A NEW METHOD FOR EVALUATING FRACABILITY OF SHALE RESERVOIRS

by

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In this paper, the reservoir brittleness index is determined by mineral composition and content ratio of shale reservoir, and the cementation degree of rock in different reservoirs is predicted based on spontaneous potential and natural gamma logging, and combined with the fracture toughness characteristics of rock mechanics, a new evaluation and prediction method for fracturing ability of shale reservoir is established, which integrates rock mineral composition, cementation degree and fracture toughness of rock. This model can be used to obtain quantitative characterization of fracturing ability in laboratory and field through laboratory test or field logging data. The fracability model established in this paper has been applied and analyzed in typical shale Wells and the evaluation results are consistent with the productivity monitoring data after fracturing, which verifies the accuracy of the model established in this paper.

Key words: *shale reservoir, brittle minerals, cementation degree, fracture toughness, fracability*

Introduction

The porosity and permeability of shale reservoirs are extremely low, thus it is difficult to efficiently develop shale resources by relying on the natural porosity and pressure of the formation [1, 2]. Fracturing and reconstruction of shale reservoirs are required in most cases. Fracability is often used to characterize the ability of shale to be effectively fractured during hydraulic fracturing. Therefore, the fracturing engineering sweet spot of shale reservoir accurately identified is the key to efficient development [3, 4]. The main problems with the existing methods for predicting the fracturing ability of shale reservoirs are:

- The core experimental test can only evaluate a certain block and a certain well section, and the specific parameters are affected by the core quality, the brittleness evaluation of the whole well section and the whole region cannot be realized.
- The brittleness evaluation method based on mineral component content method only considers the mineral component factors, and does not consider the influence of cementation and diagenesis on rock strength, resulting in low accuracy of brittleness evaluation, weak

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reference, and also unable to realize the brittleness evaluation and optimization of the whole well interval.

– Existing studies only consider the content of different brittle minerals, and do not consider the different degrees of influence of different minerals on brittleness, resulting in poor accuracy of brittleness evaluation results.
– The research objects of existing brittleness evaluation models are mainly shale gas reservoirs and tight sandstone reservoirs, and there are few studies on fracturing performance evaluation of shale reservoirs. In this paper, the brittleness index of brittle minerals, the degree of reservoir rock cementation and fracture toughness are comprehensively considered to achieve an accurate prediction of the fracturing ability of shale reservoirs, and play a certain guiding role in the identification of fracturing sweet spots of shale reservoirs [5, 6].

Evaluation of brittleness index based on mineral composition

Most of the existing studies on the influence of mineral content on brittleness of shale reservoirs only consider the influence of the content of brittle minerals, and do not consider the difference in the influence coefficient of different brittle minerals [7-9]. The ratio of the sum of quartz, dolomite, calcite and other carbonates to the total mineral content is commonly used as the brittleness index B is given:

$$B = \frac{W_{\text{QFM}} + W_{\text{carb}}}{W_{\text{tot}}} \tag{1}$$

where W_{QFM} is the quartz mineral content in shale, W_{carb} – the carbonate mineral content in shale, and W_{tot} – the total content of inorganic minerals in shale.

This method can be considered as the proportion of quartz and carbonate minerals in the total shale minerals, and does not further analyze their specific influence degree, which often leads to poor accuracy of brittleness prediction results. In addition, the influence of the degree of rock cementation on the fracability of shale reservoirs is often ignored in the current research on the fracability of shale reservoirs, which leads to the low accuracy of predicting the fracability of shale reservoirs [10, 11].

