instruments USB-9219 DAQ card. This DAQ card has a dedicated connection setup specifically for thermocouples. Refer to the information on the back of the DAQ to properly the thermocouple and pressure transducer.

    Figure 2 in Appendix.A shows the front panel of the program. By pressing "Ctrl + e" you can switch between the front panel and the block diagram when open. Note that the data saved in the specified file will be overwritten if the file name is not changed for each run of the program. Explore the program to understand its functionalities before conducting the experiment.

i. Copy the program lab1c.vi to the place of your preference such that you can explore the program without modifying the original. Use the copy for the whole experiment.

ii. Connect the leads for both the thermocouple and MKS transducer to the DAQ card. The information on the DAQ card itself will help setting it up correctly. Disconnect the signal leads temporarily for the MKS transducer from the DAQ card before turning on the power for the apparatus.

iii. Power on the isentropic blowdown apparatus by switching the power strip located on the rear leg on the left hand side of the table. The Omega pressure transducer's displays should turn on. The gauge pressure should read approximately 0 psig and the absolute approximately 14.7 psia.

iv. Determine the barometric pressure (i.e. atmospheric pressure) of the room using the lab barometer. Convert this pressure to psi. Also record the reading of the Omega absolute pressure transducer at atmospheric pressure. Note the difference between the barometer and the Omega absolute pressure transducer at atmospheric pressure. Use this difference to "zero" the Omega transducer to the barometer reading within its resolution. You can apply this correction (deviation) to all of the Omega transducer readings; and you will now be able to use it as the local standard.

Calibration of MKS Baratron transducer

Calibration of the MKS Baratron transducer and T-type thermocouple must be performed before taking any measurements for data analysis.

3. Draw a diagram of the calibration system setup in your logbook. A schematic drawing of the most important components is shown in Fig. 3. Close the Release Valve and Main Control Valve while opening the other two valves. **Confirm that the compressed air line at the wall is open; open if closed.** Carefully pressurize the system using the Main Control Valve to approximately 80 psia. **Do not adjust the pressure regulator**. Feel free to experiment with the operation of the valves on the apparatus. The TA will assist you if necessary. Notice that when the Tank Valve is closed, the tank will be isolated from the line reading Bourdon tube pressure gauge, and then only the Omega absolute pressure transducer and MKS Baratron pressure transducer will sense the tank pressure. You will calibrate and run the experiments with the Tank Valve closed **after pressurizing** it using the Main Control Valve.
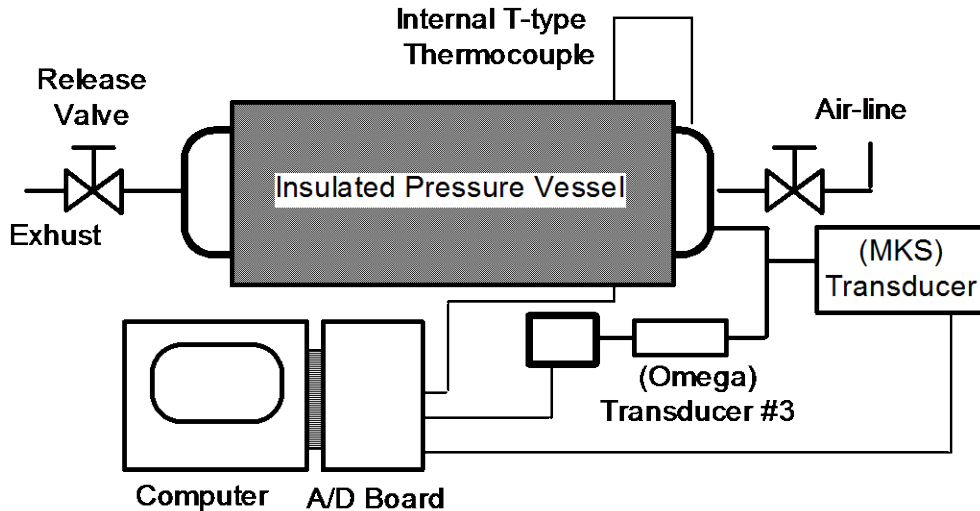
Figure 3 Schematic diagram for pressure discharge experiment

4. Under the Lab1c section on the course website, there is a document called Precision and Bias Errors. The PDF is titled "Determining Accuracy and Precision of Measurements: Using Calibration to Estimate Bias and Precision Errors" and provides an outline on performing a calibration to determine the precision and bias errors for the sensors.

