Brittleness Evaluation of Chang7 Reservoir in Longdong Area Based on Mechanical Parameters and Stress-strain

Zhenhua Li 1,*, Suya Zhang 2 and Feng Cao 1

1 School of Energy Engineering, Longdong University, Qingyang, China
2 School of Foreign Languages, Longdong University, Qingyang, China

*Corresponding author e-mail: 250759492@qq.com

Abstract. Brittleness determines the effect of reservoir fracturing and is the key to improve unconventional oil and gas production. In order to accurately understand the brittleness and fracture parameters of the reservoir, triaxial compression test and stress-strain analysis were carried out on the Chang 7 rock samples from well N-1 and well Z-1 in Longdong area of Ordos basin, based on which, the brittleness index was calculated. The results show that the brittleness index calculated by stress-strain method is 51.95%-52.96% and by mechanical parameters method is 57.2%-57.5%; the brittleness index is high, indicating that chang7 reservoir in Longdong area has high brittleness, which is conducive to later fracturing.

1. Introduction
With the increasing demand for oil and gas in the world and the gradual depletion of conventional oil and gas resources, unconventional oil and gas resources have gradually become a hot area of exploration and development [1-2]. Because of the characteristics of low porosity and permeability of unconventional oil and gas, it is difficult to produce industrial oil and gas flow under natural conditions, and it must be fractured in industrial exploration. Brittleness, as an important parameter of formation drillability analysis and fracturing, is the key of unconventional reservoir fracturing.

Longdong area is located in the southwest of Ordos basin, which mainly spans Tianhuan depression and Yishan slope(Fig. 1). Chang 7 reservoir of Longdong area is dominated by deep and semi-deep lacustrine deposits with deltaic front and front deltaic bays alternating, the rapid expansion of the lake basin and the continuous and stable deep-water sedimentary environment provide the necessary conditions for the formation of unconventional oil and gas resources. Because of the low porosity and low permeability of Chang 7 reservoir, it is very important to study the fracturing ability. In this paper, the evaluation methods of brittleness index are discussed, and the stress-strain and rock mechanics parameter method are mainly used to analyze the brittleness index of Chang 7 reservoir in Longdong area, which would provide parameter basis for the selection of favorable fracturing zone and scheme design.

2. Calculation methods of reservoir brittleness
Brittleness is an important index to measure rock fracturing ability, which determines the effect of reservoir fracturing and is the key factor to improve permeability and production of unconventional oil and gas. Now there is no such an unified definition for brittleness, so there is no fixed method for
Brittleness evaluation. There are more than 20 methods to measure brittleness. Scholars in different fields put forward different definitions and evaluation formulas for brittleness in order to satisfy different purposes. For oil and gas reservoirs, rock brittleness is generally defined as the difficulty degree of transient change before rock fracture, which reflects the complexity degree of fracturing. The more brittle the rock is, the more likely it is to fracture, and the more likely it is to form a complex fracture network. Brittleness can be quantitatively represented by brittleness index. At present, the main brittleness evaluation methods in petroleum geology include mechanical parameter method, mineral component method, stress-strain method, strength ratio method and material hardness method. The detailed calculation formula of brittleness index is shown in Table 1.

**Table 1. Summary of the evaluation methods of the brittleness index.**

| Principle                          | Formula                                      | Variable specification                                      | Method                                |
|------------------------------------|----------------------------------------------|------------------------------------------------------------|--------------------------------------|
| Hardness or soundness              | $B = H/K_{IC}$                               | $H$ is hardness, GPa; $K_{IC}$ is toughness, MPa           | Hardness test; toughness test        |
| Strength ratio                     | $B = \sigma_c/\sigma_t$                      | $\sigma_c$ is compressive strength, MPa; $\sigma_t$ is tensile strength, MPa | Uniaxial compression test; Brazilian split test |
| Stress-strain                      | $B = (\sigma_p - \sigma_t)/\sigma_p$        | $\sigma_p$ is shear strength, MPa; $\sigma_t$ is residual shear strength, MPa | Stress strain test                   |
| Mechanical parameters              | $B = (\Delta E + \Delta \mu)/2$             | $\Delta E$ is Normalized Young's modulus; $\Delta \mu$ is Normalized Poisson's ratio | Triaxial compression test            |
| Rock mineral components            | $(W_Q + W_D)/W_T$                            | $W_Q$ is Quartz content, $W_T$ is Total mineral content $W_D$ is dolomite content | X-ray diffraction test               |
3. Britteness evaluation based on stress-strain method

3.1. Method and principle
The stress-strain method mainly uses the performance of brittleness failure on the stress-strain curve to evaluate brittleness. The typical stress-strain curve is shown in Figure 2. If the strength of the rock after the peak is soon at minimum, its brittleness is high; otherwise, if it is basically unchanged or the change is very slight, its brittleness is low. The stress-strain method reflects both the mechanical characteristics before and after the peak (the peak strain reflects the difficulty of brittleness failure, and the curve shape after the peak indicates the strength of brittleness), it is simple and practical. Its brittleness calculation formula is as follows:

\[
B = \left(\frac{\sigma_p - \sigma_r}{\sigma_p}\right) \times 100\%
\]

In the above formula: \(B\) is rock brittleness index, dimensionless; \(\sigma_p\) is compressive strength, MPa; \(\sigma_r\) is residual strength after rock failure, MPa.

