A method to analyze fracture communication in carbonate reservoirs

Yudi Geng¹, Zhiyuan Liu¹, Yuqing Liu², Jiahao Zhan², Zhou Zhou²

¹Sinopec Northwest Oilfield Branch, Urumqi, Xinjiang, China
²State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum (Beijing), Beijing, China

Abstract. Large amounts of oil and gas resources are stored in carbonate rocks, and fracturing is an important technology to exploit carbonate reservoirs. The communication between artificial fractures and natural fractures is very important for the fracturing effect of carbonate reservoirs. Effect evaluation after fracturing lacks quantitative description. Therefore, it is necessary to study the fracturing effect of carbonate reservoirs. This paper analyzes the pressure curve obtained in true triaxial fracturing experiment. The communication with natural fracture and vugs in the process of fracture propagation is explored. Finally, the pressure curve characteristics of artificial fracture communicating with natural fracture cavity under different modes are obtained, and the communication between artificial fracture and natural fracture is identified.

Key words: Carbonate reservoirs; Fracturing experiment; Numerical analysis

1. Introduction

In this paper, the impulse analysis method is established by analyzing the acoustic emission diagram and pressure curve of rock fracturing experiment, and the proportion range of impulse corresponding to different fracture communication modes is obtained.

MJ Mayrhofer¹² et al. Put forward the concept of SRV (modified reservoir volume) based on the study of shale fracture morphology with microseismic, and under some conditions, with the increase of shale fracturing volume, the quantitative calculation method of shale fracturing stimulation effect is proposed. However, due to the great difference of lithology between shale and other rocks, this calculation method is not suitable for other types of rocks; Fisher MK³ et al. Described the morphology of hydraulic fractures in shale formation according to the complexity of fracture morphology, and divided them into four categories: single fracture, complex multi fracture, complex fracture after natural fracture opening and complex network fracture; Kao Jiawei⁴ et al. Studied the complexity of fracturing fractures under different conditions and obtained several hydraulic fracture propagation modes under the condition of high horizontal stress difference and low horizontal stress difference. Fang Haoqing⁵ et al. Simulated the steering and propagation conditions of fracturing fractures underground, and studied the influence of various parameters on rock fracture propagation; Li Chunyue⁶ et al. Proposed several evaluation methods for the transformation effect of reservoir temporary plugging fracturing.

However, none of the above studies involves how to quantitatively evaluate the communication...
between fractures and pores in carbonate reservoirs after fracturing. Therefore, basing on the pressure curve in the fracturing experiment, this paper analyzes the situation that the artificial fractures communicate with the natural fractures and vugs after fracturing.

2. A method of impulse analysis
Impulse is the change of momentum of an object in classical mechanics, which is a process physical quantity. The general calculation method is the product of force and its action time, which can describe the cumulative force effect of a particle in a period of time [4]. Its calculation formula is as follows:

\[ I = \int F \, dt \] (2.1)

I is the symbol of impulse, the unit is F \( \cdot \) s, and dt is the differential of time.

In the physical simulation experiment of fractured rock, the pressure on the pressure curve often drops rapidly in a short time when the fracture communicates, turns or breaks through the natural fracture, and the pressure is released instantly. Combined with the definition of impulse, it is found that the impulse formula can effectively describe this process. It can be seen from the impulse formula that the application of the impulse concept in the analysis of fracturing curve needs to integrate the time region of a certain pressure drop section, while the traditional integration method needs to first fit the curve, and then use the mathematical formula to calculate. The fracturing curve produced by the large-scale true triaxial physical simulation experimental device has the characteristics of small pressure recording scale and short time recording interval. Therefore, basing on the definition of integral, this section calculates the impulse of pressure drop section in fracturing curve according to the following formula:

\[ \int_a^b f(x) \, dx = \lim_{n \to \infty} S_1 + S_2 + \cdots + S_n \] (2.2)

\[ S_n = f(x) \, dx \] (2.3)

\( f(x) \) is the function and \( S \) is the area of a small area with \( dx \) as the scale.