5. At the computer, begin running lab1c.vi for calibration of the MKS pressure transducer. Change the file name and path where the calibration data is to be saved, if necessary. Note the important configurations of the DAQ card and LabView program in your logbook, including the connection channel and port, measurement range of the channel, channel mode, sample rate, etc. Set the sample rate to 100 HZ and the voltage range for pressure readings to ± 5 *V*. Note: you should be able to determine an appropriate sample rate such that good results can be obtained while the data written to the file is not noisy.

6. Using the Omega Absolute Pressure Transducer display as the lab standard, develop a calibration curve for the MKS pressure transducer. Do this by recording the readings of the Omega Transducer digital display and the MKS voltage output (from the LabView VI) at eight pressures from atmospheric up to approximately 80 psia. Repeat readings at one of the pressures at least 10 times to determine precision and repeatability errors. This, along with the error of the linear fit, will be used to determine the accuracy of the MKS Baratron pressure transducer. If there are small pressure leaks in the system, group members will work together to call out readings to synchronize the data collection. Describe any such strategies in your logbook in the procedure section.

Calibration of T-type thermocouple

7. With the tank un-pressurized, allow the tank to come to thermal equilibrium. Using a thermistor as a standard, take reading at room temperature to estimate the accuracy of the tank thermocouple. Using an ice-point temperature cell and thermistor as your temperature

standard, determine the instrument error for the thermocouple in the tank. Note that the thermocouple cannot be removed from the tank, so you will use another T-type thermocouple with the same connector to the DAQ as used in the experiment. One possible approach is to take readings in the ice point cell and also at ambient temperature with the thermocouple and thermistor to determine possible bias and uncertainty errors. Then combine the ice point and room temperature measurements to estimate a total instrument error for the thermocouple. Note that the Ice Point Cell takes time to reach proper temperature; allow up to 10 minutes for the unit to cool from room temperature. Your group will determine your own procedure for this calibration. Document all steps in your logbook. Record all data and report the accuracy of the thermocouple. For this calibration, change the user input options in the front panel of the LabView program if needed. Also, report important configuration changes to the DAQ card and LabView program in you logbook. This concludes the calibration portion for this experiment and makes a good stopping point for Day 1.

Measurement of Blow-down process

8. Record pressure and temperature decay during the blow-down process for different orifice restrictions attached to the outlet of the tank by opening the Release Valve. Set up the appropriate user input options in lab1c.vi for recording the data. There are four caps with different opening orifice sizes, and a long tube. Note that you should allow the tank to come to thermal equilibrium (as close as possible) after pressurizing it for each run. Consult the previous steps for pressurizing the tank and configuring the options, if needed.

9. At the end of recording your data, disconnect the MKS pressure signal from the DAQ, turn off power to the system, and turn off the compressed air line to the system. Perform the steps in this order to prevent a signal from being connected to the DAQ when it might be powered off. **The DAQ should never have sensors connected to it without being powered.** The very low voltage level of a thermocouple is an exception to this rule.

Analysis

10. Perform calculations for the uncertainty and accuracy of the MKS Baratron and thermocouple. Report the results in your logbook in terms of a 95% confidence interval for the MKS transducer and an overall instrument accuracy for the thermocouple.
11. Discuss your observations of each orifice size and tube used in the experiment. For example, note how the decay of (dimensionless) system pressure and the time required to reach the end of choked flow varied for each orifice. Provide plots of the experimental results in your logbook (dimensionless pressure versus time).
12. See pages 61- 65 of the lecture notes [1] on the course website for the theoretical background of the system modeled in this experiment and the equations needed for the analysis. Based on an appropriate physical model, set up a spreadsheet to calculate the "apparent" discharge coefficient (C_D) versus pressure ratio (see plot in the "Data Reduction" handout [2] for reference) for each orifice used in the experiment; discuss the results as appropriate.

