# Lab 8
# Mass Flow Controller Flow Verification Using the Pressure Rate-of-Rise Technique

Name: ________________________

## Purpose

The purpose of this lab is to:

1) Understand how to verify the mass flow from an MFC by using the pressure rate-of-rise technique.
2) Determine the gas correction factor for a gas other than nitrogen/air.

## Review

The pressure rate-of-rise technique is a proven primary standard method that is used to calibrate mass flow instruments as well as to verify flow controller settings. The technique uses the relationship between throughput and the rate of rise of pressure as gas flows into a known, fixed volume.

Properly designed rate-of-rise calibration systems can achieve accuracies of 0.2% to 1.0%. Devices using the rate-of-rise technique include stand-alone calibration systems and dedicated instruments that are incorporated in a process tool's gas box or gas panel.

In some process tools, a rate-of-rise system may be improvised by using the tool's pumps, process manometer and isolation valving. Owing to a number of factors such as volume and temperature variations, this is usually more of a consistency check as opposed to a precise calibration method.

The equation for determining mass flow as determined by the pressure rate-of-rise method is:

$$Q = 79\left[\frac{273}{273+T}\right]\left[V\frac{\Delta P}{t}\right] \qquad \text{Equation 1}$$

where $Q$ is in standard cubic centimeters per minute (sccm), $T$ is in °C, $V$ is in liters, $P$ is in torr and $t$ is in seconds. Explain the elements of the above equation in terms of units conversion, adjustment to standard conditions, and the relationship between mass flow, speed and pressure ($Q=PS$).

This exercise will be divided into three parts:

1) *System Volume Determination:* Since the volume of the VTS-1 system is unknown, we will determine its volume by flowing gas at a known throughput into the manifold and observing the pressure change over a known period of time.
2) *MFC Flow Determination:* With the flow controller set at an unknown rate, we will determine that mass flow rate by observing the pressure rate-of-rise into the (now) known volume of the manifold.
3) *Gas Correction Factor Determination:* We will determine the real flow of another gas, dissimilar to air/nitrogen, with a known nitrogen equivalent flow and then determine the gas correction factor (GCF) for that particular gas.

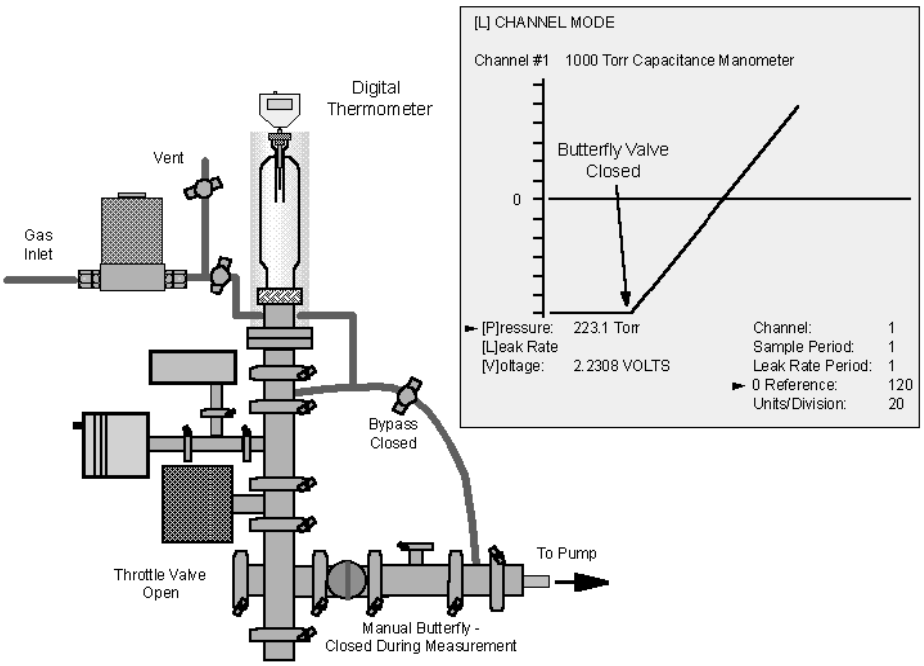
## Part I: System Volume Determination

The flow calculation will be meaningless unless the volume of the system (*V* from Eqn. 1) is accurately known. In dedicated calibration systems the volume is determined by weighing the entire system before and after filling with water. Since water has a density of 1 gm/cc, the volume can be determined with a high degree of precision. In the case of the trainer, and process tools, that is not a practical option. Instead what is usually done is to flow gas from a known good (recently calibrated) MFC into the system at a specified flow rate and solving Eqn. 1 for volume. Rewrite Eqn. 1 to solve for volume.

$V =$

Set up the system as shown in the figure on the next page. As temperature deviations from standard conditions (defined as 0 °C) will affect the results, we will monitor the prevailing temperature by inserting the thermometer into the chamber as shown. The gas source to the MFC can be either room air (through the sintered filter) or dry air or nitrogen from a gas line. A watch with a second hand or a stop watch (preferred) will be required.

