Compressibility Factors of Gases

ver 6.75

Introduction

There are three unique experimental methods used to determine the pressure-volume-temperature behavior of gases. One method requires the measurement of the temperature, pressure, volume, and mass of the gas; the mass is held constant and the volume may or may not be varied. A second method requires the measurement of only temperature and pressure; both the mass and volume are allowed to vary. The third method requires the measurement of only the temperature and a differential pressure; in this case a comparison is made between an unknown gas and a carefully stated reference gas. The second method, due to Burnett, will be used in this experiment.

The experimental aspects of Burnett's method consist of alternately expanding a gas isothermally from a chamber of volume V1, initially at high pressure, into a chamber of volume V2 and evacuating the second chamber. Initially, the first chamber is filled with an inert gas and the second chamber is evacuated. The pressure inside the first chamber is recorded. Gas is allowed to isothermally expand from the first chamber into the second. This is allowed to proceed until equilibrium is established, i.e. net gas flow from the first chamber into the second will naturally stop. The pressure inside the chambers is then recorded and the second chamber is evacuated. This process is repeated until pressures too low for accurate measurement are reached.

Data Analysis

A constant N unique to the apparatus used can be defined as follows:

$$N = \frac{V_1 + V_2}{V_1} \quad (1)$$

the terms V_1 and V_2 refer to the volumes of chamber 1 and chamber 2, respectively. The number of moles, n, initially present in chamber 1 is given by:

$$n = \frac{P_0 V_1}{z_0 RT} \quad (2)$$

where: P_0 = initial pressure in chamber 1
z_0 = compressibility factor of gas at P_0 in chamber 1
R = universal gas constant
T = temperature of the constant-temperature water bath

After the first expansion the total number of moles present in chambers 1 and 2 is unchanged from the initial amount, n. This amount is given by:

$$n = \frac{P_1 V_1}{z_1 RT} + \frac{P_1 V_2}{z_1 RT} \quad (3)$$

the pressure P_1 and z_1 are the pressure and compressibility factor after the first expansion.

Combination of equations (1-3) eliminates the terms n,V_1 and V_2 resulting in:

$$\frac{P_0}{P_1} = N\frac{z_0}{z_1} \tag{4}$$

After the r^{th} expansion, the pressure ratio is:

$$\frac{P_{r-1}}{P_r} = N\frac{z_{r-1}}{z_r} \tag{5}$$

Both theory and experiment indicate that compressibility approaches unity as pressure decreases. This suggests that:

$$\lim_{P\to 0}(z) = 1 \tag{6}$$

The limit of equation (5) becomes:

$$\lim_{P\to 0}\left(\frac{P_{r-1}}{P_r}\right) = N \tag{7}$$

Equation (7) allows the apparatus constant, N, to be evaluated as the y-intercept of a plot of P_{r-1}/P_r versus P_{r-1}.

Pressure P_r and compressibility z_r after the r^{th} expansion can be related to the ratio of pressure and compressibility at initial conditions by the expression:

$$P_r N^r = \left(\frac{P_0}{z_0}\right) z_r \tag{8}$$

Applying equation (6) to equation (8) results in:

$$\lim_{P\to 0}(P_r N^r) = \frac{P_o}{z_0} \tag{9}$$

The initial pressure-compressibility factor ratio is evaluated as the y-intercept of a plot of $P_r N^r$ versus P_r. Once N and P_0/z_0 are calculated, the compressibility after each expansion can be evaluated using equation (8).

