Chapter 13 – Gas Bearing Formation Interpretation

Lecture notes for PET 370
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Prepared by: Thomas W. Engler, Ph.D., P.E.
Gas-Bearing Formation Interpretation

- **Effect of gas on neutron log response**
  - Lower hydrogen content than calibrated value, thus higher count rate resulting in low $\phi_a$.
  - Shale effect is opposite to the gas effect, makes detection extremely difficult.

- **Effect of gas on density log response**
  - Presence of gas reduces bulk density, resulting in a high apparent porosity.
  - Shale effect can increase or decrease bulk density, dependent on shale’s bulk density.

- **Effect of gas on sonic log response**
  - Increase in sonic log porosity in poorly-consolidated sands.
  - Not quantitative or predictable.
• Log response is function of different depths of investigation of the FDC – CNL tools and the degree of invasion.
Gas-Bearing Formation Interpretation

Classification

Type I: mirror image, gas crossover (both FDC and CNL investigate same Saturation profile)

Type II: asymmetric gas crossover

Type III: Shaly gas sand

Idealized example of saturation effects on density and neutron logs. (Helander, 1983)
Density – neutron log illustrating Type I gas effect (Hilchie, 1978)

- deep invasion, or
- Extremely shallow invasion
Density – neutron log illustrating the effect of shallow to moderate invasion. (Type II) (Bassiouni, 1994)
Density – neutron log illustrating a gas-bearing shaly sand. (Type III) (Hilchie, 1978)
Porosity and Lithology Determination from Formation Density Log and CNL* Compensated Neutron Log

For CNL logs before 1986, or labeled NPHI

*Mark of Schlumberger
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Gas-Bearing Formation Interpretation

Porosity Determination

• Assume invasion extends beyond the density tool,

\[ \rho_b = (1-\phi)\rho_{ma} + \phi[S_{xo}\rho_{mf} + (1-S_{xo})\rho_g] \]  \hspace{1cm} (1)

where

\[ \rho_g \] is “apparent gas density” seen by the density log

In terms of porosity, Eq (1) can be written as

\[ \phi_D = \phi[S_{xo} + (1-S_{xo})(\phi_D)g] \]  \hspace{1cm} (2)

where

\[ (\phi_D)g = \frac{\rho_{ma} - \rho_g}{\rho_{ma} - \rho_{mf}} \]  \hspace{1cm} (3)

* gas density is \( f(P,T,\gamma) \)

* Mud filtrate density is \( f(\text{salinity}) \)

\[ \rho_{mf} = 1 + 0.73n \]  \hspace{1cm} (4)

Where \( n \) is fractional salinity \((C_{ppm} \times 10^{-6})\)
* Assume invasion extends beyond the zone of investigation of the neutron tool,

\[ \phi_N = (1 - \phi)H_{ma} + \phi[S_{xo}H_{mf} + (1 - S_{xo})H_g] \]  

(5)

Where,

\[ H_{ma}, \ H_{mf} \ and \ H_g \] are hydrogen indices for matrix, filtrate and gas, respectively,

\[ H_{mf} = (1 - n)\rho_{mf} \]  

(6)

\[ H_g = 9 \left[ \frac{4 - 2.5\rho_g}{16 - 2.5\rho_g} \right] \rho_g \]  

(7)

\[ H_{ma} = 0 \] for pure ss, lms, or dolomite.  

(8)
Case I: Fresh mud, low pressure reservoir

- Consider the simple case of:
  1. fresh mud $\Rightarrow \rho_{mf} = 1, H_{mf} = 1$
  2. Low pressure $\Rightarrow \rho_g \approx 0, H_g \approx 0$

solve for porosity,

$$\phi = \frac{(\rho_{ma} - \rho_b) + \phi_N}{\rho_{ma}} \text{, or}$$

$$\phi = \left(\frac{\rho_{ma} - 1}{\rho_{ma}}\right)\phi_D + \frac{\phi_N}{\rho_{ma}}$$

(9)  

(10)  

solve for flushed zone saturation,

$$S_{xo} = \frac{\phi_N}{\phi}$$

(11)
Gas-Bearing Formation Interpretation

General case

Empirical derivation, applicable for any $\rho_g$.

$$\phi^2 = \frac{\phi_D^2 + \phi_N^2}{2[1 + 0.12(1 - S_{xo})]^2 \left[1 + 0.5n(1 - S_{xo})\right]^2} \quad (12)$$

