Different Topics about Heavy Oil

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Outline

- Diffusion of Gases in Bitumen
- Role of Micro-Bubbles in Solution Gas Drive
- Effect of Pressure decline Rate and Pressure Gradient
- Effect of Pressure Gradient on Gas Mobility

Diffusion of Gases in Bitumen

Diffusion of Gases in Bitumen

- **Bitumen represents an emerging source of energy**
- **Bitumen viscosity is an obstacle to recovery and processing**
- **Viscosity can be reduced by mixing with light gases at high pressure**
- **Ethane, Carbon Dioxide, and Methane are among gases that can be used**

Diffusion of Gases in Bitumen

Molecular Diffusion plays an important role in the rate of dissolution of gases in bitumen

Problem Statement

How to estimate the diffusion coefficient of gases in bitumen

Introduction

Existing Interpretation Methods

Direct Methods

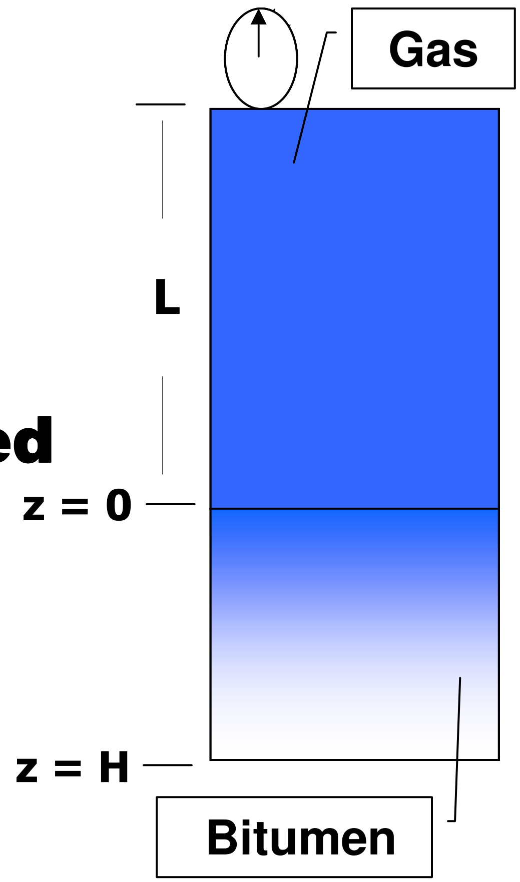
Measure the composition of the diffusing component with time, Sigmund (1976)

Indirect Methods

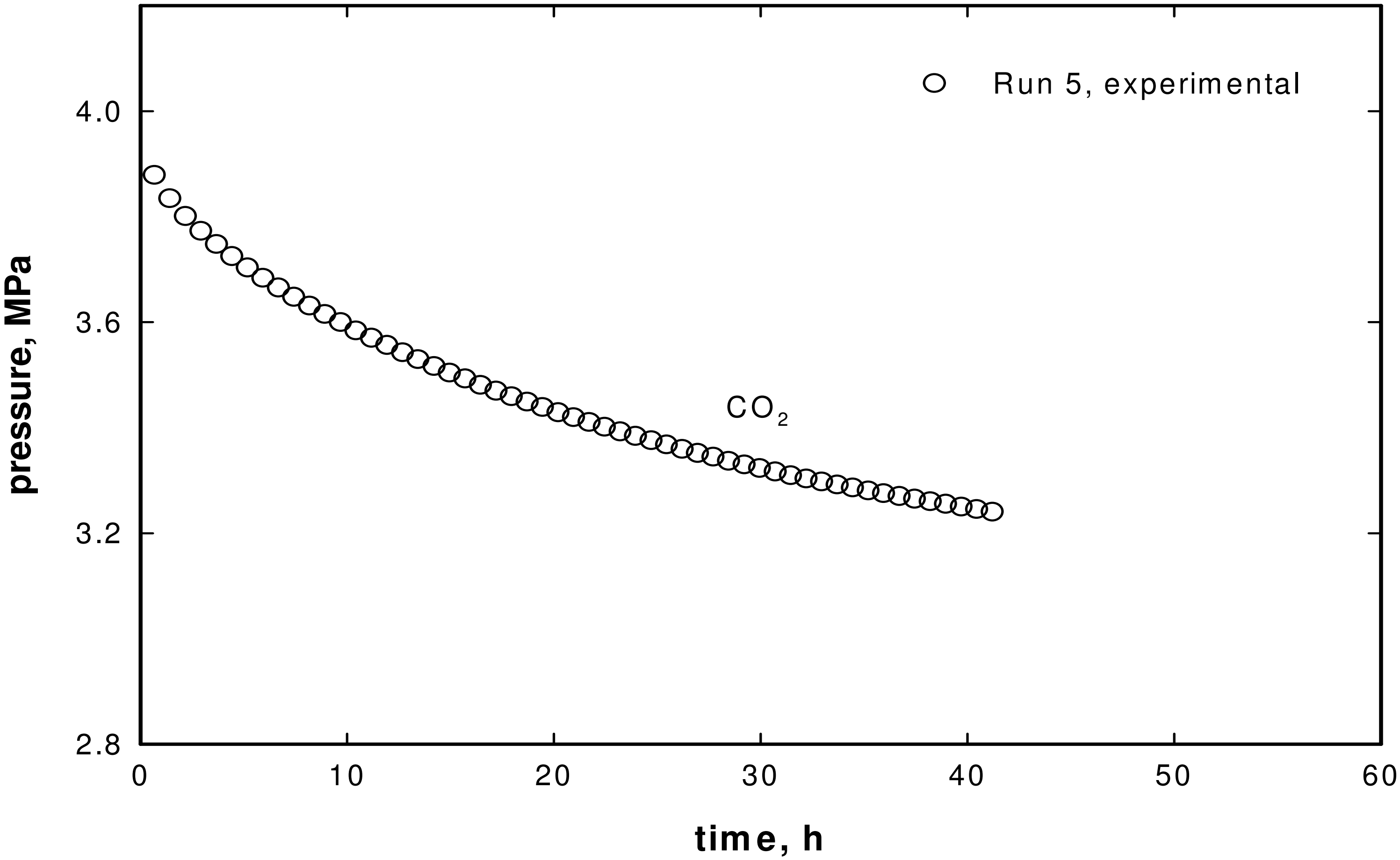
measure one of the system properties (eg. system pressure, *Riazi, 1996)* as result of diffusing component

Pressure Decay Measurement

- A constant volume of gas
- Diffused into the bitumen
- The gas pressure is measured with time



Results



Run 5, experimental
4.0
3.6
3.2
2.8
pressure, MPa
CO2
0
10
20
30
40
50
60
time, h

Methodology

- **Forward problem:** prediction of observations provided all the parameters defining the model are known

  diffusion coefficient and forward model $\longrightarrow$ pressure

- **Inverse problem:** using the results of actual observations to determine the optimum values of the parameters characterizing the system

  p vs. t and the inverse model $\longrightarrow$ diffusion coefficient

Mathematical Model

Direct problem

$$P(t) = P_{\mathrm{i}} \exp\left(\frac{\sqrt{D}\, ZRT \sqrt{t}}{LMK_{\mathrm{h}}}\right)^2 \operatorname{erfc}\left(\frac{\sqrt{D}\, ZRT \sqrt{t}}{LMK_{\mathrm{h}}}\right)$$

Inverse Model

Given experimental P vs. t $\longrightarrow$ find D

The pressure equation in the gas zone

$$P(t) = P_\mathrm{i} \exp\left(\frac{\sqrt{D}}{K_\mathrm{h}} \frac{ZRT\sqrt{t}}{LM} \right)^2 \operatorname{erfc}\left(\frac{\sqrt{D}}{K_\mathrm{h}} \frac{ZRT\sqrt{t}}{K_\mathrm{h} LM} \right)$$

Estimation of Diffusion Coefficient

Graphical Approach

Graphical Methods

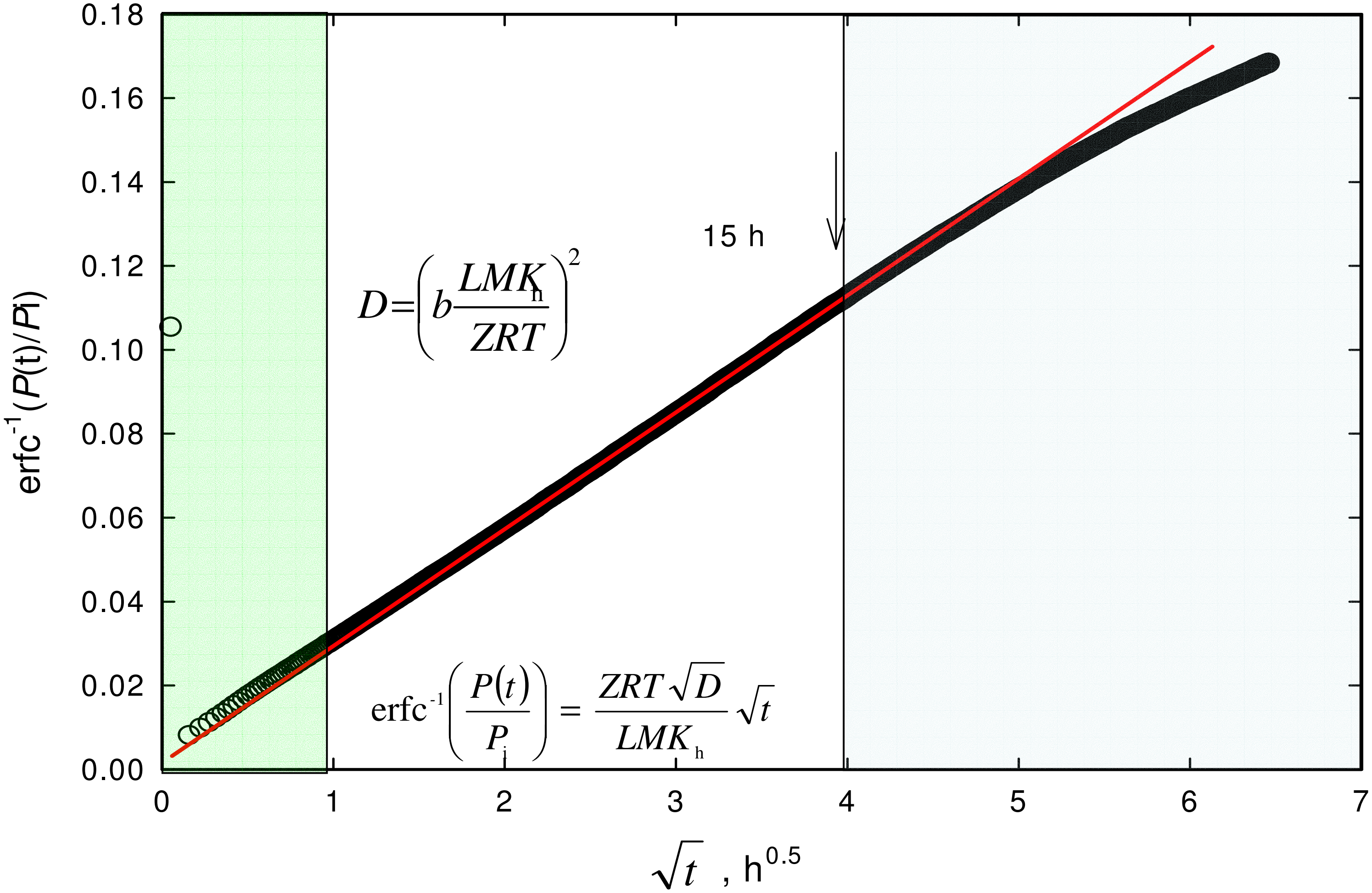
$$P(t) = P_i \exp\left(\frac{\sqrt{D}ZRT\sqrt{t}}{LMK_h}\right)^2 \operatorname{erfc}\left(\frac{\sqrt{D}ZRT\sqrt{t}}{LMK_h}\right)$$