The main interference modes between natural fractures and hydraulic fractures are as follows:

1. Hydraulic fractures propagate directly through natural fractures;
2. Fracturing fluid makes natural fractures expand;
3. When hydraulic fractures meet natural fractures, they propagate along natural fractures [5].

This paper mainly researches the communication effect of fracturing fractures with natural fractures and vugs. Therefore, the impulse corresponding to the fracturing curve line that penetrates natural fracture, turns along natural fracture, communicates with natural fracture, expands natural fracture and communicates with natural hole is defined as effective fracturing impulse.

Calculate the area of all descending segments with negative impulse

\[ S_{down} = P \cdot dT \] (2.4)

\( S_{down} \) is the graphic area of some areas, \( P \) is the average pressure of two data points, and \( dT \) is the time difference between the two data points.

Add \( S_{down} \) to obtain the total impulse value, and then calculate the impulse corresponding to each pressure drop section and its percentage in the total impulse.

\[ I_{acc} = \lim_{n \to \infty} S_{down1} + S_{down2} + \cdots + S_{downn} \] (2.5)

\[ I_{down} = \int_a^b S_{down} \] (2.6)

\( I_{acc} \) is the total impulse and \( I_{down} \) is the impulse of the pressure drop section with \( a \) as the starting
point and b as the ending point.

Analyzed all of the impulses and their corresponding fracturing sections, and then the effective fracturing impulses are obtained. Counted the effective fracturing impulses in the experimental curve and analyzed them, finally the connection between fracture and hole communication and pressure curve is obtained.

3. Physical simulation experiment of carbonate fracturing

In this part, the physical simulation experiment of carbonate rock fracturing is carried out. Many groups of experiments are carried out under different conditions, and the acoustic emission energy analysis method is used to analyze the fracturing results. This paper mainly studies the communication between artificial cracks and natural cracks under different experimental conditions.

![Figure 3.1. Schematic diagram of hydraulic fracturing simulation experimental device.](image)

The following is the parameters of one fracturing experiment:

| Number | Natural fracture density | In-situ stress/MPa | Difference between maximum and minimum in-situ stress/MPa | Delivery capacity | Viscosity/ mPa ∙ s |
|--------|--------------------------|-------------------|----------------------------------------------------------|------------------|-------------------|
| 01     | 9%                       | 20/15/11          | 4                                                        | 10ml/min         | 10                |

The experimental pressure curve and acoustic emission diagram are obtained as follows:
Figure 3.2. Fracture curve and acoustic emission diagram.

Figure 3.3. Sample model diagram after fracturing.

Large fluctuation of acoustic emission signal intensity indicates crack initiation or fracture-cavity communication: strong signal expands the crack matrix, a small amount of weak signal is restarted for natural cracks, and a large number of weak signal accumulation is communicated to the hole. The first pressure drop point in the wellhead pressure curve is the fracture pressure of rock sample, and the sudden drop of wellhead pressure indicates the fracture propagation, while the fracture pressure connecting natural fractures or extending along natural fractures will be lower than the initial fracture pressure.

The experimental rock sample fractures form double wing fractures from the matrix. During fracturing, the fractures on the left connect the natural fractures with a dip angle of 45° from the left side of 3 cm away from the wellbore. The fracture in the right connects the natural fracture with a dip angle of 45° at the right side of 3 cm from the wellbore.

Since then, the fracturing fractures on both sides have expanded along the direction of natural fractures, and the left fractures have expanded along the direction of 45° with the horizontal principal stress, communicating with the natural hole with a diameter of 4 cm at the bottom angle. After entering the hole, the fracture on this side has stopped expanding, and the left fracture expansion range is ~45° ~ 45°. The right fracture also turns along the natural fracture, but due to the left fracture entering the hole, the pressure required for the right fracture expansion is insufficient, so the expansion is stopped, and the right fracture expansion range is ~45° ~30°.

