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Summary on Qualitatively Identification Methods for Shallow-Buried Natural Gas Reservoir

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Abstract: Well logging curves are carried out normalization correction, the conventional logging data could identify the oil and water beds, but also the oil reservoir with obvious variation and great burial depth. While the shallow buried gases reservoir, the normal interpretation ways aren't enough to meet the production. After analyzed the characteristics of gas reservoir indication curves such as neutron, density and acoustic logging, the log interpretation methods which base on 3 porosity log curves is proposed. According to the actual well testing, these methods used to identify the shallow-buried natural gas reservoir are economically feasible.
Keywords: shallow-buried natural gas reservoir, gas bed indicated parameter, gas reservoir coincidence curve.

INTRODUCTION

Theoretical analysis and experiment indicate that the density of gas is less dense than oil and water, the dense of gas rock is less than the rock bearing oil and gas, and therefore, the seismic data has been used as one of the most effective means of identification the natural gas reservoir [1]. As a result of the hydrogen index of natural gas is less than the oil and water, the neutron porosity logging which reflects formation gas concentration is decreased with the raise of formation gas concentration, so wide spread using the response of a neutron porosity log to identify the natural gas reservoir [2]. P-wave velocity of gas rock is less than the rock bearing oil and gas, and longitudinal wave offset time will increase, hence, the longitudinal wave offset time of AC is also an important information. For the rock with same lithology and physical property, the gas bed with capture cross section is below the water layer. Thus can identify the gas bed based on capture cross section [3].

GAS BED INDICATED PARAMETER RECOGNITION METHOD

Three porosity logging differential method

The density of gas is far less dense than oil and water, thus the value of dense of gas bed is also less than the bed bearing water completely; the gas' hydrocarbon index is far less than 1, and the "excavation effect" exists in, therefore, neutron value lower in gas bed than in bed bearing water completely; when gas exists in reservoir, longitudinal wave offset time will increase, and cycle-skip could even occur. That is longitudinal wave offset time lower in gas bed than in bed bearing water completely [4]. This is the physical infrastructure of using 3 porosity logging to identify the gas bed.

$$Pa1 = (\phi_{Sc} + \phi_{Dc} - 2\phi_{Nc}) \times 100 \qquad (1\text{-}1)$$

Among them, $\Sigma = \Sigma_{ma}\left(1 - V_{sh} - \phi\right) + \Sigma_f (1 - S_g)\phi + \Sigma_{sh} V_{sh} + \Sigma_g S_g \phi$;

$$\phi_{Dc} = \phi_D - V_{sh} \cdot \phi_{Dsh} \ ; \ \phi_{Nc} = \phi_N - V_{sh} \cdot \phi_{Nsh}$$

In this formula, *x*—is stratal lithological index of the ,dimensionless.

In natural gas bed, ϕ_{Sc} increases, ϕ_{Dc} will increase, ϕ_{Nc} will decrease, if $Pa1 > 0$,is the gas bed; if $Pa1 \approx 0$,is the oil or water layer. Using 3 porosity logging all of the time shows the advantage of this approach.

A-K method

In a neutron-density cross plot, the slope of a line joining points of rock frame and pore fluid is:

$$A = \frac{\rho_{ma} - \rho_f}{\Phi_{Nf} - \Phi_{Nma}} = \frac{\rho_b - \rho_f}{\Phi_{Nf} - \Phi_N} \quad (1\text{-}2)$$

In a neutron-acoustic cross plot, the slope of a line joining points of rock frame and pore fluid is:

$$K = \frac{\Delta t_f - \Delta t_{ma}}{\Phi_{Nf} - \Phi_{Nma}} \times 0.01 = \frac{\Delta t_f - \Delta t}{\Phi_{Nf} - \Phi_N} \times 0.01 \quad (1\text{-}3)$$

In natural gas bed, ρ_b and Φ_N decreases, Δt will increase, thus *A* and *K* will decrease. A-K combination is used as the gas zone identification parameter. The parameter $Pa2$ in following figure 2 is the gas zone identification schematic.

$$Pa2 = \sqrt{(\rho_{ma} - \rho_f)^2 + [(\Delta t_f - \Delta t_{ma}) \times 0.01]^2} - \sqrt{(\frac{\rho_{bc} - \rho_f}{\phi_{Nf} - \phi_{Nc}})^2 + \left[(\frac{\Delta t_f - \Delta t_c}{\phi_{Nf} - \phi_{Nc}}) \times 0.01\right]^2} \quad (1\text{-}4)$$

If $Pa2 > 0$,is the gas bed; if $Pa2 \approx 0$, is the oil or water layer. This approach has such advantages as using 3 porosity logging all of the time, and small effect of porosity variation.