3.2. Britteness index calculated by stress-strain method
Through stress-strain analysis of typical cores of well N-1 and Z-1 in Longdong area, the stress-strain curve (figure 3) and test results (table 2) are obtained. By using formula (1), the brittleness indexes of well N-1 and well Z-1 in Chang 7 reservoir of Longdong area are 51.95\% and 52.96\%, respectively, which are high, indicating that Chang 7 reservoir of Longdong area has good fracturing ability.
Figure 3. a Stress-strain curve of L1-3 rock sample of well N-1. b Stress-strain curve of L3-4 rock sample of well Z-1.

Table 2. Brittleness index of Longdong Chang 7 based on stress-strain method.

| Well | Lithology  | Depth(m)  | Sample number | density(g/cm$^3$) | $\tau_p$(MPa) | $\tau_r$(MPa) | Brittleness B (%) |
|------|------------|-----------|---------------|------------------|---------------|--------------|------------------|
| N-1  | fine sandstone | 1489.6-1494.3 | L1-1 | 2.665 | 198.74 | 90 | 54.71 |
|      |            |           | L1-3 | 2.462 | 200.85 | 92 | 54.19 |
|      |            |           | L1-4 | 2.470 | 205.42 | 109 | 46.94 |
|      | mean       |           |       | 2.469 | 201.46 | 99 | 51.95 |
| Z-1  | fine sandstone | 1792.3-1801.84 | L3-3 | 2.388 | 197.73 | 82 | 58.53 |
|      |            |           | L3-4 | 2.396 | 204.58 | 105 | 48.68 |
|      |            |           | L3-5 | 2.368 | 202.73 | 98 | 51.66 |
|      | mean       |           |       | 2.383 | 202.45 | 99 | 52.96 |

4. Brittleness evaluation based on rock mechanical parameters

4.1. Method and principle

The mechanical properties of rock are closely related to its brittleness. Poisson’s ratio indicates the ability of rock to resist damage under stress, and Young’s modulus indicates the ability to maintain fracture. Generally speaking, the higher Young’s modulus and the lower Poisson’s ratio, the more brittle the rock is. As rock brittleness is a comprehensive reflection of Young’s modulus and Poisson’s ratio, Rickman [13] proposed a brittleness index calculation formula based on rock mechanical parameters (formula 4), that is, the normalized Young’s modulus and Poisson’s ratio are taken 50% respectively for weight calculation.

The typical stress-strain curve is shown in Figure 2. If the strength of the rock after the peak is soon at minimum, its brittleness is high; otherwise, if it is basically unchanged or the change is very slight, its brittleness is low. The stress-strain method reflects both the mechanical characteristics before and after the peak (the peak strain reflects the difficulty of brittleness failure, and the curve shape after the peak indicates the strength of brittleness), it is simple and practical. Its brittleness calculation formula is as follows:

$$\Delta E = \frac{E - E_{\min}}{E_{\max} - E_{\min}} \times 100\%$$ (2)
\[
\Delta \mu = \frac{\mu_{\text{max}} - \mu}{\mu_{\text{max}} - \mu_{\text{min}}} \times 100\% 
\]  

(3)

\[
B = \frac{\Delta E + \Delta \mu}{2} \times 100\% 
\]  

(4)

In the above formula, \(\Delta e\) is the normalized Young’s modulus, %; \(E\) is Young’s modulus of the rock, GPA; \(\Delta \mu\) is the normalized Poisson’s ratio, %; \(\mu\) is Poisson’s ratio, dimensionless; \(B\) is the brittleness index, %; the subscripts min and max respectively represent the maximum and minimum values of this parameter in a certain stratum.

4.2. Brittleness index calculated by mechanical parameters

Triaxial compression test is carried out in rock samples from well N-1 and Z-1 of Chang 7 reservoir in Longdong area (the specification of the rock samples is Φ38.1mm×h76.2mm), and the test results are shown in table 3. After obtaining the rock mechanical parameters, the normalized Young’s modulus and Poisson’s ratio can be calculated by formula (2) and (3), and then the brittleness index of rock samples can be obtained by taking 50% of the normalized Young’s modulus and Poisson’s ratio respectively by formula (4). The maximum and minimum values of Young’s modulus measured in well N-1 are 2.443GPa and 1.291GPa respectively, the maximum and minimum values of Poisson’s ratio are 0.255 and 0.191 respectively, and the calculated brittleness index is 57.5%. The maximum and minimum values of Young’s modulus measured in well Z-1 are 2.556GPa and 1.929GPa respectively, the maximum and minimum values of Poisson’s ratio are 0.289 and 0.175 respectively, and the calculated brittleness index is 57.2%.