13. Since pressure is the driving force for this process, use the measured pressure in the isentropic equation to calculate the corresponding ideal temperature for an isentropic process. By using the measured pressure in the isentropic equation, the corresponding temperature for an isentropic process undergoing the measured pressure change can be calculated. Compare the temperature response for an isentropic process with the measured temperature (i.e. plot T vs. P for measurements and isentropic process). Starting temperature for the isentropic process should be the starting measured temperature. How "close" to isentropic is our process, and what might be causing the difference? The equation relating the initial ("1") and final ("2") states of an ideal gas undergoing an isentropic process is:

$$\frac{T_2}{T_1} = (\frac{P_2}{P_1})^{(k-1)/k} \tag{1}$$

where the initial conditions for the process at state "1" are fixed for the process. State "2" can be considered the state after the next time step. Use the starting measured values for temperature (T_1) and pressure (P_1) along with the measured pressure as the second state (P_2) to calculate T_2 using the isentropic process equation 1. T_2 and P_2 then will become the initial conditions for the next time step. Repeat this for all the time steps. **For Equation 1 to give proper results, both T_1 and T_2 must be absolute temperature (K).** See an example comparison between measured and isentropic process data in Figure 3 in Appendix.A; heat transfer is quite noticeable.

14. Perform an uncertainty analysis. Estimate the uncertainty of the measured discharge coefficients using error propagation. Discuss the uncertainty of the measurements of the discharge coefficients; discuss all your elemental errors and identify the largest sources of error.

REFERENCES

[1] L.D Chen, "Experimental Engineering Lecture Notes",
http://www.engineering.uiowa.edu/~expeng/lecture_notes/LD_Chen_Notes.pdf (1996).