At the early time the exponential term is close to one

$$\underbrace{\operatorname{erfc}^{-1}\left(\frac{P(t)}{P_i}\right)}_{Y} = \underbrace{\frac{ZRT\sqrt{D}}{LMK_h}}_{b}\ \underbrace{\sqrt{t}}_{X}$$

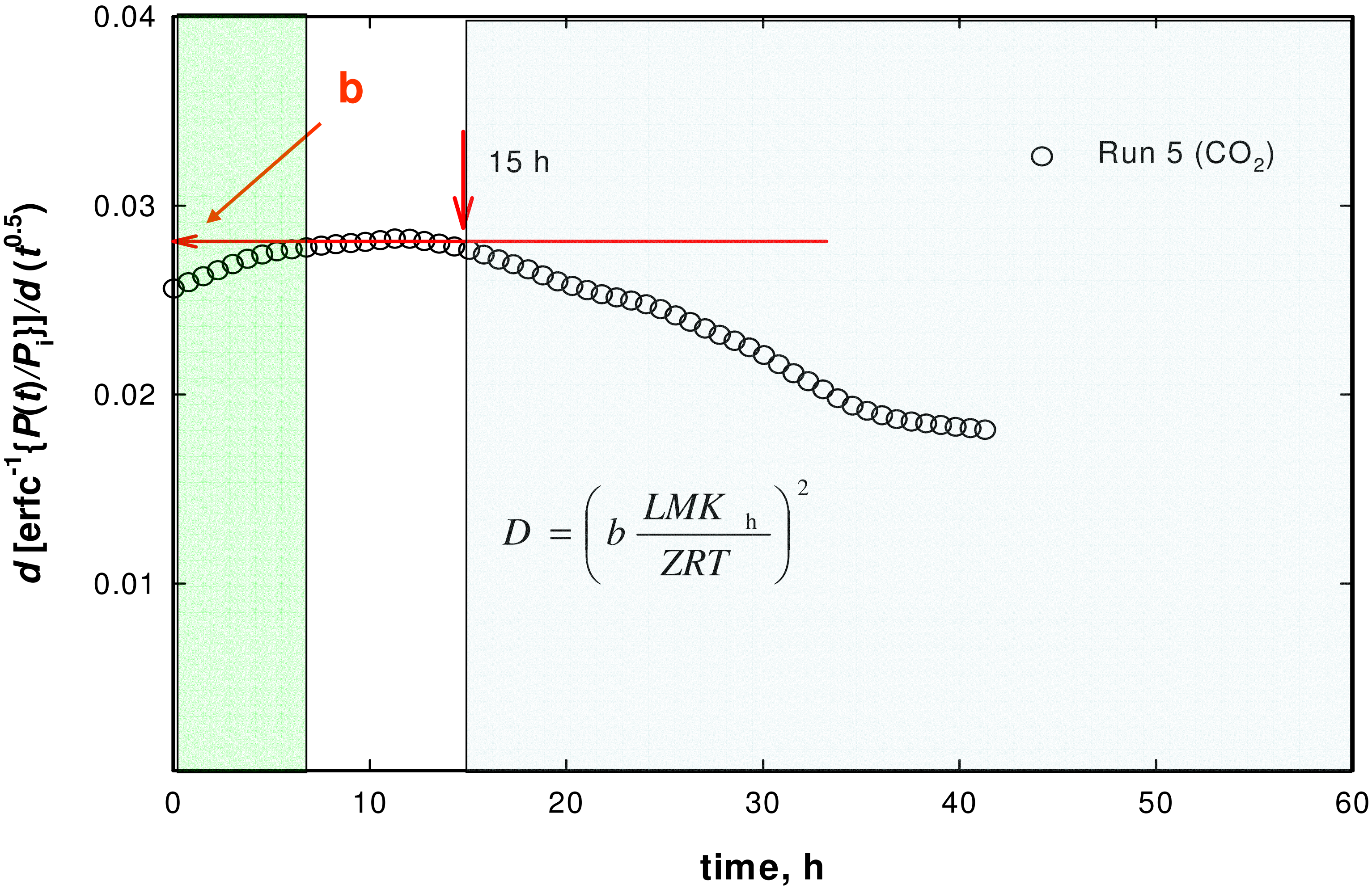
$$\underbrace{\frac{d[\operatorname{erfc}^{-1}\{P(t)/P_i\}]}{d(\sqrt{t})}}_{Y} = \underbrace{\frac{\sqrt{D}ZRT}{K_h LM}}_{b}$$

Results



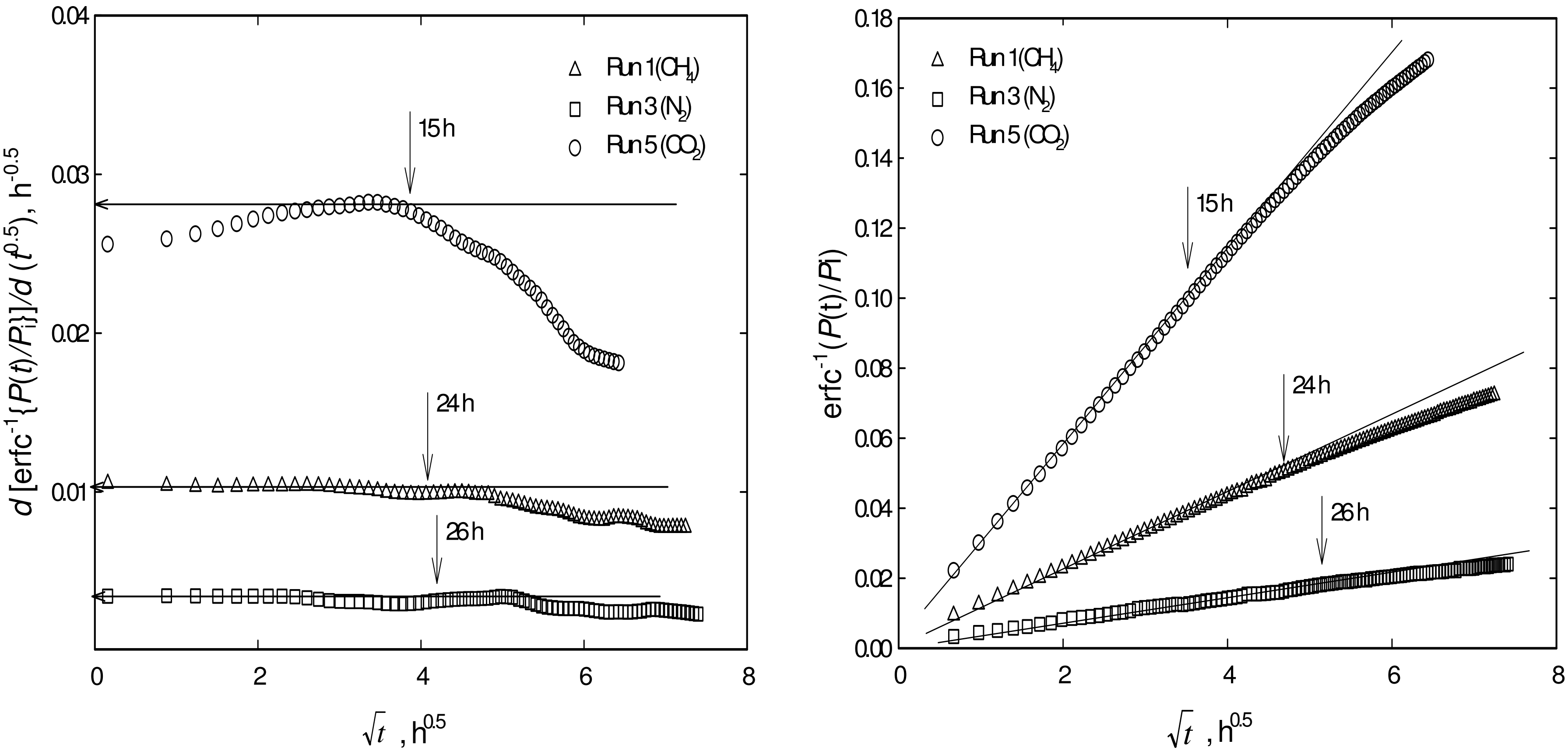
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
5
6
7
erfc^{-1}(P(t)/P_i)
$\sqrt{t}$, h$^{0.5}$
15 h
$D = \left(b\frac{LMK_h}{ZRT}\right)^2$
$\mathrm{erfc}^{-1}\left(\frac{P(t)}{P_i}\right) = \frac{ZRT\sqrt{D}}{LMK_h}\sqrt{t}$

