Reservoir Fluids

PETE 310

Lab 3: Determination of the Gas Compressibility Factor Z

Learning Objectives:

Evaluate the compressibility factor of two different gases CH_4, and C_3H_8 as a function of pressure and temperature.

Prove (or disprove) the validity of the law of corresponding states

Compare values of z-factors determined in this experiment with published values from z-factor charts

To detect faulty data and to diagnose a potential leak by observing data that do not "behave" properly.

General Skills

Use of Excel spread sheets and graphs

Working with different units and converting one set to another

Background from Class

Intensive and extensive properties

Ideal gas models and evaluation of ideal gas volumes

Reduced properties (p_r and T_r)

Evaluation of gas densities using the z-factor

Definition of the z-factor

The compressibility factor, z, is the ratio of the volume actually occupied by a given mass of gas (n) at given pressure and temperature to the volume that the same mass of gas would occupy if it behaved like an ideal gas at the same pressure and temperature. Thus:

$$z = \frac{V^{real}}{V^{id}} \tag{1}$$

Knowledge of the pressure/volume/temperature (PVT) behavior of natural gases is necessary to solve many petroleum engineering problems. Gas reserves, gas metering, gas pressure gradients, pipeline flow and compression of gases are some of the problems requiring precise calculation of gas density.

The compressibility factor equation of state for a real gas is:

$$pV = znRT \tag{2}$$

where,

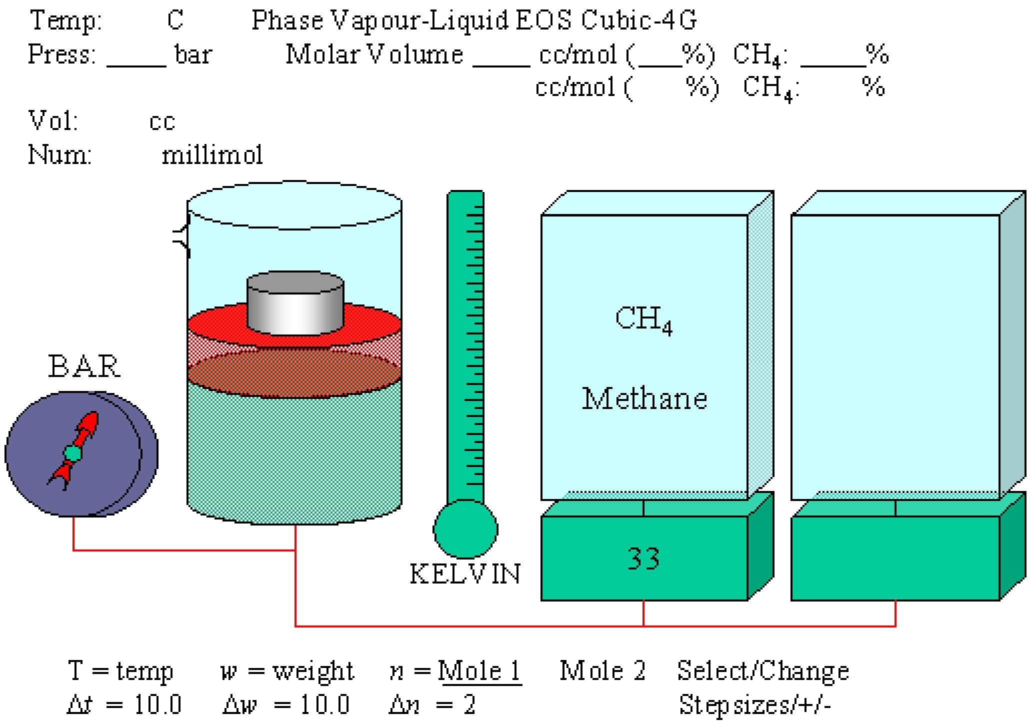
p	=	absolute pressure
V	=	volume of gas
n	=	number of moles
R	=	universal gas constant
T	=	absolute temperature

For an ideal gas, by definition z = 1. Therefore for the same amount of gas (n) we can calculate its ideal gas volume as,

$$V^{id} = \frac{nRT}{p} \tag{3}$$

Apparatus:

Virtual SOPE PVT cell



Procedure:

You must repeat all the following steps for each gas and for each temperature. For three temperatures and two gases, if you take about 15 pressure points per gas, the total number of data points you will need to collect is 90.

