

Lab 10: Choked Flow

SAFETY SECTION: Labs 10 and 11 deal with compressed air. Compressed gases, when compared to incompressible liquids, have additional safety concerns because a lot of energy can be stored in a compressed gas. If that energy is released suddenly, it can propel dust and other solids at high speed and create harmfully large sound levels. Do not place your face or head in the path of high-speed gas flow. Long pants, closed toed shoes and safety glasses must be worn at all times.

You will fill a tank with compressed air at pressure around 75 psig. The tank is rated to handle a pressure considerably larger than this. In addition, there is a pressure relief valve on the tank to release pressure if it were to get too high. Therefore, the risk of a tank rupture is negligible.

Begin your lab by holding a team planning session (3 minutes):

1. **This lab will require additional preparation time.** You should have previously read the first 4 ½ pages of “Tank Blowdown Math” posted on Learning Suite, seeking to understand the principles of compressible flow and the key equations you will need to analyze your data.
2. Review the safety information above.
3. One person should serve as leader/coordinator. All team members should strive to make the team function better through various roles: observer, recorder, devil’s advocate, etc. Ask for each other’s input and opinions, help each other, and try to come to consensus after an appropriate amount of brainstorming and analysis.
4. Make a plan for how you will complete the lab activities. Each person should fill out their own lab report as activities are completed. At the end of the hour, after shutting down equipment appropriately, get the TA to initial the end of your report.

Background: Compressible fluid mechanics governs situations in which fluid density can significantly change, either while the fluid is stored in a tank or while it is moving along a flow path. For storage of fluids, one can use an equation of state to determine density under the prevailing pressure and temperature. For flowing systems, the key principle to determine if pressure drop is enough to generate density changes is whether the fluid velocity is close to or exceeds the speed of sound. For reference, the speed of sound in air is around 340 m/s and in liquid water is around 1500 m/s.

The first 4 ½ pages of the document “Tank Blowdown Math” posted on Learning Suite provide needed equations and background. The document discusses the principle of *choked flow* which governs flow of gases through constrictions with high pressure drops.

Project: In this lab you will do a transient mass balance on a tank while filling it with compressed air. You will learn to use a gas mass flow meter. You will also determine the discharge coefficient CC_{dd} for one of the orifices that can be used to empty the tank. You will need this information when for Lab 11.

1. **Pre-Lab Preparation:** Answer the following questions to prepare for the data collection and analysis

- a. What is meant by "choked flow"?
- b. You are discharging an air-filled tank through a small orifice. What is the tank gauge pressure (in psig) at which the discharge will transition from choked flow to subsonic flow? Use the standard atmospheric pressure in Provo, $0.84 \text{ atm} = 12.3 \text{ psi}$.
- c. The tank pressure gauge gives gauge pressure, while required thermodynamic calculations need absolute pressure. How do you convert between one and the other?
- d. Do an online search for "thermal mass flow meter principle of operation." Explain what you learned about how the device measures mass flow of a gas.
- e. The mass flow meter we use in this lab gives flow in standard liters per minute (SLM). How do you convert between this quantity and a mass flow rate in units of gram/min?

2. Familiarization. Identify the following items on the apparatus (check mark each):
- a. ___ The black/red flow control knob on the building compressed air supply. Make sure it is fully open when you begin and fully closed when you are done. If the knob doesn't turn easily it may be locked, pull the red disk out.
 - b. ___ The mass flow meter on the supply line. Make sure it is plugged in and has warmed up, reading close to zero.
 - c. ___ The small black/red flow control knob between the mass flow meter and the tank.
 - d. ___ The pressure gauge on the tank. Turn it on.
 - e. ___ The four outlet orifices on the tank, each controlled with an on-off ball valve. The product number on each orifice gives the size: H-40BR means diameter 0.040 inch, H-20BR means diameter 0.020 inch, etc.
 - f. ___ The two pressure relief valves with pull rings, one of which has an on-off valve.

3. Fill the Tank at a fixed mass flow rate and use this to estimate actual tank volume.
 - a. Start the tank empty (gauge pressure zero)
 - b. Open the flow control valve and quickly adjust it to get as close to 20 SLM flow rate. Begin a stopwatch at the same time. Continue to adjust the knob to maintain 20 SLM. Record the time when this is no longer possible and flow has dropped to less than 10 SLM. Close the valve and record the tank pressure as well.

Filling time: _____

Final tank gauge pressure: _____

Estimate of final tank absolute temperature: _____

- c. Estimate the tank actual volume in liters by using a mass balance and the above data. You need to understand what exactly the flow meter is measuring. The calculation requires a single line of math once you understand the concepts. Show that your volume estimate is reasonable based on the approximate length and diameter of the tank.

- d. During the filling process, you had to keep adjusting the control knob to maintain a steady flow rate. Which way did you have to adjust the knob (more open or more closed)? Explain physically why this was necessary.

- e. Once you conclude the filling process and the control valve is fully closed, the pressure in the tank continues to drift slightly. Why is this? (the answer is not that the gauge is wrong).
4. Determine the Discharge Coefficient for at least one orifice under choked flow conditions.
- a. To determine C_d for an orifice, you need to determine the mass flow through the orifice for a given upstream tank pressure (see “Tank Blowdown Math” Eq. 12). This is best done by setting up a steady-state condition in which you are filling and emptying the tank at the same rate, so that the flow meter on the tank inlet is telling you what is going through the orifice. This should be done while maintaining the tank at high pressure and the orifice at high flowrate so that choked flow prevails and the digital measurements are more accurate.
 - b. If you assume your experiment is at steady state, but it actually isn't, your results will be inaccurate. How will you know if you have achieved steady-state conditions in your experiment? In other words, what physical evidence will you use to determine this? Be specific.
 - c. Record below the results for at least one experiment and at least one orifice.
 - d. When done with the experiment, leave the tank depressurized with all valves closed.
 - e. How long did it take to achieve steady-state behavior in your experiment? Can anything be done to decrease this time?

- f. Determine C_d for at least one orifice from your results in part **b**. Show your calculations. Is your result reasonable? Explain.

Grading Rubric (to be completed by TAs)

	Points	Max
Completed activities and write-up		8
Steady state achieved; Calculations accurate		6
Safety and equipment shutdown TA initial: _____		1
Total		15