Results



0.04
0.03
0.02
0.01
b
15 h
Run 5 (CO_2)
$D = \left(b \frac{LMK_h}{ZRT} \right)^2$
$d\,[\mathrm{erfc}^{-1}\{P(t)/P_i\}]/d\,(t^{0.5})$
0
10
20
30
40
50
60
time, h

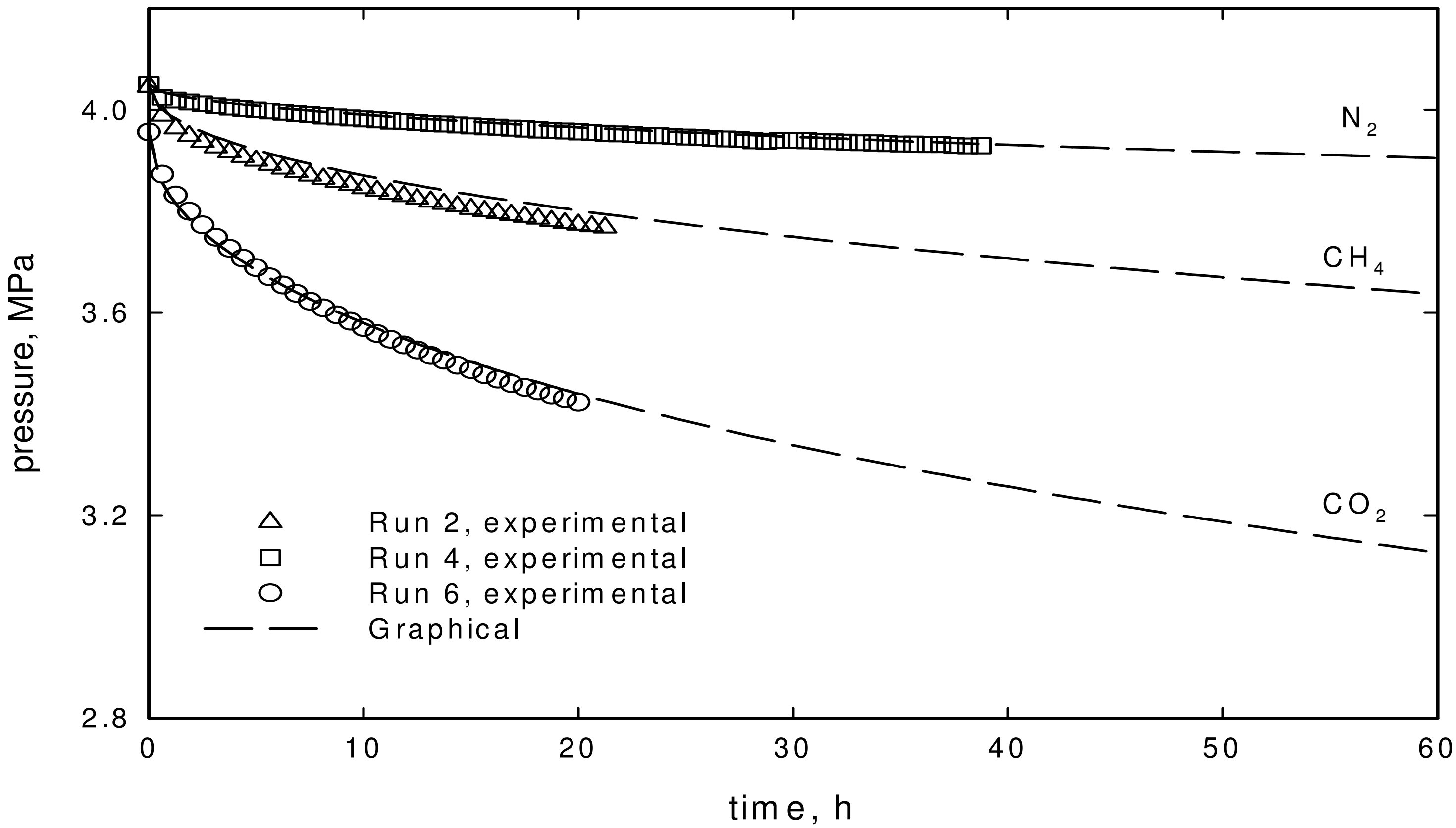
Results



0.04
0.03
0.02
0.01
0
2
4
6
8
$d\,[\mathrm{erfc}^{-1}\{P(t)/P_i\}]/d\,(t^{0.5})$, h$^{-0.5}$
$\sqrt{t}$, h$^{0.5}$
15 h
24 h
26 h
Run 1 (CH_4)
Run 3 (N_2)
Run 5 (CO_2)
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
$\mathrm{erfc}^{-1}(P(t)/P_i)$

Results

$$P(t) = P_i \exp\left(\frac{\sqrt{D}RTZ\sqrt{t}}{LMK_h}\right)^2 erfc\left(\frac{\sqrt{D}RTZ\sqrt{t}}{LMK_h}\right)$$



Conclusions

- **Simple graphical methods were developed for estimation of diffusion coefficient**

- **The novelty of the proposed methods are :**

1. **Its simplicity**

2. **Ability to isolate portions of the pressure-decay data affected by experimental artifacts such temperature fluctuation**

3. **Diagnostic the early and late time measurement and excluded them from estimation of the diffusion coefficient**

Conclusions

- **The diffusion was not used as an adjustable coefficient to match the entire pressure decay profile**

- **The diffusion coefficients are in the same range of the reported values by other investigators**

Other Graphical Methods

- "*The Importance of Graphical Methods in Obtaining the Diffusion Coefficient of gases in Bitumen and Heavy Oil*", **SPE ATCE 2006 SEP 24-27, San Antonio**

- "*An Inverse Solution Methodology for Estimating the Diffusion Coefficient of Gases in Athabasca Bitumen from Pressure-Decay Data*", **Journal of Petroleum Science and Engineering, Vol. 53, Issues 3-4, Sep 2006, 189-202.**

- "*Development of Graphical Methods for Estimating the Diffusivity Coefficient of Gases in Bitumen from Pressure-Decay Data*", **Energy and Fuel, 2005, 19, 2041-2049.**

Other Graphical Methods

- "*Determination of the Gas Diffusivity Coefficient in Bitumen by Graphical Methods*", *Canadian International Petroleum Conference, Calgary; June 7-9, 2005*

- "*New Analytical Methods for Determination of the Gas Diffusivity Coefficient in Bitumen*", *54th Canadian Chemical Engineering Conference, Calgary, Canada; October 3-6, 2004*

Micro-Bubbles Flow in Solution Gas Drive, Existence and Importance

Introduction

- **The demand for oil grows every year as more countries aspire to higher style of living**
- **demand for oil grows every year as more countries aspire to higher style of living**
- **the era of conventional oil is coming to a close**
- **world energy trends indicate that there is an excellent opportunity for Heavy Oil to flourish as a major resource base in the future**

Introduction

- **more research is needed to establish the foundation upon which Heavy Oil’s future will be built**

- **The non-equilibrium behavior characterizes SGD in heavy oils inspired many to conduct experimental and model studies**

- **“foamy oil” which is a special type of two-phase flow in which the gas phase can flow without being a continuous, Maini (1996)**

Introduction

- **Geomechanical effects that contribute to this behavior, Geilikman et al. (1994)**

- **In one popular theory, the dispersed gas is in the form of micro-bubbles; bubbles smaller than the pore size that flow with the oil, Smith (1988)**

- **Ward et al. (1982) indicated the possibility of generating micro-bubbles in the porous media**

- **Islam and Chakma (1990) investigated the role of the micro-bubbles and found that the micro-bubbles increase the recovery factor substantially**

Introduction

- **Bora et al.(2000) visualization experiments could not confirm the existence of stable micro-bubbles. However, their results of 2003 etched glass micro-model indicate that the micro-bubbles contribute to oil production**

- **Sahni et al. (2004) stated " the micro-bubbles seen in very high depletion rate micro-model of Bora et al. could not be observed in subsequent micro-model experiments"**

- **Shahabi et al. (2005) questioned the existence of micro-bubbles in real reservoirs**