Table 3. Results of triaxial compression test.

| Well  | Lithology       | Depth (m)       | Sample number | confining pressure (MPa) | Es (GPa) | \(\mu_s\) |
|-------|----------------|-----------------|---------------|--------------------------|---------|----------|
| N-1   | Fine sandstone | 1489.6-1494.3   | L2-1          | 1.350                    | 2.427   | 0.214    |
|       |                |                 | L2-2          | 0                        | 1.291   | 0.243    |
|       |                |                 | L2-3          | 1.647                    | 2.427   | 0.243    |
|       |                |                 | L2-4          | 5                        | 2.415   | 0.197    |
|       |                |                 | L2-5          | 2.443                    | 2.013   | 0.286    |
|       |                |                 | L2-6          | 0                        | 1.929   | 0.289    |
|       |                |                 | L3-1          | 5                        | 2.336   | 0.270    |
|       |                |                 | L3-2          | 2.323                    | 2.013   | 0.213    |
|       |                |                 | L3-3          | 2.475                    | 2.490   | 0.231    |
|       |                |                 | L3-4          | 2.525                    | 2.525   | 0.177    |
|       |                |                 | L3-5          | 2.556                    | 2.556   | 0.175    |
5. Conclusion

In oil and gas geology, rock brittleness is defined as the difficulty of transient change before rock fracture. The larger the rock brittleness is, the better the fracturing ability is, and the more complex fracture networks are formed. Different definitions of brittleness and different calculation methods of brittleness index often lead to errors in evaluation results, so choosing appropriate calculation method is essential in brittleness evaluation. The brittleness index of Chang 7 reservoir in Longdong area obtained by stress-strain method is 51.95% ~ 52.96% and it is 57.2% ~ 57.5% by rock mechanical parameters method. The brittleness index ranges from 51.9% to 57.5%, indicating that Chang 7 reservoir in Longdong area has high brittleness and good fracturing ability. It can form complex fracture networks rapidly in operation, which is conducive to oil and gas development.

Acknowledgments
This work was financially supported by Xifeng Technology Bureau Fund Project, project number XK2019-10, and by Department of industry and information technology Funds of Gansu Province, project number GGLD-2019-066.

References

[1] JinLan, Guiwen Wang, Zhuiying Fan. Research progress on the evaluation methods of brittleness index of unconventional oil and gas reservoir. Petroleum Science Bulletin. (2016)330-341.
[2] Chenchen Zhang, Dazhong Dong, Yuman Wang. Research progress of shale reservoir brittleness, Xinjiang Petroleum Geology. (2017)111-117.
[3] Huayang Li, Cancan Zhou, Changxi Li. Logging evaluation method of brittle index of tight sandstone. Xinjiang Petroleum Geology. (2014)35(5): 593-597.
[4] Xiaoyan Qin. Brittle geophysical logging evaluation of continental shale based on rock mechanics characteristics. Progress in Geophysics, (2016) 762-769.
[5] Haiyan Diao. Mechanical properties and brittleness evaluation of shale reservoir. Journal of rock, 2013, 9(9): 3300-3306.
[6] Jianmeng Sun, Zhilei Han, Ruibao Qin. (2015) Well logging evaluation methods for fracturing ability of tight gas reservoir. Petroleum Journal. (36): 74-80.
[7] Jinzhou Zhao, Wenjun Xu, Yongming Li. A new method for evaluating the fracturing ability of shale reservoir. Natural Gas Geoscience. 2015, 26(6):1165-1172.
[8] Junliang Yuan, Jingen Deng, Dingyu Zhang. (2014) Fracturing evaluation technology of shale gas reservoir. Petroleum Journal. (34): 523-527.
[9] Kuangsheng Zhang, Shun Liu, Jianfang Jiang. Calculation method and field application of brittleness index of Chang 7 tight reservoir. Oil and Gas Well Testing. 2014, 23(5): 29-33.
[10] Qinghui Li, Mian Chen, Yan Jin. (2012) Laboratory evaluation methods and improvement of shale brittleness. Journal of rock mechanics and Engineering. (31);1680-1685.
[11] GAO Quan, TAO Junliang, HU Jianying, et al. Laboratory study on the mechanical behaviors of an anisotropic shale rock[J]. Journal of Rock Mechanics and Geotechnical Engineering, 2015,7(2):213-219.
[12] Martin J.A. geomechanical approach to evaluate brittleness using well logs: Mississippian limestone, Northern Oklahoma[D]. Texas: The University of Texas at Arlington, 2015.
[13] Rickman R, Mullen M J, Petre J E, et al. A practical use of shale petrophysics for stimulation design optimization: all shale plays are not clones of the Barnett Shale[C]. SPE Annual Technical Conference and Exhibition, Denver, Colorado, USA, 21-24 September, 2008.