[2] Experimental Engineering course website,
http://www.engineering.uiowa.edu/~expeng/laboratories/lab_references/Lab%201c%20-%20Example%20Calcs.pdf
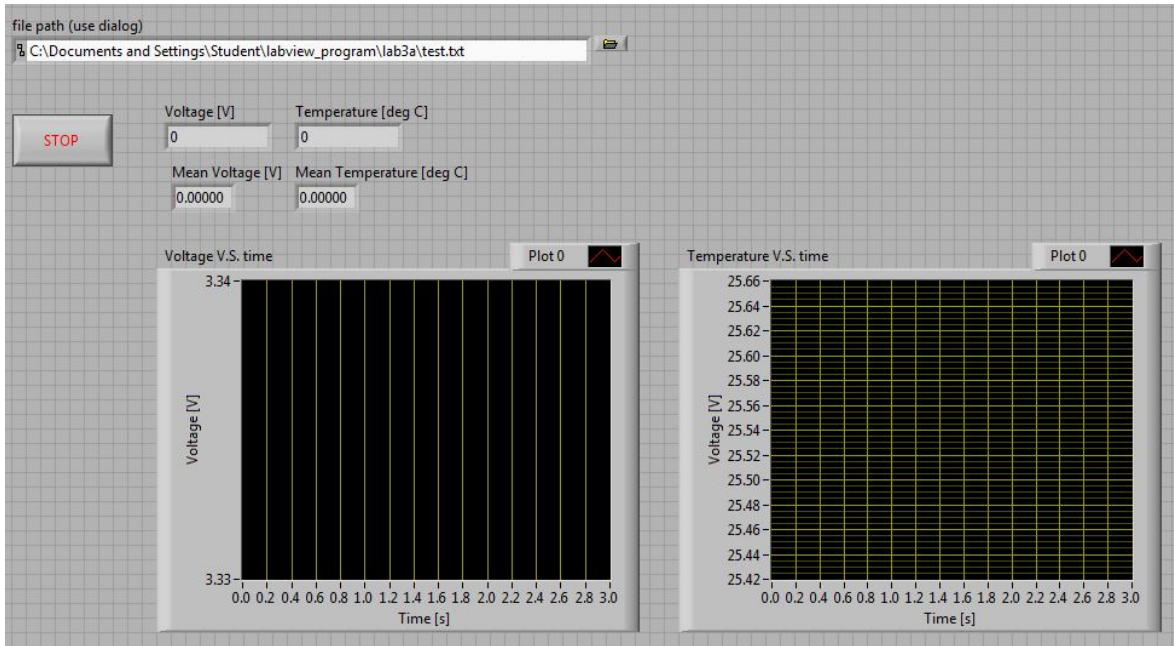
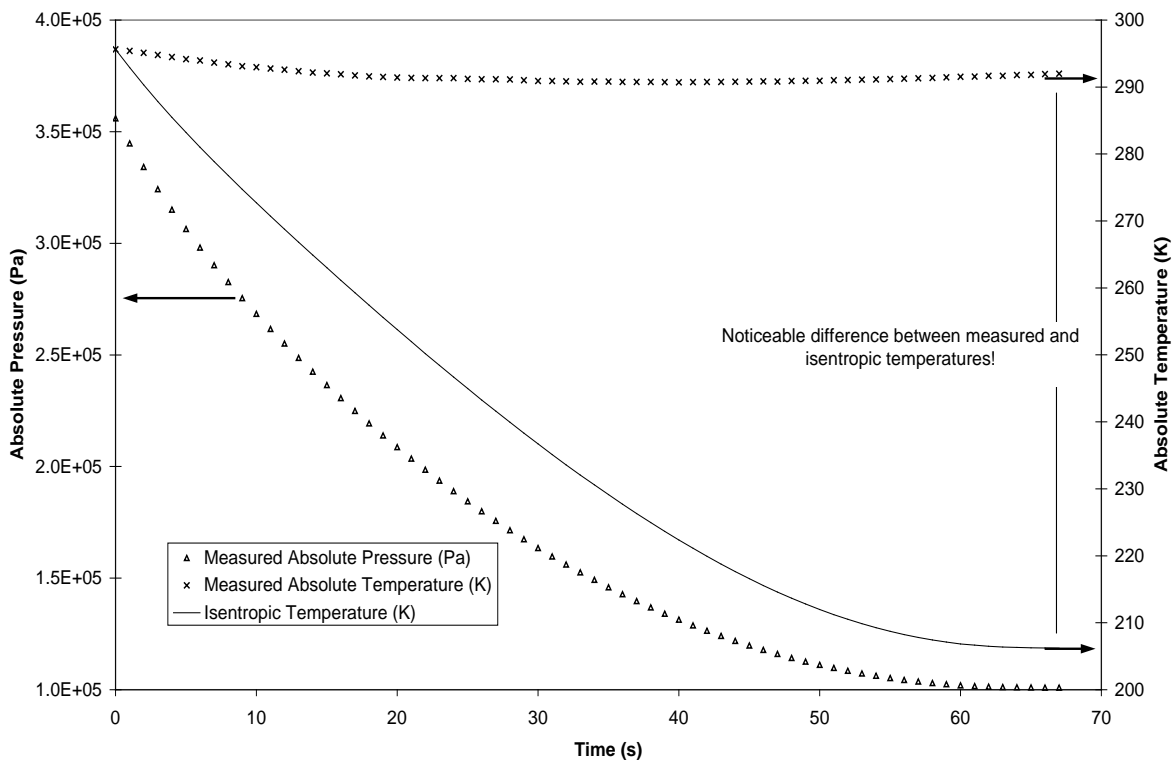## APPENDIX.A FIGURES

Figure 2 Screenshot of front panel of lab1c.vi

Fig 3 Comparison between experimental and isentropic process