Objective

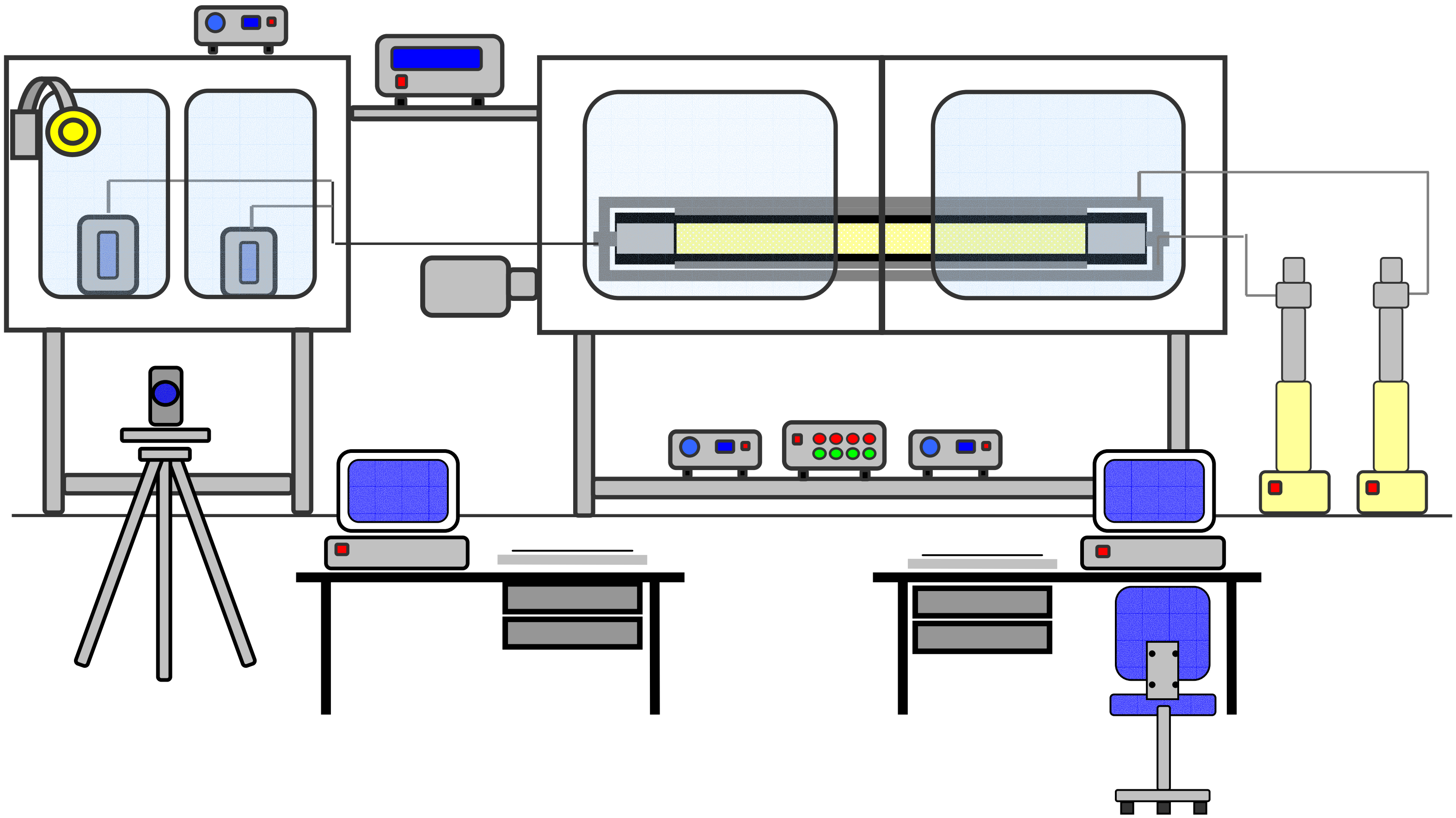
Examine the role of micro-bubbles in heavy oil subjected to solution gas drive

Hypothesis

The theory of the micro-bubbles flow is examined by measuring the density of the flowing fluids

- **If the micro-bubbles are present, then these bubbles flow with the oil after the bubbles are nucleated, affecting the bulk density of the flowing fluid**
- **On the other hand and in the absence of micro-bubbles, the bubbles grow in-situ and are trapped in the porous media**

Experimental Set-Up



Fluids and sand-pack

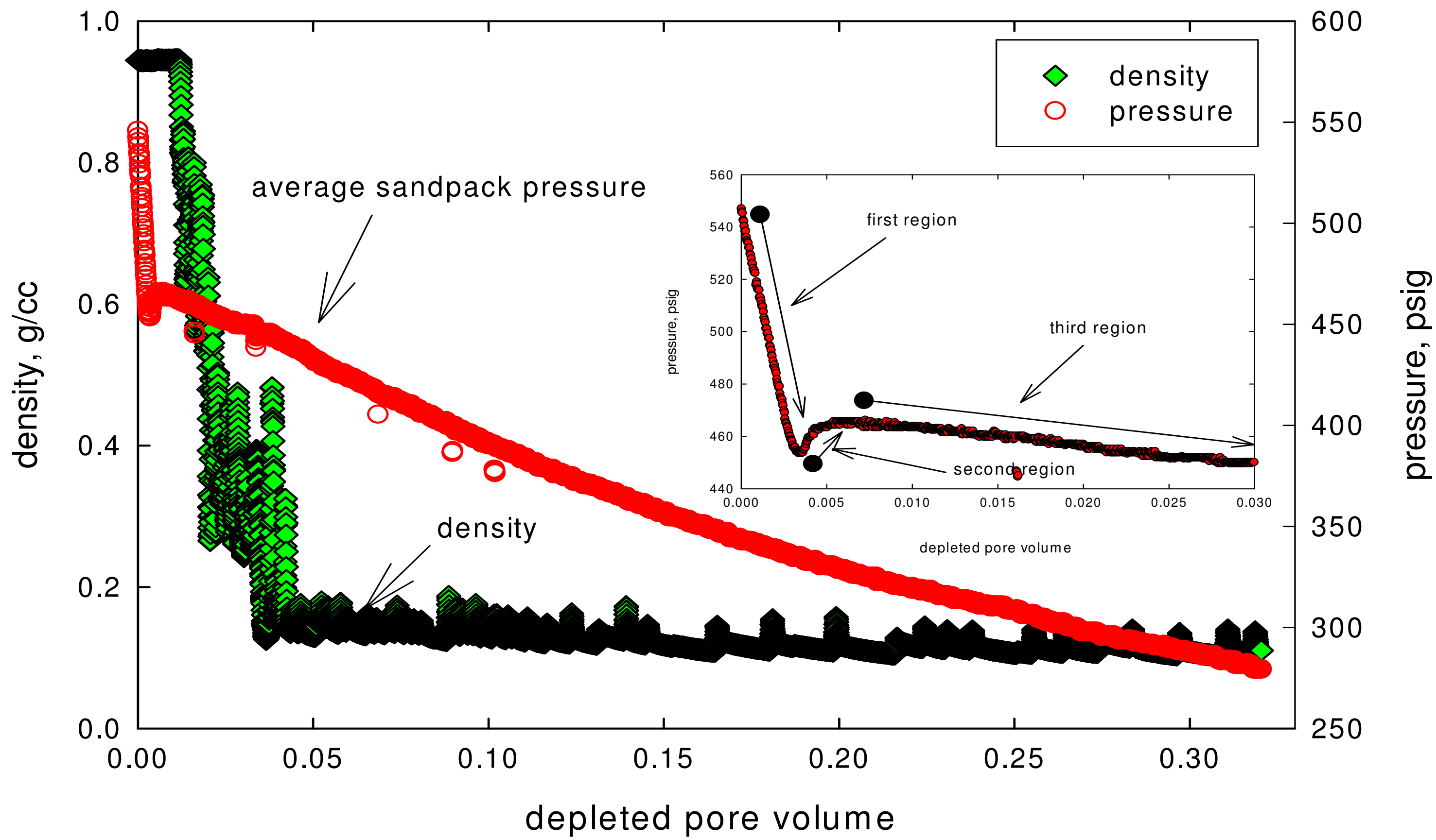
Properties	Value
Grain size	50 - 75 μm
L	60 cm
D	2.54 cm
Porosity	0.39
K_{eff}	1.1 Darcy
P_b	487 psi
GOR at P_b	17.3 scc/scc
Viscosity of live oil	5650 cp

Experiments

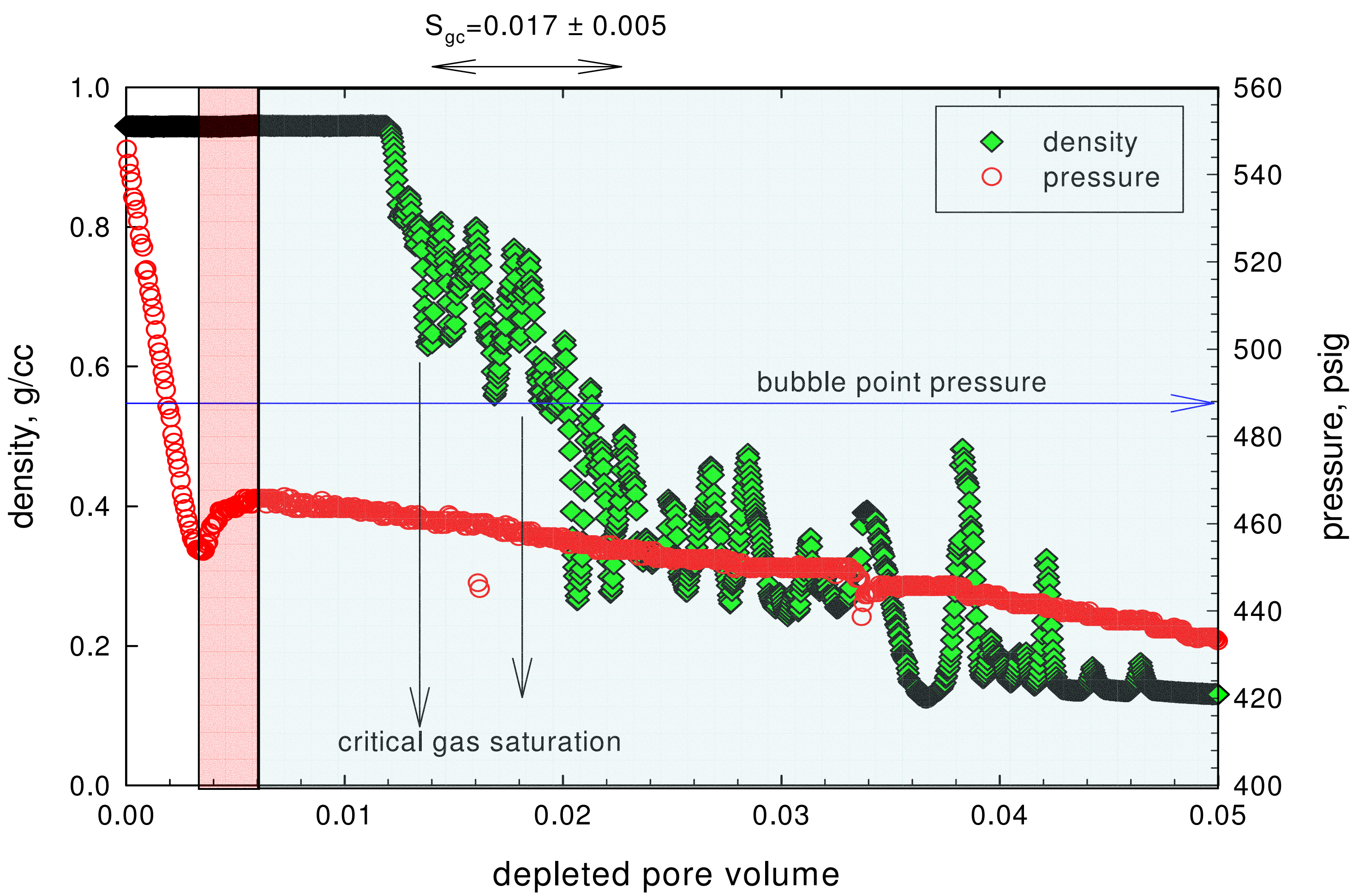
Two depletion tests at constant rate were performed:

- **Slow depletion test, 0.02 pv/day**
- **Fast depletion test, 0.15 pv/day**

Result: Slow Test

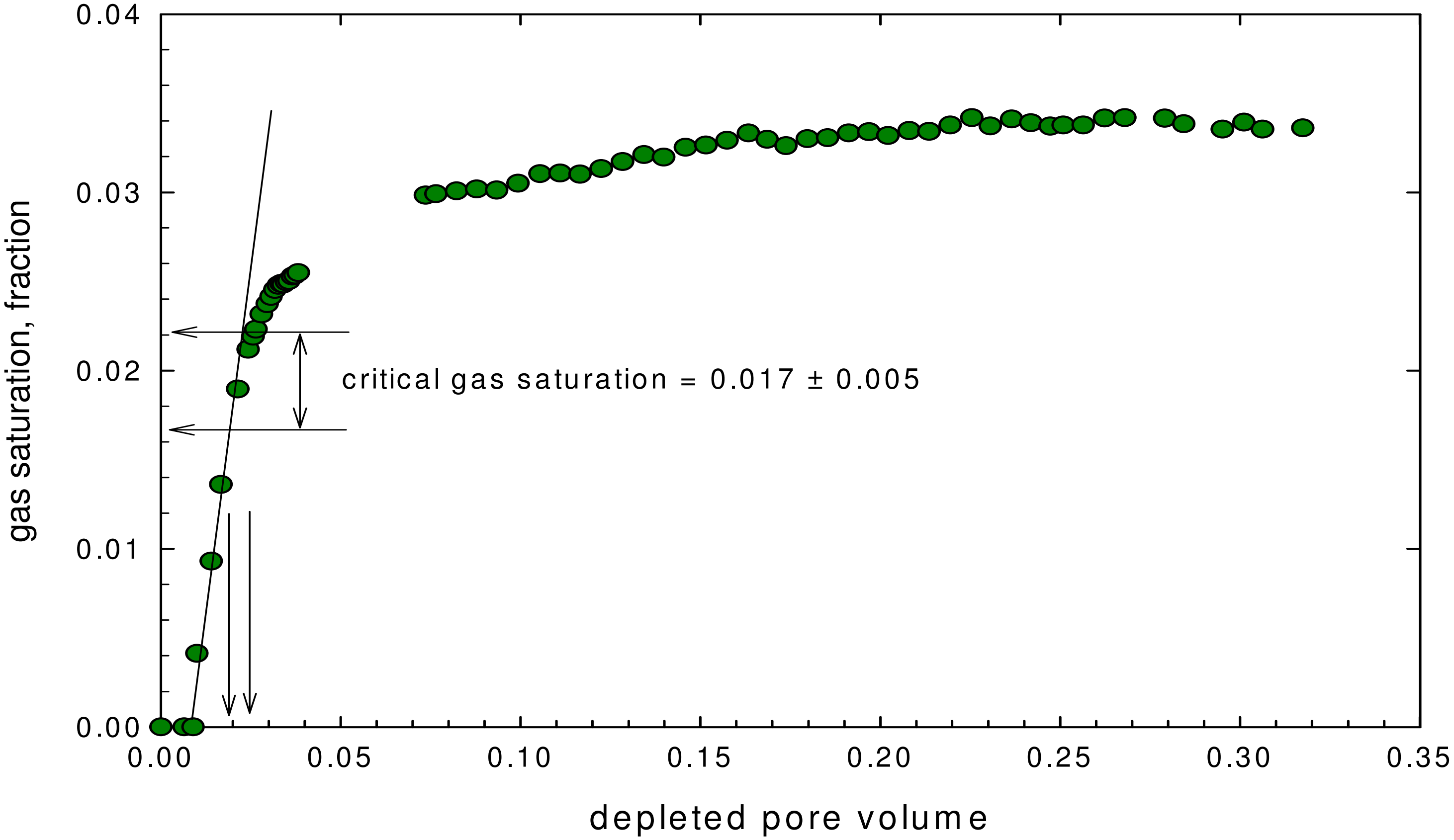


Results

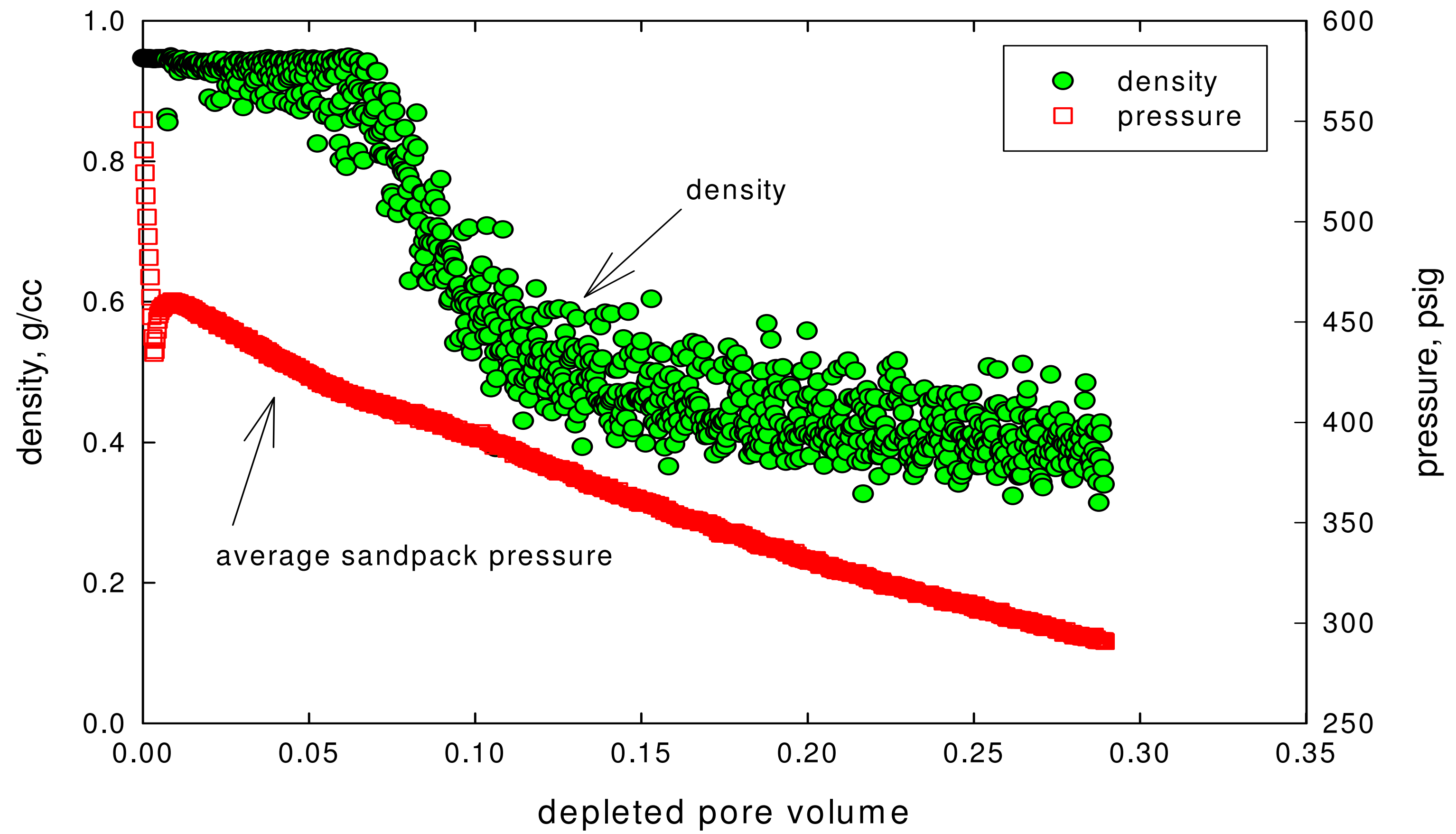


S_{gc}=0.017 ± 0.005
density
pressure
bubble point pressure
critical gas saturation
density, g/cc
pressure, psig
depleted pore volume
1.0
0.8
0.6
0.4
0.2
0.0
560
540
520
500
480
460
440
420
400
0.00
0.01
0.02
0.03
0.04
0.05