If fresh mud,

$$\phi^2 = \frac{\phi_D^2 + \phi_N^2}{2[1 + 0.12(1 - S_{xo})]^2} \quad (13)$$

Further reduce by assuming $S_{xo}$ is large, such that $0.12(1 - S_{xo}) \rightarrow 0$,

$$\phi = \left(\frac{\phi_D^2 + \phi_N^2}{2}\right)^{1/2} \quad (14)$$
Gas-Bearing Formation Interpretation

- A properly calibrated neutron log will respond to hydrogen in water and hydrocarbons.
- Due to low H\textsubscript{2} content of gas, the neutron log responds to the water fraction, only.
- Difference between two formations is the “Excavation” of 15% by volume of matrix material and replaced by gas.
- Magnitude of excavation effect dependent on hydrocarbon saturation and fluid HI.
* Empirical correction,

\[ \Delta \phi_{\text{Nex}} = k(2\phi^2 S_{\text{wh}} + 0.04\phi)(1 - S_{\text{wh}}) \]  

(15)

Where,

\[ k = \left( \frac{\rho_{\text{ma}}}{2.65} \right)^2 \]  

(16)

\( S_{\text{wh}} \) is the equivalent saturation based on the hydrogen content of the pore fluids,

\[ S_{\text{wh}} = S_{\text{xo}} H_{\text{mf}} + (1 - S_{\text{xo}}) H_{\text{g}} \]  

(17)

When fresh mud and low pressure gas are assumed, then \( S_{\text{wh}} = S_{\text{xo}} \)

* Add correction to neutron log reading,

\[ \phi_{\text{Nc}} = \phi_{\text{N}} + \Delta \phi_{\text{Nex}} \]  

(18)
Example

\( S_{wh} = S_{xo} = 0.5 \), fresh mud, \( H_{gas} = 0 \)

Measured Neutron porosity = 24%

Excavation effect, \( \Delta \phi_{Nex} = 6\% \)

Corrected neutron porosity = 24 + 6 = 30%

Typical excavation effect curve:
Dolomite, \( \phi = 30\% \), \( H_{gas} = 0 \)
Gas-Bearing Formation Interpretation

On density logs:

\[ \Delta \rho_g = \phi(1 - S_{xo})(\rho_{mf} - \rho_g) \]

Or

\[ \Delta \phi_{Dg} = \phi(1 - S_{xo})(1 - \phi_{Dg}) \]  \hspace{1cm} (19)

On neutron logs:

\[ \Delta \phi_{Ng} = \phi(1 - S_{xo})(H_{mf} - H_g) + \Delta \phi_{Nex} \]  \hspace{1cm} (21)
Gas-Bearing Formation Interpretation

**INPUT DATA**
\{ρma, ϕw, ρb or ϕb, Cppm, P,T,γ\}

**INITIAL GUESS**
ϕ
Sxo
{crossplot} (Eq.11)

**GAS DENSITY**
(EOS)

**Hydrogen Indices**
Hmf (Eq.6)  Hg (Eq.7)

Δρg or ΔϕDg
{Eq.18}  {Eq.19}

S_{wh} {Eq.17}

Excavation Effect
{Eq.15}

ΔϕNg {Eq.20}

Update ϕ and Sxo
< TOL?

N  Y

STOP END

Mineral Fractions
ρ_{maa}
13.1 A clean sandstone, suspected to be gas bearing, had the following recorded log readings: a lithology-correct $\phi_N = 5\%$ and a $\rho_b = 2.00$ gm/cc. Assuming the gas is low density and the mud is fresh mud, determine the true porosity and the flushed zone saturation.
13.2 Repeat Ex. 13.1 but include the excavation effect. Compare with the answers to Example 13.1.
13.3 A clean, gas-bearing sandstone exhibited neutron and density porosity readings of 10 and 20 %, respectively. Assume a fresh mud filtrate. Investigate the effect of gas density on the resulting true porosity and flushed zone saturation by considering two separate cases: (1) with a gas density assumed to be zero, and (2) a gas density = 0.25 gm/cc. Ignore excavation effect.
13.4 In Example 13.3, consider the porosity readings are on a *limestone matrix*. Determine the true porosity and flushed zone saturation. What is the effect in change of matrix type?

Chapter 16 – Evaluation of Gas-Bearing Formations