The influence of brittle mineral content and brittleness coefficient on brittleness

According to the experimental results combined with the research of relevant scholars [12], quartz has the strongest influence on the brittleness index in shale reservoirs, and quartz has a significantly stronger influence on shale brittleness than calcite and dolomite under the same other components. Based on the analysis of the experimental results, the formula for calculating the brittleness index considering the mineral component content and the relative brittleness coefficient of each component is obtained:

$$MIB = \frac{v_{\text{quartz}} + 0.268v_{\text{calcite}} + 0.415v_{\text{dolomite}} + 1.318v_{\text{pyrite}}}{v_{\text{quartz}} + 0.268v_{\text{calcite}} + 0.415v_{\text{dolomite}} + 1.318v_{\text{pyrite}} + 0.046v_{\text{clay}}} \tag{2}$$

where v_{quartz} is the quartz mineral content in shale, v_{calcite} – the calcite mineral content in shale, v_{dolomite} – the dolomite mineral content in shale, v_{pyrite} – the pyrite mineral content in shale, and v_{clay} – the clay mineral content in shale.

The higher the relative content of rigid components, the better brittleness and fracturing ability, the brittleness index evaluation method is called mineral component content and brittleness coefficient index method (MIB).

Study on the degree of rock cementation

By analyzing the content of mineral components, it is found that the diagenesis of rock also has a certain influence on the fracturing property of rock. On the basis of the same mineral component content, the different diagenesis of rocks will lead to the change of their micro-structures, which will lead to the difference in the degree of rock cementation, and ultimately affect the fracturing property of the formation [13].

Diagenesis can be obtained by laboratory experiments, calculated by the molar Coulomb criterion according to the parameters of rock cohesion and internal friction angle, and the intensity of diagenesis can also be quantitatively characterized by the log data of mineral components. Some scholars have analyzed different diagenesis and conventional logging data and found that the most sensitive logging data types are spontaneous potential and natural gamma logging data. This paper draws on the research results of Wang [14] and takes the difference between the normalized gamma curve and SP curve as the diagenetic coefficient, *C*, to realize the quantitative characterization of rock diagenesis, showed in tab. 1. The calculation formulas of *C*, are shown:

$$SP_1 = \frac{SP_{\max} - SP}{SP_{\max} - SP_{\min}}, \;\; GR_1 = \frac{GR_{\max} - GR}{GR_{\max} - GR_{\min}}, \;\; C = GR_1 - SP_1 \tag{3}$$

where SP is the spontaneous potential logging value, GR – the natural gamma logging value, $SP_{\max}$ – the max spontaneous potential logging value, $SP_{\min}$ – the min spontaneous potential logging value, $GR_{\max}$ – the max natural gamma logging value, and $GR_{\min}$ – the min natural gamma logging value.

Table 1. Evaluation results of diagenetic coefficient

Diagenesis type	Diagenetic coefficient, C_1	Porosity [%]
Strong cementation and weak dissolution	≥0.4	≤0.05
Medium cementation and weak dissolution	0~0.4	0.05~0.08
Moderate dissolution and weak cementation	–0.15~0	0.08~0.2
Strong dissolution and weak cementation	≤–0.15	≥0.2

According to the aforementioned results, the *C* is normalized by:

$$C = \frac{C_{\max} - C}{C_{\max} - C_{\min}} \tag{4}$$

where $C_{\max}$ is the larger the diagenetic coefficient and $C_{\min}$ – the smaller the fracturing property of the reservoir.

Prediction of shale fracture toughness

Generally, the smaller the fracture toughness of the rock, the easier the hydraulic fracture propagates forward, and the smaller the fracture toughness of the reservoir is easy to induce shear failure of natural fractures that are not in the established expansion path of hydraulic fractures, easy to connect hydraulic fractures and natural fractures, and easy to obtain larger reconstruction volume and complex fracture network. The fracture toughness can be obtained by the fracture toughness test experiment and can also be calculated by the well logging curve.

Based on acoustic time lag log, density log and gamma ray log, combined with relevant empirical formulas, acoustic velocity, tensile strength and other parameters can be calculated, and then the fracture toughness log value of shale reservoir can be obtained. The fracture toughness can be predicted by logging data, that is to say:

$$V_{\mathrm{p}} = \frac{1}{AC} \times 1000000 \tag{5}$$

where V_{p} is the longitudinal wave velocity and AC – the acoustic time difference logging value.