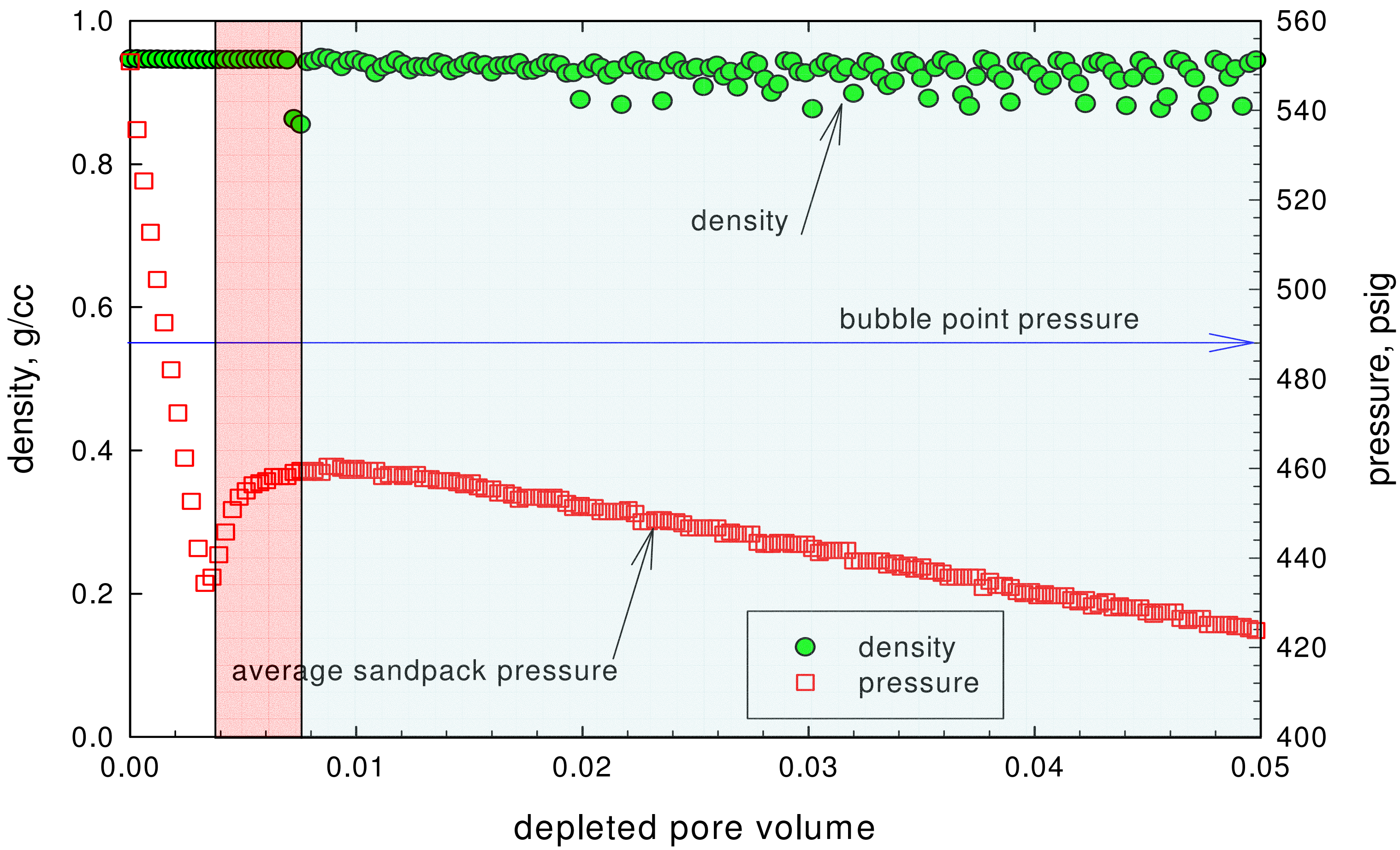
Result: Average Gas Saturation



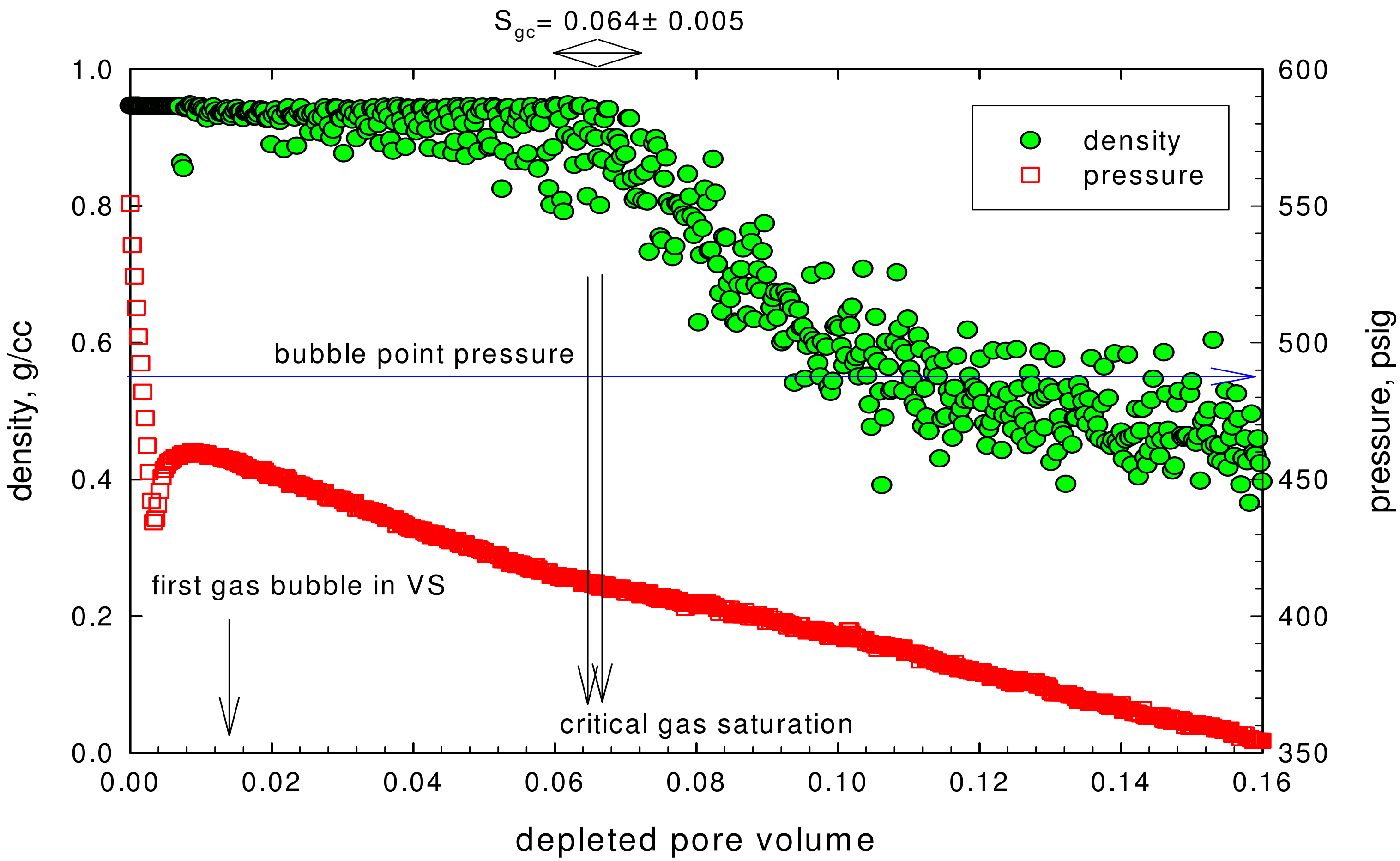
Result: Fast Test



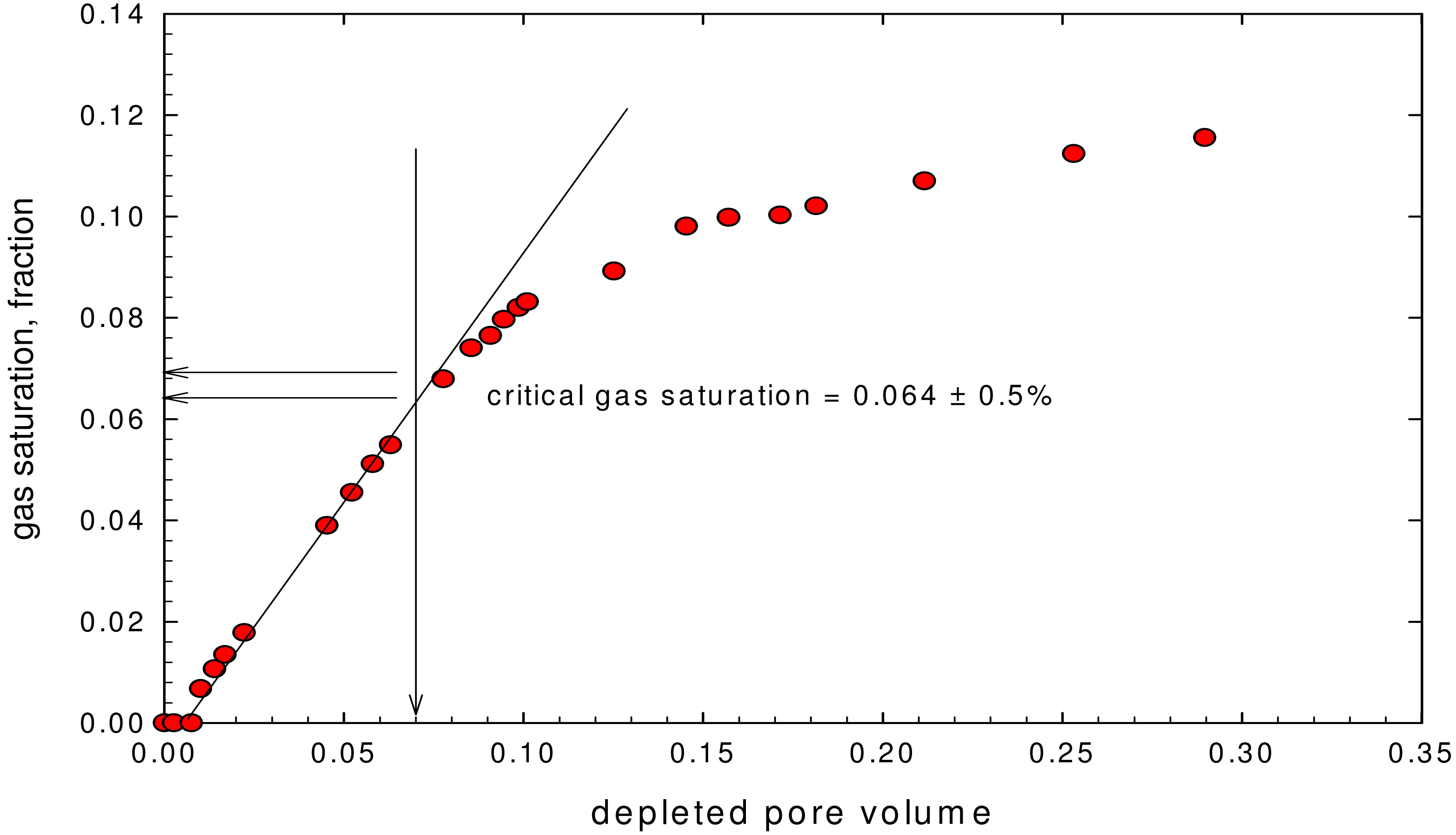
Result: Fast Test-Early Time



Result: Fast Test-Early Time



Result: Average Gas Saturation

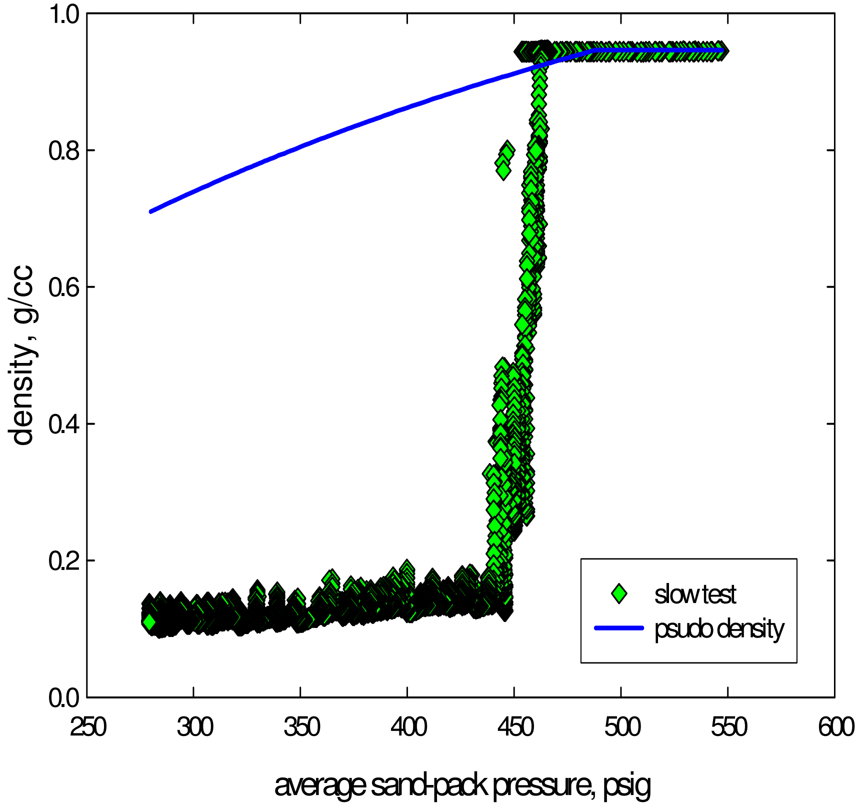