Start by zeroing the MFC. With the system at atmosphere and both the inlet and outlet tubes of the MFC pinched closed, give the MFC a set point of 0 sccm. Adjust the zero pot on the MFC until the flow indication (Channel 4) reads 0.0 sccm. If the MFC is not zeroed, what will be the effect on the measurement?




The results of this measurements you will take are dependent upon the MFC being the only source of gas entering the system. Leaks, real and/or virtual, will add to the gas that the MFC is supplying to the system. To ensure that these other effects are negligible, perform a pressure rate-of-rise leak test (upleak test) by pumping the system to its base pressure with the MFC's pinch clamp closed, isolating the system by closing the butterfly valve and monitoring the pressure rise as measured by the convection Pirani gauge over a 3 minute (180 second) period. Consider the results satisfactory if the pressure rate-of-rise is less than a few milliTorr/second. <u>Enter your data in the table below.</u> (Two lines are provided in case it is necessary to correct a problem and redo the test.)

| Run | Initial Pressure ($P_1$) | Final Pressure ($P_2$) | $\Delta P$ ($P_2$-$P_1$) | Elapsed Time ($t$) | Pressure Rate-of-Rise ($\Delta P/t$) |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |

Open the butterfly valve and repump the system to base pressure and zero the capacitance manometer. For this test, what problems, if any, would result from the capacitance manometer not being properly zeroed?

Now, open the MFC's pinch clamp so that gas can flow into the system. The base pressure should rise to a new steady-state value. You are now ready to begin the test. When the butterfly valve is closed, the pressure will rise quickly. A suggested procedure is to close the valve and start timing when the pressure passes some value, say 5 Torr. The final pressure measurement is taken after the passage of about 3 minutes (180 seconds). As the pressure is rising, observe the trace on the computer display. Is it linear? What would variations in the slope indicate?

Use the table below for your data and calculate the system volume (*V*) in liters. Perform the test two or three times to check your consistency. Does the calculated volume seem reasonable?

| Run | $P_1$ | $P_2$ | $\Delta P$ | $t$ | $T$ | $V$ ($Q$=40 sccm) |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |

Discuss some of the sources for inaccuracy or inconsistency in performing this test. Include factors that are induced by the system itself, the accuracy of the MFC (specified as ≤ ±1% of full scale), and your manual data gathering technique.

## Part II: Flow Determination

Now that the volume of the system has been determined, we can now use the system to check the flow from the MFC on a routine basis. Rather than wait for the MFC to lose its calibration, we will determine the actual flow from the MFC with an unknown set point.

Have your instructor or lab assistant enter a new set point for the MFC. He or she will ensure that the Type 146 controller is set so that the flow is not displayed.

Pump the system to its base pressure and perform the rate-of-rise test as before. Enter your data and results in the table below. This time you will solve for $Q$ using Equation 1.

| Run | $P_1$ | $P_2$ | $\Delta P$ | $t$ | $T$ | $Q$ ($V$= *liters*) |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |

When you are satisfied that you have performed the test correctly, view the set point that was entered and list the value here. Discuss your results.

Now that you know the system volume you can also compute the system leak rate based on the data that you obtained while performing the upleak check (page 3). What is the leak rate in std. cc/second? (Note the units!)

## Part III: Determining a Gas Correction Factor

Mass flow controllers are usually calibrated for nitrogen. Since the calibration of an MFC is dependent upon the thermal properties of the gas flowing through the MFC, correction factors have to be applied when other gases are used with the instrument. Since the pressure rate-of-rise method is gas independent, it represents a very reliable way to determine these *gas correction factors* (GCF). The GCF is the factor that the set flow would have to be multiplied by to get the true flow:

$$\text{Gas GCF} = N_2 \text{ GCF } (1.000) \times \text{Actual Flow/Set Flow} \qquad \text{Equation 2}$$

Attach a source of gas other than air or nitrogen to the inlet of the MFC. Argon is a good option as is canned "dust remover spray" (1,1,1,2 tetrafluoroethane). Helium can be used but its GCF is nonlinear and will vary with different flow rates. (Actually, the pressure rate-of-rise technique is quite valuable for determining GCFs under specific conditions of flow for gases such as helium.) If you use helium, try several different flow rates to observe this effect.

Run the rate-of-rise test as before and enter your data and results in the table on the next page. Solve for *Q* using Equation 1.

| Run | Flow Set Point | $P_1$ | $P_2$ | $\Delta P$ | $t$ | $T$ | $Q$ ($V=$ *liters*) |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| 3 | | | | | | | |

Compute the GCF using Equation 2. How does your result compare with the published value (look in the back of the MFCs instruction manual).

Lab written by S. Hansen at MKS Instruments and M. Quirk at Austin Community College, based on information from the VTS-1 equipment manual written by MKS Instruments, Inc. Comments may be submitted to S. Hansen at: MKS Instruments, Inc., Six Shattuck Rd., Andover, MA 01 or by email to hansens@mksinst.com.