Part A.

The gases are C_1, and C_2

1. Set temperatures. These will be determined from their reduced temperatures (1.2, 1.6, and 2.0).

2. Fill the cell with gas at low pressure (1.1 bar is close enough to atmospheric pressure)

3. Determine the mass and the moles charged in the PVT cell and record this value.

4. Increase the pressure on the PVT cell by adding weights. The fluid volume will become smaller and you may not be able to determine these volumes precisely. However, even if this becomes too small the software evaluates internally the molar volume (V/n) in cc/mol (which is an intensive property) that you can use in Eq. (2).

5. Design the pressure steps such that you have enough number of points to determine z up to the highest allowable number of weights in the cell. (The maximum pressure, given by the weights on top of your cell is about 175 bar). Be reasonable 2 points is too little, 100 points is too many!!! – Justify your selection of pressure steps in writing.

6. Repeat steps 5 and 6 and write down the cell volume, the molar volume, and the pressure for future plotting in an Excel worksheet.

7. Calculate the 'ideal gas molar volume' for every data point collected (Eq. 3).

8. Determine the z-factor using Eq. (1)

9. Calculate the reduced pressure (p_r for every gas)

10. Plot the z-factors versus reduced pressure for each gas along each reduced isotherm – Overlap all these plots in one graph (for 3 temperatures and 2 different gases). That is 6 plots.

Part B.

When you made the plots in part A (item 10) , you may find out that the z-factor obtained does not cover a range of pressures large enough. Your highest pressure was 175 bar and you would like to 'see' the behavior at higher pressures (see figures in McCain book).

However, we can be ingenious and take advantage of our knowledge of intensive properties and evaluate the z-factor at much higher pressures by using a fixed volume cell.

Procedure

1. Charge the PVT cell with the same gas as in part A and at the same temperature but begin the experiment at the pressure you ended in the previous experiment (you already have all the lower pressure points anyway). Start with a fixed volume of about 30 cm^3 (the mass of gas will be determined by this volume). Record the mass (moles) for each component.

2. Lock the volume (using the 'v' key) –now your volume is fixed.

3. Increase the pressure in the cell by charging more mass of the component in question. This can be physically done, when you open the PVT cell to a cylinder that is at a **higher pressure** than the PVT cell… otherwise your fluid would flow in the reverse direction.

4. Record the number of moles that you are filling the cell with and the pressure. Here milimoles are simply read from the handy molemeter. In real life, you would have to weight the gas cylinder before and after the charges and determine the mass loaded in the PVT cell by converting the weight difference to moles. (**Hint:** possible quiz question)

5. Be very careful, as you stuff more mass into the cell the pressure will increase very rapidly. The safe limit is below 900 bar, be careful, the cell may explode!

6. Record the new pressures, and the number of moles in the cell. These, along with the temperature, and the volume that was already fixed, will be used to evaluate the z-factor – using the real equation of State (Eq. 2).

7. Add these new points to the points you had earlier and finish the z-factor plots for all the temperatures and gases (item 11 part A)