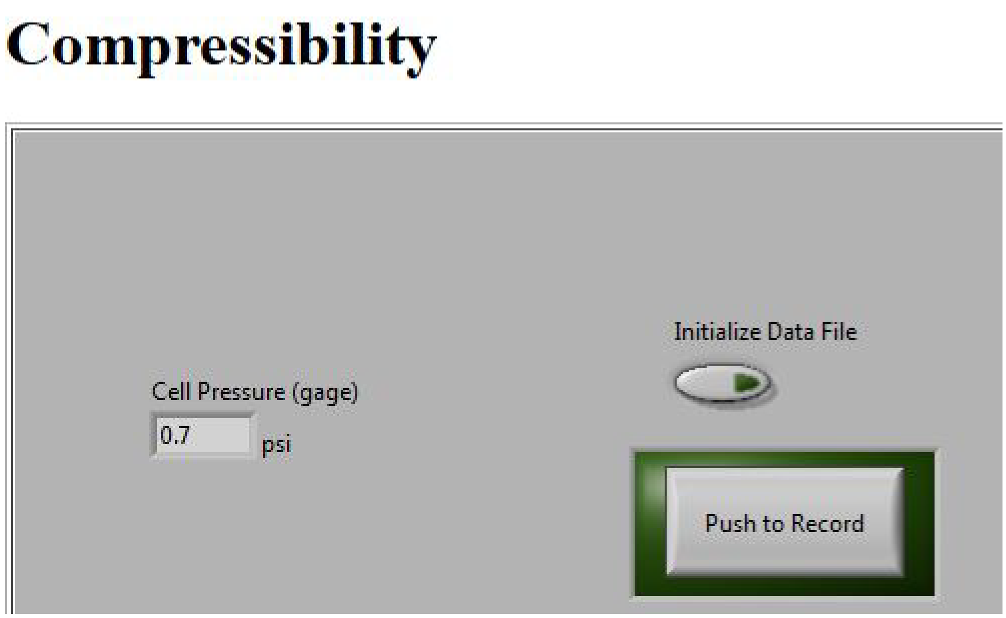

Figure 1 Labview VI screen capture

EXPERIMENTAL PROCEDURE

Operation of the compressibility experiment is simple. It is required, however, to be familiar with the purpose of each piece of equipment before operating the apparatus. Safety glasses should be used at all times. Below is a list of equipment.

- Valve 1: allows pressurized gas to enter the system. This valve must not be open at the same time as valve 3 or valve 5.
- Valve 2: allows gas to pass between chambers 1 and 2.
- Valve 3: allows the vacuum gauge to measure pressure. This gauge must not be exposed to positive gauge pressure (greater than ambient). Do not open this valve before valve 5 if the system is pressurized.
- Valve 4: allows the pressure gauge to measure pressure. This valve remains open.
- Valve 5: allows gas to escape to the ambient atmosphere.
- Temperature bath: the temperature controller should be turned on during operation. Do not adjust settings on the controller.
- Pump: evacuates gas from the system when valve 3 is open.

START-UP

Before any data is collected, the following procedures should be followed.

1. Close all valves except for Valve 4(V4).
2. Open Valve 2 (V2) and Valve 3 (V3). Evacuate the system (using the pump) to a moderately low absolute pressure.
3. Close V3. Slightly open Valve 1 (V1). V2 is still open.
4. Allow gas to flow into the system until the pressure gauge reads :: 50 psig.
5. Close V1. Slightly open Valve 5 (V5) in order to reduce system pressure to ambient pressure.
6. Close V5. Open V3. Evacuate the system to the lowest possible absolute pressure.
7. Close all valves.

DATA COLLECTION

Once start-up procedures are completed, these steps can be followed:

1. Open V1 slightly in order to fill chamber 1 with an inert gas.
2. Allow gas to continue to flow until the pressure is :: 750-800 psig.
3. Close V1. Allow the admitted gas to reach thermal equilibrium (i.e. do not proceed for a few minutes). Record the pressure at equilibrium.
4. Open V2 slowly. Gas will flow (:: 2 psi/sec) from chamber 1 to chamber 2. Keep V2 open until equilibrium is established (gas flow stops and the pressure ceases to decrease).
5. Close V2. Record the pressure (gauge or Labview (see fig 1; go here)).
6. Open V5 in order to reduce system pressure to ambient. Close V5 once accomplished.
7. Open V3 and evacuate the system to the lowest possible absolute pressure.
8. Close V3.
9. Repeat steps 4-8 until very low pressures (:: 5-15 psig) are reached.
10. In order to shutdown close all valves and turn off the temperature controller after step 8.