The shear wave velocity V_{s} reads:

$$V_{\mathrm{s}} = 0.5715 \times V_{\mathrm{p}} + 132.09 \tag{6}$$

The elastic modulus logging value, E, is given:

$$E = 1000000 \times \rho \times V_{\mathrm{s}}^2 \times \left[3 \times \left(\frac{V_{\mathrm{p}}}{V_{\mathrm{s}}}\right)^2 - 4\right]\left[\left(\frac{V_{\mathrm{p}}}{V_{\mathrm{s}}}\right)^2 - 1\right]^{-1} \tag{7}$$

where ρ is the density.

The shale content index reads:

$$S = \frac{GR - 25}{225} \tag{8}$$

where GR is natural gamma logging value. The shale content SH can be given:

$$SH = \frac{2^{2S} - 1}{3} \tag{9}$$

The compressive strength, σ_{c}, is given:

$$\sigma_{\mathrm{c}} = [0.0045 \times E \times (1 - SH) + 0.008 \times SH \times E] \times 200 \tag{10}$$

The tensile strength, S_{t}, reads:

$$S_{\mathrm{t}} = \frac{\sigma_{\mathrm{c}}}{12} \tag{11}$$

The rock fracture toughness, K_C, can be written:

$$K_C = 0.0059 S_{\mathrm{t}}^3 + 0.0923 S_{\mathrm{t}}^2 + 0.517 S_{\mathrm{t}} - 0.3322 \tag{12}$$

Establishment of fracturing ability prediction model

Considering the fracture toughness value of the reservoir, combined with the influence of brittleness index and cementation degree, a new fracturing evaluation model of shale reservoir is established. The fracturing property of reservoir, F_{rac}, is given:

$$F_{\mathrm{rac}} = \frac{BI}{K_C C_C} \tag{13}$$

where BI is the brittle coefficient, K_C – the rock fracture toughness, and C_c – the digenetic coefficient.

The fracability is normalized by using the method of range transformation make its range between zero and one, which is convenient for more intuitive evaluation on site [2]. This prediction model has been used to predict the fracability in 20 Wells, and its accuracy is more than 85%. The relationship between yield and fracturing index is shown in fig. 1, which realizes a more accurate prediction of the fracability of shale reservoir.

Conclusion

This evaluation method not only considers the influence of brittle mineral mechanical properties of shale oil reservoir itself, but also considers the influence of reservoir rock cementation degree and fracture toughness, so that the fracturing ability evaluation is more

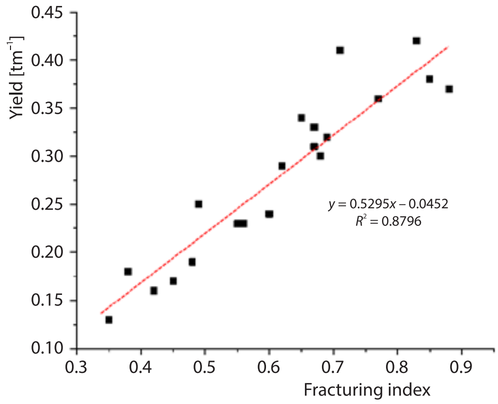

Figure 1. Relationship between yield and fracturing index under the same geological conditions

comprehensive and accurate. The accuracy of the prediction model can reach more than 85%, which has a guiding role in the identification of fracturing sweet spots in shale reservoirs. The prediction parameters required by this evaluation method can be obtained by logging data, and then the brittleness prediction profile of the whole well section can be obtained, which is conducive to screening the sweet spot of fracturing engineering. Using the adjacent well data, the 3-D fracturing ability profile can be established in the study area, and then the fracturing ability of shale reservoir can be accurately predicted.

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Nomenclature

E – elastic modulus logging value, [GPa]
V_p – longitudinal wave velocity, [ms^{-1}]
V_s – shear wave velocity, [ms^{-1}]

Greek symbol

ρ – density, [kgm^{-3}]

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