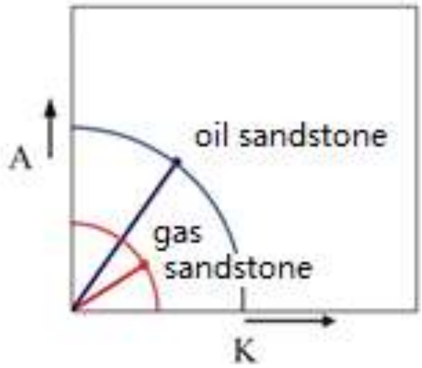

Fig-1: Using A-K method as gas zone identification schematic

The differential method of apparent difference of fluid and apparent density of fluid

In cross plot of true porosity(ϕ)and density porosity (ϕ_{Dc}), as shown in Figure2, take the cross over point which corresponding fluid density value as apparent density of fluid, that cross over point from the one line which linking origin (0, 0) and point A (ϕ , ρ_{bc})adds to the line vertical lines of $\phi = 100\%$. By the similar triangles, can get:

$$\frac{\phi}{1.0} = \frac{\rho_{ma} - \rho_{bc}}{\rho_{ma} - \rho_{fa}} \quad (1\text{-}5)$$

And the expression of apparent density of fluid ρ_{fa} is:

$$\rho_{fa} = \rho_{ma} - \frac{\rho_{ma} - \rho_{bc}}{\phi} \quad (1\text{-}6)$$

In cross plot of true porosity(ϕ)and acoustic porosity(ϕ_{Sc}), as shown in Figure3, take the cross over point which corresponding fluid density value as apparent difference of fluid, that cross over point from the one line which linking origin (0, 0) and point A(ϕ , Δt_c) adds to the line vertical lines of $\phi = 100\%$. By the similar triangles, can get:

$$\frac{\phi}{1.0} = \frac{\Delta t_c - \Delta t_{ma}}{\Delta t_{fa} - \Delta t_{ma}} \quad (1\text{-}7)$$

And the expression of apparent difference of fluid Δt_{fa} is:

$$\Delta t_{fa} = \Delta t_{ma} + \frac{\Delta t_c - \Delta t_{ma}}{\phi} \tag{1-8}$$

In natural gas bed, ρ_{bc} decreases, Δt_c increases, and $\Delta t_{fa} > \Delta t_f$, $\rho_{fa} < \rho_f$, so the gas identification parameters are defined as follows:

$$Pa3 = \Delta t_{fa} / \Delta t_f - \rho_{fa} / \rho_f \tag{1-9}$$

If $Pa3 > 0$,is the gas bed; if $Pa3 \approx 0$, is the oil or water layer. This approach has such advantage as using density and sonic logging only. The testing depth of density and sonic logging are lower to the compensated neutron logging yet, therefore the ability and accuracy of indication gas formation is bad when the more deeply invades.

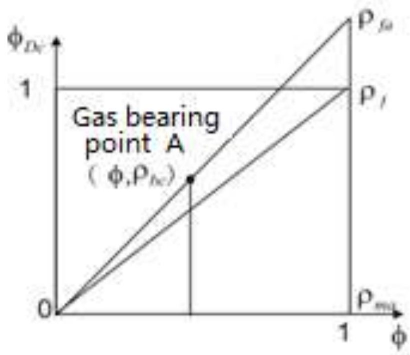

Fig-2: Cross plot of true porosity and density porosity

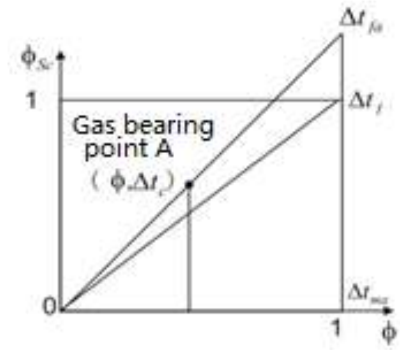

Fig-3: Cross plotof true porosity and acoustic porosity

Equivalent elastic modules difference method

The definition of the rock's equivalent modulus of elasticity is:

$$E_c = E \frac{1-\sigma}{(1+\sigma)(1-2\sigma)} \tag{1-10}$$

Due to the relationship between the rock's wave velocity and E 、 σ 、 ρ_b , derive that:

$$E_c = \frac{\rho_b}{\Delta t^2} \times 10^{16} \tag{1-11}$$

The differential ratio value of equivalent modulus of elasticity is:

$$Pa4 = \frac{E_{cw} - E_c}{E_c} = (\frac{\rho_{WF}}{\Delta t_{WF}^2} - \frac{\rho_{bc}}{\Delta t_c^2}) / (\frac{\rho_{bc}}{\Delta t_c^2}) \tag{1-12}$$

Among them, $\rho_{WF} = (1-\phi)\rho_{ma} + \phi\rho_f$, $\Delta t_{WF} = (1-\phi)\Delta t_{ma} + \phi \Delta t_f$.

In this formula, ρ_{WF} —is the density value of rock when water saturation is 100%, , g/cm^3 ;

Δt_{WF} —is the value of AC when water saturation of rock is 100%, $\mu s/ft$.

