Research and Application of Segmented Acid Fracturing by Temporary Plugging in Ultradeep Carbonate Reservoirs

Yang Wang,* Yu Fan, Changlin Zhou, Zhifeng Luo, Weihua Chen, Tingting He, Hongming Fang, and Yan Fu

ABSTRACT: The ultradeep carbonate reservoir in Sichuan Basin is characterized by deep burial depth, high temperature, and strong heterogeneity. In the early stage of production, the vertical well acid fracturing is the main reservoir stimulation method, and the horizontal well stimulation technology is not mature enough to release the production capacity of gas wells. Segmented acid fracturing of the ultradeep horizontal wells currently faces the following problems: the strong heterogeneity of reservoir leads to the difficulty of fine segmentation; the high reservoir temperature requires higher performance of working fluid; the reaction rate between acid and rock is fast and the action distance of acid is short, and there is low fracture conductivity under high closure stress. In view of the above problems, the fine segmented design method was studied, and the high-temperature-resistant authigenic acid and gelling acid systems were developed. The viscosity of authigenic acid is greater than 150 mPa s after shearing at 160 °C and 170 s⁻¹ for 50 min, and the highest acid generation concentration is 4.05 mol/L. The gelling acid system has both the properties of high-temperature resistance and low friction resistance; not only can it meet the requirements of the retarding rate and the corrosion inhibition ability when the reservoir temperature is 160 °C but also the resistance reduction rate is up to more than 70%. By alternating injection of authigenic acid and gelling acid, the acid-etched fracture length and conductivity were, respectively, increased by 80% and 45%. The application of this technology in the horizontal well of the ultradeep carbonate reservoir in Sichuan Basin can increase the productivity by 3 times when compared with the vertical well acid fracturing, and a better stimulation effect has been achieved.

1. INTRODUCTION

The ultradeep carbonate reservoir in Sichuan Basin is rich in natural gas resources and has great exploration and development potential. In the early stage of production, the vertical well acid fracturing is the main reservoir stimulation method, the test production after acid fracturing varies greatly, and the average test production per well is only $35 \times 10^4$ m³/d, which cannot meet the needs of high-efficient exploration and development of gas reservoirs. Segmented acid fracturing of horizontal wells is an important way to improve the production of gas wells. At present, segmented acid fracturing of horizontal wells in middle and deep buried gas reservoirs is becoming increasingly mature, mainly including hydrojet segmented acid fracturing, open-hole packer and pressure-controlled sieve tube segmented acid fracturing, open-hole packer and slide sleeve segmented acid fracturing, temporary plugging segmented acid fracturing, and other technologies. The reservoirs in Sichuan Basin are characterized by deep burial (7300–7500 m), high temperature (160 °C), and strong heterogeneity. There are many technical difficulties in segmented acid fracturing technology for ultradeep horizontal. (1) The reservoir heterogeneity is strong and the reservoir permeability and porosity are very different; therefore, there is no effective subsection design method at present. (2) A working fluid that has high-temperature resistance, retarding rate, corrosion inhibition, and low friction resistance is required due to this reservoir’s high temperature (>160 °C) and long pipe string length (7600–8500 m), and conventional gelling acid cannot meet the stimulation requirements of the ultradeep reservoir at present. (3) The acid and the rock react too fast at high temperature, and the effective action distance of the acid liquid is not enough. In the early stage of production, the fracture length provided by the well test is only...
38 m when the gelling acid fracturing technology is used, and the conductivity of the fracture is low under high closure stress, which cannot meet the requirements of stable production in the later stage.  

To improve the stimulation effect of gas wells, the authors put forward the segmentation method for the horizontal well, developed a new type of authigenic acid, and optimized the acid fracturing technology, and this technology has been applied in three wells in Sichuan Basin. The average test production per well is $127 \times 10^4$ m$^3$/d, which is three times higher than that of the acid fracturing in vertical wells.