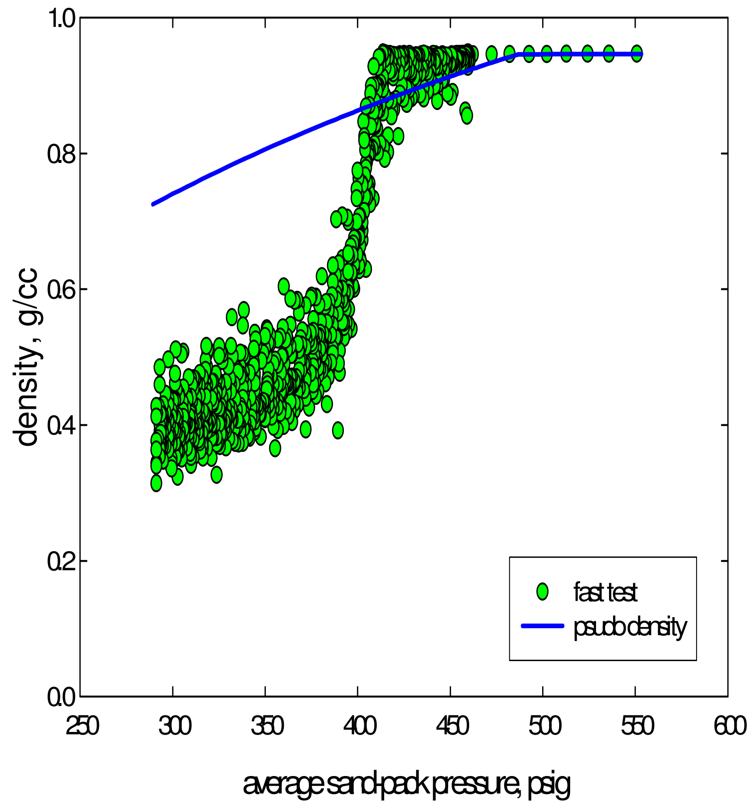
Pseudo-phase density

If the gas bubbles can flow with oil, then we want to calculate the density of the mixture

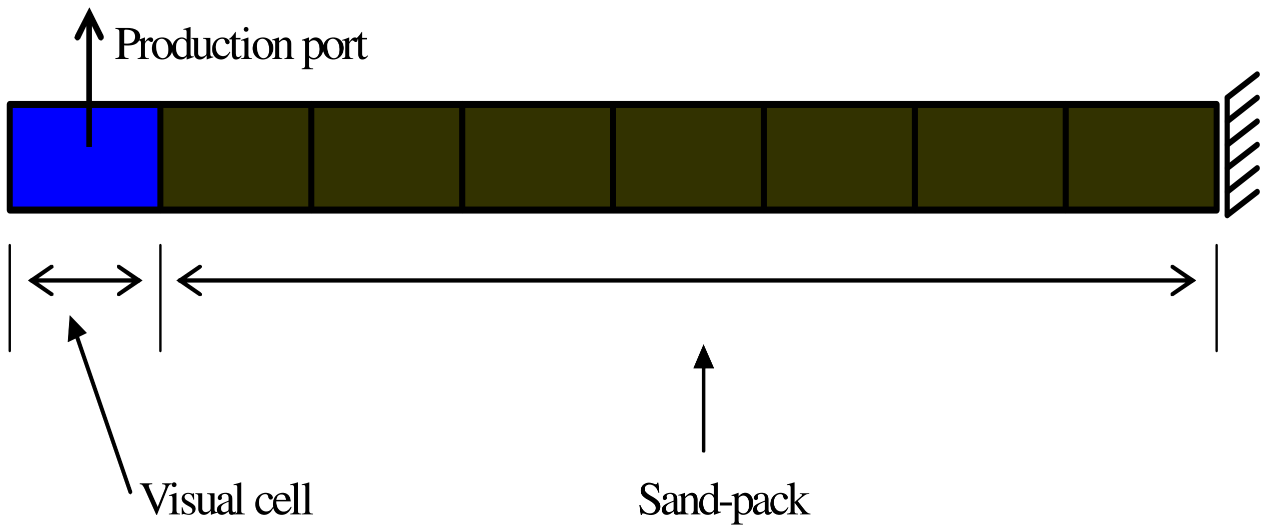
$$\rho_m = \frac{\rho_{o\,sc} + R_s \rho_{g\,sc} + \dfrac{P_{rc}\left(R_{si} - R_s\right) B_g M_w}{RT}}{B_o + B_g\left(R_{si} - R_s\right)}$$