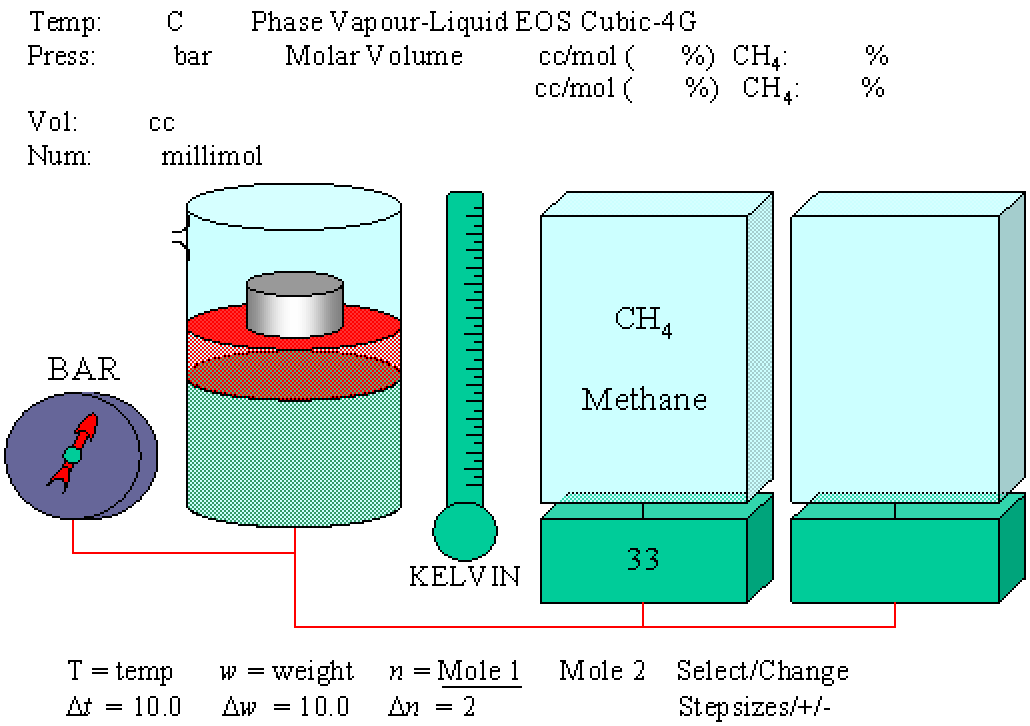
8. Compare these final plots with the charts from class and discuss the results obtained

A sample of the way the data should be reported is as follows.

Sample :	CH_4			
Tc =	------- units			
Pc=	------ units			
T_{r1} =	1.5	T = --- F	(^oC)	
n	------			
p (bar)	V (cm^3/mol)	V^{id} (cm^3/mol)	Z	p_r
-------	-------	-------	-------	-------
-------	-------	-------	-------	-------
-------	-------	-------	-------	-------
-------	-------	-------	-------	-------
-------	-------	-------	-------	-------
-------	-------	-------	-------	-------
-------	-------	-------	-------	-------
-------	-------	-------	-------	-------
-------	-------	-------	-------	-------
175	-------	-------	-------	-------
p (bar)	n		Z	p_r
-------	-------	V1	-------	-------
-------	-------	V1	-------	-------
-------	-------	V1	-------	-------
-------	-------	V1	-------	-------
-------	-------	V1	-------	-------
-------	-------	V1	-------	-------

The numbers in the blue shaded part are from Part A of the experiments and the final pressure should be about 175 bar. The numbers in the green shaded columns are for the constant volume experiments ($V_1 = 30\ cm^3$ approximately). The number of moles will be increasing. The last (and highest) pressure in the green shaded area should be about 900 bar.

Virtual PVT Cell



Part C.

Your data has a leak!

One of the most aggravating experiences in real laboratory experiments is when leaks develop and you are not aware of them. Leaks may occur because pressure seals and gaskets deteriorate over time and as a result the vessel cannot withstand pressures for sufficiently long time.

You are very familiar with your apparatus, and you want to get over with this experiment. Your cell was functioning well and you do not foresee any leak. The gases that you are working with are odorless, so you do not know weather there is a leak or not. One thing we know is that the higher the pressure applied to the system the faster the mass from the PVT cell is released to the lab (luckily no one is allowed to smoke).

Let's analyze the consequences of having a leak somewhere in the PVT system (those usually develop through valves). The objective of this experiment is to detect faulty data, and to diagnose a potential leak when the data do not "behave" properly.