4. Impact quantitative analysis of experimental fracturing results

The experimental results were analyzed by impulse, and the number of natural fractures and natural holes communicated twice in the fracturing process were taken as evaluation indexes, And get the fracture range of both sides of the wellbore.

Table 4.1. Partial fracturing result data.

| The serial number | Communicate the number of natural fractures | Communicate the number of natural holes | Fracture modification range |
|-------------------|--------------------------------------------|----------------------------------------|----------------------------|
| 1                 | 7                                          | 1                                      | 165                        |

Corresponding to the image of the pressure curve and acoustic emission obtained from the test, the calculation to obtain effective fracturing impulse, and will decline period of impulse cracks and holes one-to-one communication mode, all fall period of impulse in the pressure curve data, found that most effective impulse rocks account for 40%, the corresponding rock crack communication mode of impulse of the results as shown in figure,The cracks of the rock crack the corresponding effective fracturing impulse proportion are mainly distributed in between 2% and 7%, through natural cracks of the impulse of generally around 5%, while the communication of natural fracture corresponding impulse accounted at between 17% and 25%, communication natural fracture and expansion and communication natural holes corresponding to the impulse of than is generally lower than 5%.
Figure 4.1. Statistical diagram of effective fracturing impulse ratio and fracture-cavity communication mode.

5. Conclusion
In this paper, the impulse analysis method is established by analyzing the acoustic emission diagram and pressure curve of rock fracturing experiment, the impulse analysis method for fracturing curve was established.
1. The effective impulse of most rocks accounts for 40% of the total impulse
2. The impulse of artificial fracture penetrating natural fracture accounts for about 5%, When the calculation proportion of the same characteristic impulse is about 5%, the curve segment corresponding to the artificial fracture penetrates the natural fracture;
3. The impulse corresponding to natural fractures accounts for 17% - 25%, when the calculated proportion of the same characteristic impulse is within this range, the pressure change section corresponds to the natural fracture;
4. The proportion of impulse corresponding to connecting natural cracks and natural holes is generally less than 5%, when the proportion of impulse calculation is less than 5%, the curve segment corresponds to the natural vug.

References
[1] Mayerhofer M J, Lolon E P, Warpinski N R et al. What is stimulated reservoir volume [J]. SPE Production & Operations, 2010, 25(1): 89–98.
[2] Mayerhofer M J, Lolon E P, Youngblood J E et al. InTEGRATION of microseismic-fracture-mapping results with numerical fracture network production modeling in the Barnett shale [R]. SPE 102103, 2006.
[3] Fisher M K, Wright C A, Davidson B M et al. Integrating fracture mapping technologies to improve stimulations in the Barnett shale [R]. SPE 77411, 2005.
[4] Kao Jiawei, Jin Yan, Fu Weineng, et al. Experimental study on fracture morphology of deep shale under high horizontal stress difference [J]. Journal of rock mechanics and engineering, 2018, 37(6): 1332 – 1339.
[5] Fang Haoqing, Zhao Bing, Wang Wenzhi, etc. Simulation study on the steering technology of targeted fracturing prefabricated fractures in Tahe Oilfield [J]. Petroleum drilling technology, 2019, 47(5): 97-103.
[6] Li Chunyue, Fang Haoqing, Mou Jianye, etc. Experimental study on temporary plugging and steering fracturing in carbonate reservoirs [J]. Petroleum drilling technology, 2020, 48(2): 88-92.
[7] Tong Xiao. Study on shock wave pressure measurement and data processing method in explosion field [D]. Nanjing University of technology, 2015.

[8] Li Wang, Tang Chun'an, Li Lianchong. Numerical simulation study on the interference mechanism of synchronous fracturing in fractured rock mass [J]. *Journal of underground space and engineering*, 2018, 14 (03): 719-728