SHALE PETROPHYSICAL CHARACTERISTICS

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**KEY RESERVOIR CHARACTERISTICS**

The Reservoir Rock Contains a 3-D Network of Interconnected Pores which allows for to Storage and Transmission of Fluids.
The open space created between grains during deposition is referred to as the **void, or pore, space.**

- **Bulk Volume,** $V_b$
- **Pore (Void) Volume,** $V_p$

\[ \phi = \frac{V_p}{V_b} \]

**The bulk volume** $V_b$ and **the pore volume** $V_p$ are defined as:

- $V_b = \text{Bulk Volume}$
- $V_p = \text{Pore (Void) Volume}$
**KEY RESERVOIR CHARACTERISTICS**

*Permeability is defined based on an equation, developed by Henry Darcy:*

\[
k = \frac{q \mu L}{A (p_1 - p_2)}
\]

- \(q\) = Flow Rate through the Porous Medium
- \(A\) = The Area across which the flow occurs
- \(\mu\) = Fluid Viscosity
- \(L\) = Length of the Medium.
**KEY RESERVOIR CHARACTERISTICS**

\[
q = \frac{k \mu L}{A \left( p_1 - p_2 \right)}
\]

1 darcy = 1000 md

One darcy is a relatively high permeability and **millidarcy** (md) is commonly used as the permeability unit.
**Permeability Measurement**

**Gas Slippage**

Low Pressure

High Pressure

Flow Direction

$p_1$ Upstream Pressure $p_2$ Downstream Pressure

Pressure Regulator Calibrated Orifice Sample Holder

$y = 6.6321x + 28.176$

$R^2 = 0.9632$
UNCONVENTIONAL RESERVOIRS

Unconventional

Conventional

1 nanodarcy 1 microdarcy 1 milidarcy 1 darcy

0.000001 0.00001 0.001 0.1

Pore Throat Sizes in Millimeters

Natural gas molecule
Crude oil molecule
Soap film
Human hair
Sheet of paper

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SHALE GAS RESERVOIRS

- Natural fractures (porosity 2)
- Matrix pores (porosity 1)
- Adsorbed gas on particle surface (porosity 3)

Symbols:
- Shale solid matrix
- Free gas
- Adsorbed gas

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**Langmuir Isotherm**

\[ G_s = \frac{V_L p}{P_L + p} \]

- \( G_s \) = Gas Storage Capacity
- \( V_L \) = Langmuir Volume Constant
- \( P_L \) = Langmuir Pressure Constant
- \( p \) = Pressure, psia
MEASUREMENT OF SHALE PETROPHYSICAL PROPERTIES

**Pore Volume**
- Low-pressure gas pycnometry
- High-pressure mercury injection
- Low-temperature adsorption

**Permeability**
- GRI Method
- Pressure Pulse Decay

**Pore Size Distribution**
- MICP
- NMR
- SEM/STEM
- Low-temperature Adsorption

**Adsorption**
- Gravimetric
- Volumetric
**Shale Permeability Measurement**

- It is not practical to measure the permeability of shale by conventional (Steady-State) techniques because of low permeability.

- Unsteady-State Methods
  - GRI Method (Crushed Sample)
  - Pressure Pulse Decay
**CRUSHED SAMPLE PERMEABILITY**

**Developed by Gas Research Institute and is referred to as "GRI" Method.**

- No Standard Protocol
- Inconsistent Results

Particles in the 20-35 US mesh size range (0.85 to 0.5mm)
PRESSURE PLUS DECAY

- Different Interpretations
- Complex and Tedium Calculations
CHALLENGES

• Gas Slippage Correction

• Impact of Gas Adsorption

• Impact of Stress
PRECISION PETROPHYSICAL ANALYSIS LABORATORY (PPAL) AT WVU

MEASUREMENT CAPABILITIES

- **Permeability** (Nano-Darcy range).
- **Pore Volume** (0.1% accuracy).
- **Absolute Permeability** (Gas Pressure Correction).
- **Impact of Stress** (Reservoir Conditions).
- **Impact of Adsorption**
- **Pore Structure Characterization**

Accurate, Consistent, and Repeatable Results
**Absolute Permeability**

- **Traditional Klinkenberg Analysis**
  - Gas Slippage
    - Helium: \( y = 90090x - 66.106 \)
      - \( R^2 = 0.9865 \)
    - Nitrogen: \( y = 57377x + 11.06 \)
      - \( R^2 = 0.9992 \)

- **Modified Klinkenberg Analysis**
  - Gas Double Slippage
    - Helium: \( y = 8E+06x + 154.3 \)
      - \( R^2 = 0.9603 \)
    - Nitrogen: \( y = 5E+06x + 155.51 \)
      - \( R^2 = 0.9705 \)
**Adsorption Isotherm**

- **104 °F, TOC: 1.2% (Published Data)**
- **79 °F, TOC: 0.8% (PPAL)**
- **Crushed Sample (Commercial Lab)**
  - **169 °F, TOC: 0.8%**
IMPACT OF STRESS

- Porosity vs. Net Stress, psia
- Absolute Permeability vs. Net Stress, psia
- Permeability vs. Net Stress, psia
- Fracture Closure

\[ \frac{k}{k_o}^{1/3} \]

\[ \ln\left(\frac{p}{p_o}\right) \]
SEQUENTIAL STRESS

![Graphs showing permeability vs. net stress for Series 1 and Series 2. The graphs illustrate the decrease in permeability with increasing net stress.](image)
**Adsorption Isotherms**

- **Multilayer Adsorption**
- **Slit-like pores**

*Nitrogen Adsorption at Low Temperature*

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