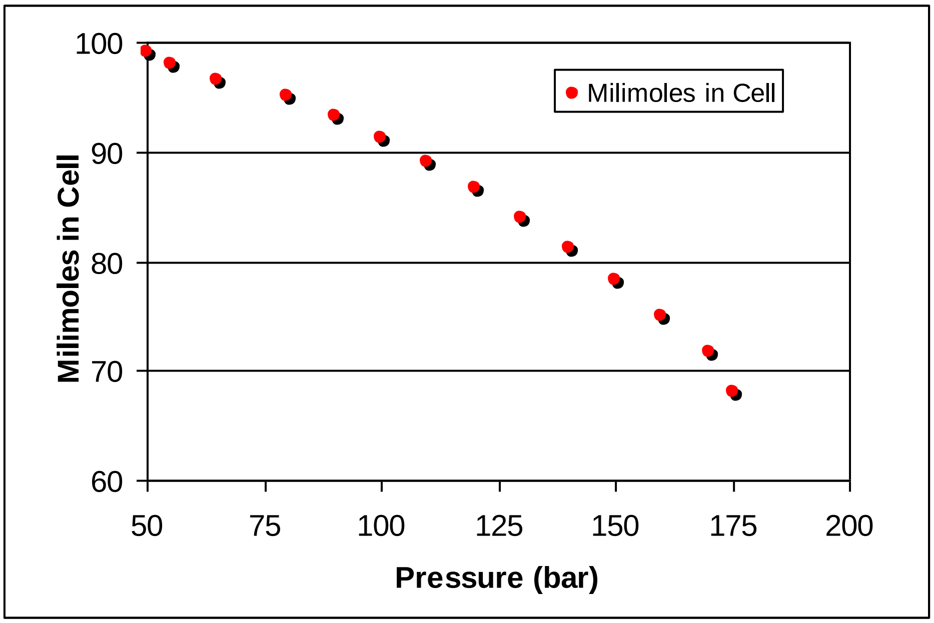
If a leak exists, as a result of pressurizing the cell some mass in the cell will escape to the surroundings, therefore the number of moles that you started with is not constant!

Let the leak be proportional to the pressure applied to the system for example

$$n_i = n_{i-1} - a \times p_i \quad (4)$$

where a is a constant expressed in millimoles/bar. In your case will be 0.02 millimoles/bar. The leak developed the moment that your cell pressure reached 50 bar. If you start with 100 millimoles at a pressure of 50 bar you will be loosing 1 millimole , if you increase the pressure to 65 bar you will keep loosing moles according to equation (4) - See the following graph (and excel calculation) to determine the number of moles leaked. An excel file is associated to this file, do not use 100 milimoles.

a=	0.02	mmoles/bar
mmoles In cell	Pressure (bar)	mmoles Lost
100	40	0
99	50	1
97.9	55	2.1
96.7	60	3.3
95.1	80	4.9
93.3	90	6.7
91.3	100	8.7
89.1	110	10.9
86.7	120	13.3
84.1	130	15.9
81.3	140	18.7
78.3	150	21.7
75.1	160	24.9
71.7	170	28.3
68.2	175	31.8



You will simulate the effects of a leak for just one gas (CH_4) and at one temperature T_r = 1.6).

1. Start will 300 millimoles at p = 40 bar

2. When p is 50 bar a leak develops! This leak will be proportional to the applied pressure and the constant *a* from equation (4) is 0.02 millimoles/bar. You may have to approximate the number of moles lost at each subsequent pressure since you have a limited number of digits that you can read in your molemeter. For example 81.2 millimoles is approximately equal to 81 and 71.6 millimoles is approximately equal to 72.

3. Record the pressures and the cell volumes (not the molar volume but the actual volume occupied by CH_4)

4. Evaluate the ideal gas volume of 300 milimoles for all these pressures (ideally

you do not have a leak).

5. Calculate the z-factor the usual way using Eq. (1).

6. Plot this new z-factor together with the previously determined z-factor and compare them.

Your report should contain the following elements

Abstract – What did you show, what is its value? Why study compressibility, z-factor? Did you get usable results?
Conclusions
Introduction

Selection of temperatures and rational for this selection?

Methods –
What software did you use?
Problems (if any and how they were solved)
What happens if a leak develops?
Discussion

- How does the z-factor change with temperature for a fixed pressure?
- How does the z-factor change with pressure at a fixed temperature?
- What did you learn about corresponding states?
-

Nomenclature
Refs (include software, per SPE style).