Density: measured & calculated

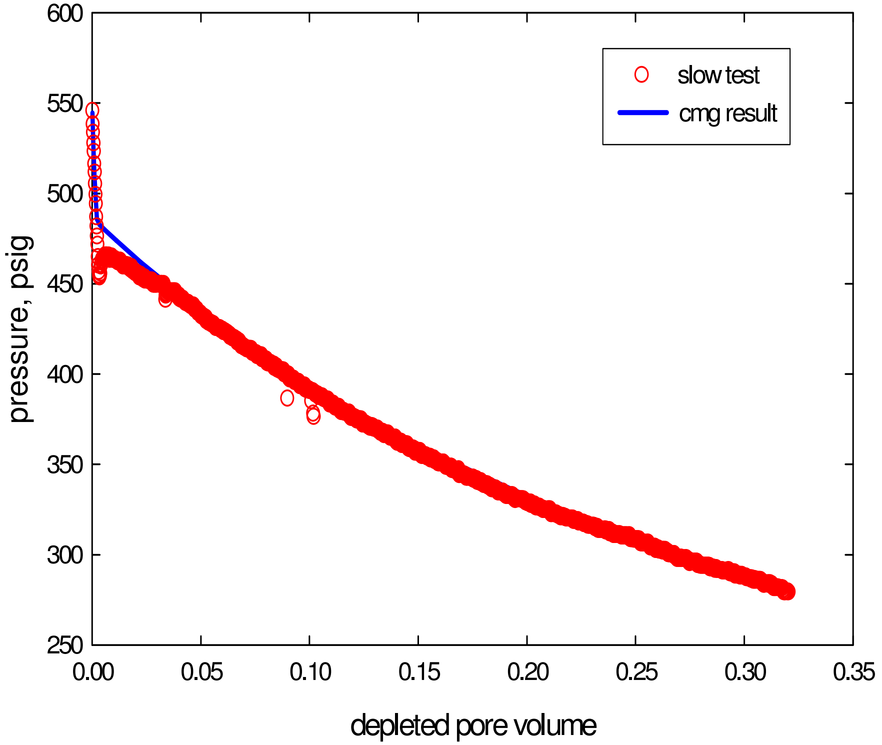


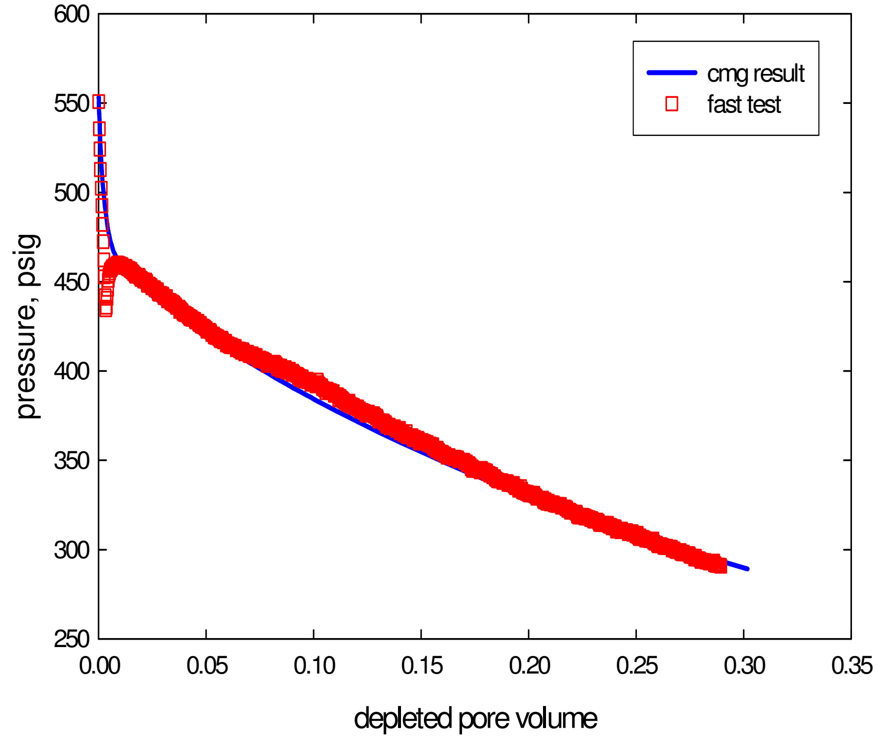


Result: Simulation



Average Sand-pack Pressure

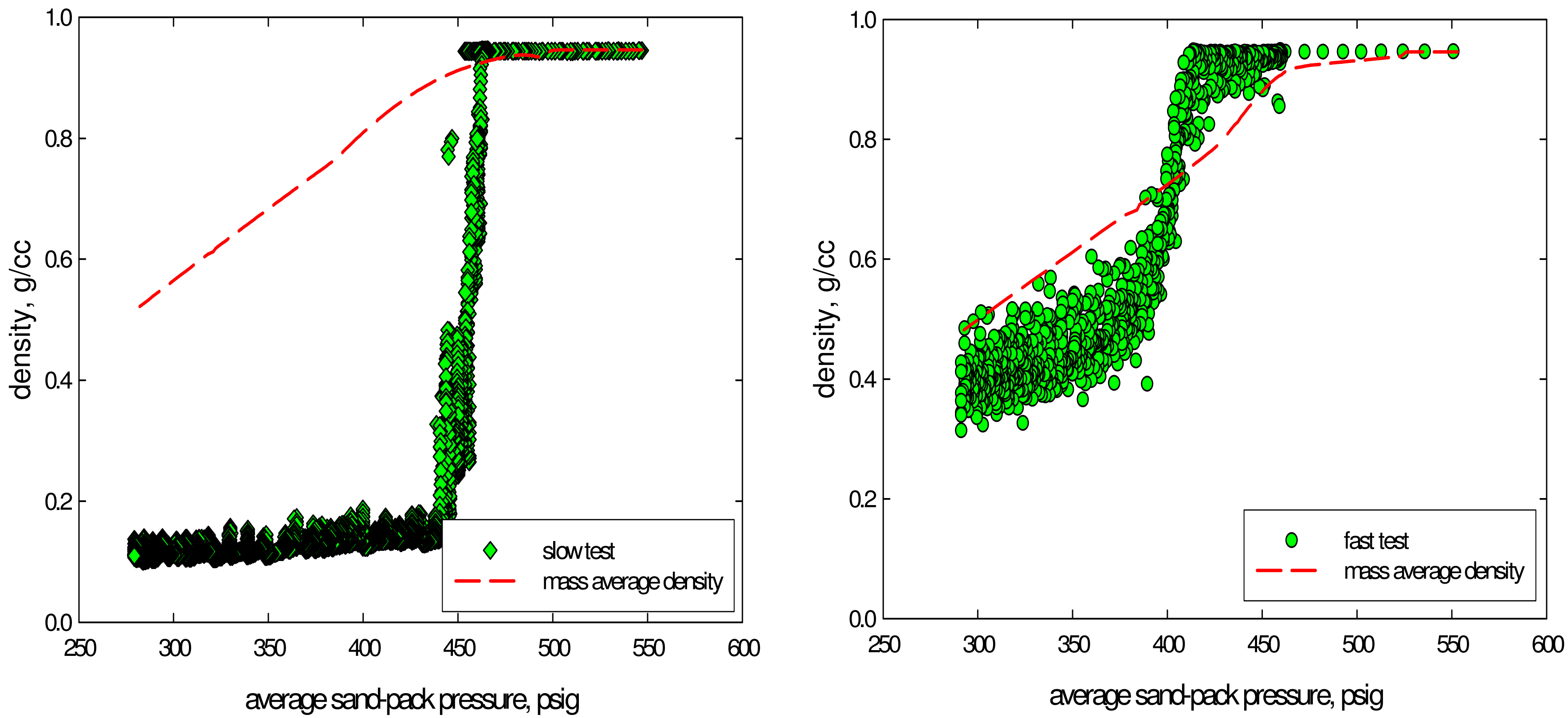




Mass average density

$$\rho_m = \frac{\dfrac{\rho_{o\,sc} + R_s \rho_{g\,sc}}{B_o} q_o + \dfrac{PM}{RT} q_g}{q_o + q_g}$$

Density: Measured & Calculated

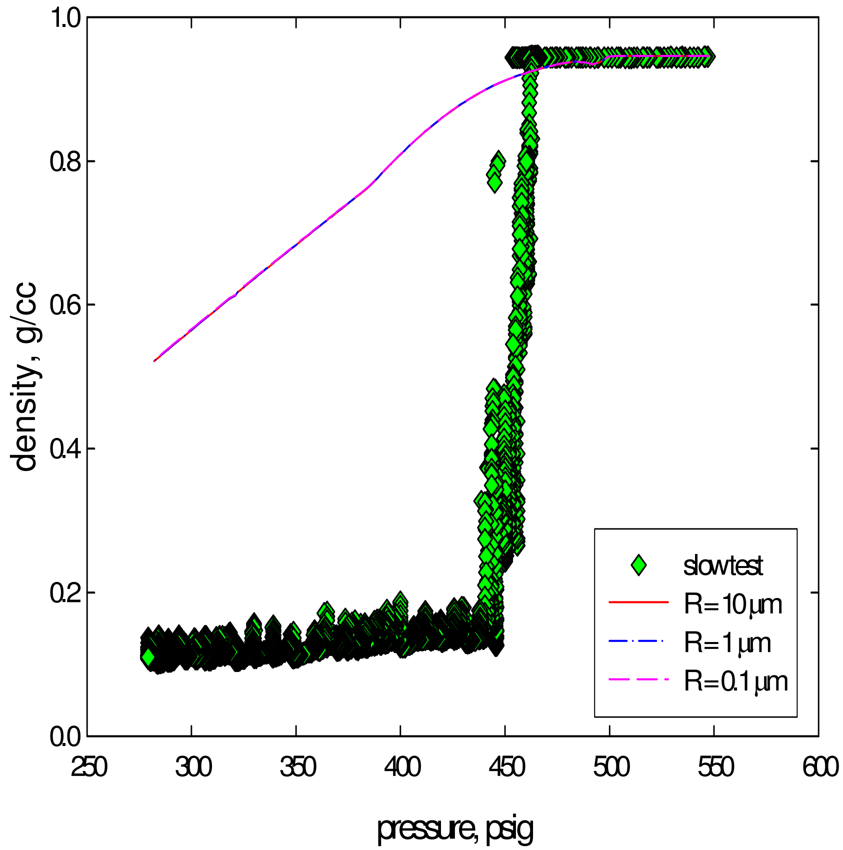


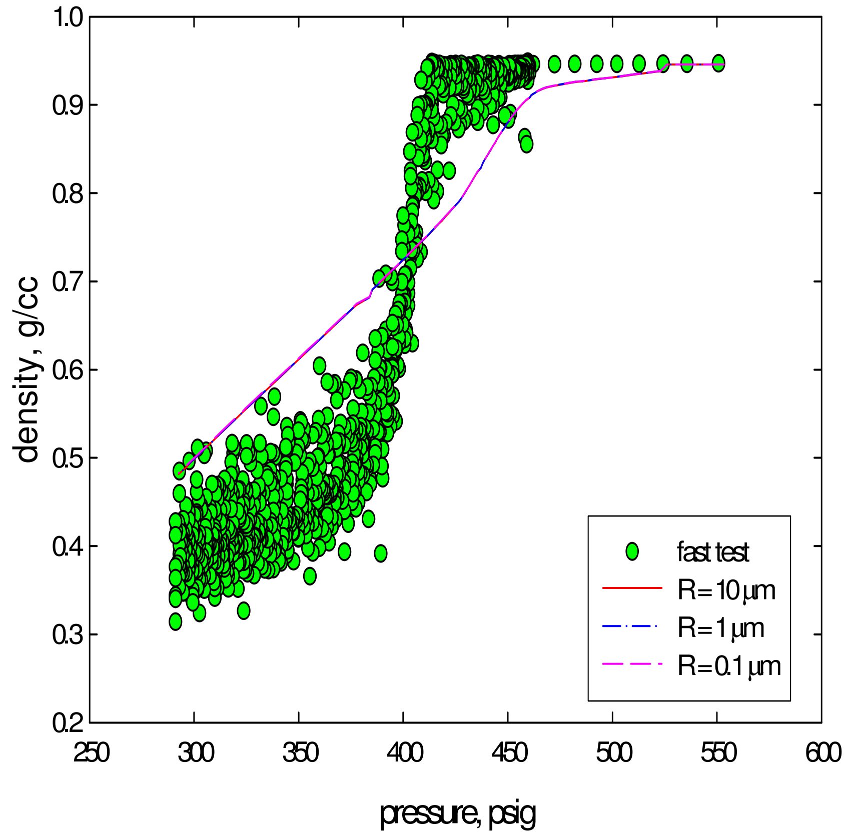
Effect of Pc on Density

$$\rho_m = \frac{\dfrac{\rho_{o\,sc} + R_s \rho_{g\,sc}}{B_o} q_o + \dfrac{PM}{RT} q_g}{q_o + q_g}$$

$$P_g = P_o + P_c$$

Effect of Pc on Density





Conclusion

- **The results we obtained so far do not confirm or negate the existence of micro-bubble**

- **If micro-bubbles exist, then they don't have significant effect on the recovery**

Thanks