In natural gas bed, ρ_{bc} decreases, Δt_c increases, and E_c will decrease, thus if $Pa4>0$, is the gas bed; if $Pa4\approx 0$, is the oil or water layer. This approach has such advantage as using density and sonic logging only. The testing depth of density and sonic logging are lower to the compensated neutron logging yet [5], therefore the ability and accuracy of indication gas formation is bad when the more deeply invades. In addition, this approach is limited by density of synthetic water layer and the accuracy of AC.

The differential method of acoustic porosity and neutron porosity

For the gas bed, acoustic porosity increases and neutron porosity will decrease, thus gas reservoirs are successfully distinguished.

$$Pa5 = 100\times(\phi_{Sc}-\phi_{Nc}) \qquad (1\text{-}13)$$

For the gas bed, if $Pa5>0$, is the gas bed; if $Pa5\approx 0$, is the oil or water layer. This approach has such advantage as using sonic and neutron logging only. The testing depth of sonic logging is lower to the compensated neutron logging yet, therefore the ability and accuracy of indication gas formation is bad when the more deeply invades.

The differential method of density porosity and neutron porosity

For the gas bed, density porosity increases and neutron porosity will decrease, thus gas reservoirs are successfully distinguished.

$$Pa6 = 100\times(\phi_{Dc}-\phi_{Nc}) \qquad (1\text{-}14)$$

For the gas bed, if $Pa6>0$, is the gas bed; if $Pa6\approx 0$, is the oil or water layer. This approach has such advantage as using neutron and density logging only. The testing depth of **density** logging is lower to the compensated neutron logging yet, therefore the ability and accuracy of indication gas formation is bad when the more deeply invades.

GAS BED COINCIDENCE CURVE RECOGNITION METHOD

Due to the measuring principle of neutron-density logging, the main role of compensated neutron logging is reflecting the hydrogen content of strata, while the role of density logging is reflecting the density content of strata [3]. Comparing the hydrogen index (HI)of equal volume of water/ oil, the gas is lower, and the density of gas is far less than the water/ oil. Neutron porosity in gas bed will decrease, the density will reduce [6]. Therefore, opposing these 2 curves, and coinciding with overlapping curves at water bed (oil layer). When these 2 curves overlapping is quite familiar, and mirror image magnitude difference is appeared on reservoir, the gas bed is distinguished. As shown in the figure 6.

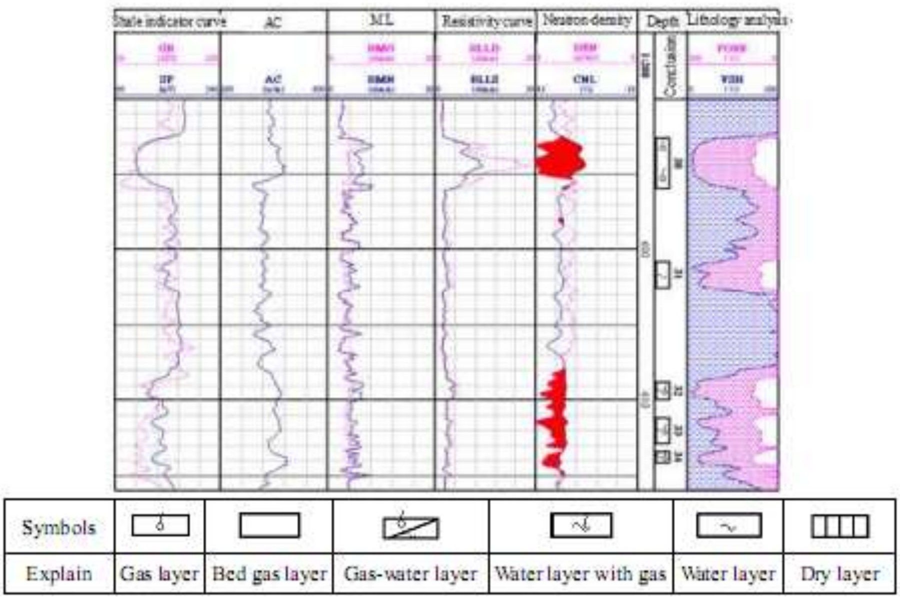

Fig-4: Well * Gas bed coincidence curve recognition**

CONCLUSIONS

(1)Analyzed the characteristics of gas reservoir indication curves such as neutron, density and acoustic logging, 6 indicated parameter are proposed to identify the shallow-buried natural gas reservoir, such as: 3 porosity logging differential method, A-K method, differential method of apparent difference of fluid and apparent density of fluid, equivalent elastic modules difference method, differential method of acoustic porosity and neutron porosity, differential method of density porosity and neutron porosity. These 6 indicated parameter are identified effectively.

(2)Take the neutron-density logging curves overlapped, mirror image magnitude difference is appeared on reservoir, the gas bed is distinguished.

(3) A last, compared the interpretation and to the actual well testing, the above methods for identification of shallow gas reservoirs are high coincidence rate, strong indicative and economically viable way.

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