2. RESULTS AND DISCUSSION

The buried depth of the ultradeep carbonate reservoir in Sichuan Basin is 7300−7500 m and the temperature is more than 160 °C. It is dominated by biological micritic limestone, dolomite, and biological dolomite. The average porosity of the reservoir is 3.6%, the permeability of the reservoir is in the range of 0.001−10 mD, and the reservoir physical parameters of some wells are listed in Table 1. The natural fractures have a significant effect on the reservoir seepage capacity. The reservoir space is mainly composed of intercrystalline pores and intercrystalline dissolved pores (Figure 1). The natural fractures are relatively developed with a fracture density of 1.8−10.9/m. Most of the early structural fractures were fully filled with calcite and asphalt, while the late fractures were unfilled or half-filled. In terms of rock mechanics, the average compressive strength of the reservoir is 504.25 MPa, the average Young’s modulus of the reservoir is $6.46 \times 10^4$ MPa, and the average Poisson’s ratio of the reservoir is 0.28. A high Young’s modulus leads to a narrow width and a large surface-to-volume ratio of the fractures, which further aggravates the acid rock reaction rate and seriously affects the length of acid-etched fractures.

2.1. Fine Segmentation Method for Horizontal Well.

The horizontal well in the ultradeep carbonate reservoir in Sichuan Basin is characterized by strong heterogeneity and a large difference in porosity and permeability. For heterogeneous carbonate reservoir, it is difficult to optimize the fracture spacing and the scheme of segmented acid fracturing in horizontal wells. At present, the main method for horizontal well segmentation in carbonate gas reservoir is to use a three-dimensional seismic profile and fracture-cavity carving to predict the spatial relationship between fracture-cavity and well trajectory and to carry out the segmented scheme design with the goal of communicating fracture-cavity. There are some limitations in the application of the above method in horizontal wells in the ultradeep carbonate reservoir in Sichuan Basin. The reservoir belongs to the fracture-pore type, and there is no large-scale fracture-cave reservoir. According to the reservoir porosity, permeability, gas saturation, and other physical parameters in Sichuan Basin, we use Eclipse to

| well     | depth of occurrence (m) | formation pressure (MPa) | reservoir porosity (%) | average permeability (mD) | reservoir temperature (°C) | rock composition         |
|----------|-------------------------|--------------------------|------------------------|---------------------------|----------------------------|--------------------------|
| SY001-X8 | 7500                    | 95.55                    | 3.3                    | 0.32                      | 163                        | grayish brown dolomite   |
| ST8      | 7437.4                  | 96.15                    | 3.6                    | 0.41                      | 159.73                     | light brown gray dolomite|
| ST3      | 7396.8                  | 95.32                    | 3.9                    | 0.67                      | 157.55                     | gray dolomite            |

Figure 1. SEM scanning of well ST8 cores.
establish the numerical simulation model of segmented acid fracturing horizontal wells in carbonate gas reservoirs (Figure 2). The relevant parameters selected in the model are shown in Table 2. At the same time, we use the model to fit the production history of the previous production data, and the fitting effect is good (Figure 3). This shows that the model can be used to guide the design of the segmented acid fracturing scheme for horizontal wells in Sichuan Basin.

![](image)

**Figure 2.** Numerical simulation model of segmented-fracturing horizontal wells.

**Table 2. Numerical Simulation Model Parameters**

| Parameter                          | Value       |
|------------------------------------|-------------|
| grid side length (m)               | 2           |
| model i-axis length (m)            | 1200        |
| model j-axis length (m)            | 400         |
| model k-axis length (m)            | 60          |
| reservoir porosity (%)             | 3.8         |
| reservoir permeability (mD)        | 0.5         |
| gas saturation (%)                 | 60          |
| fracture conductivity (D cm)       | 10          |
| half length of artificial fracture (m) | 50      |
| formation pressure (MPa)           | 96          |
| reservoir temperature (°C)         | 160         |
| rock compressibility               | 4×10⁻⁷      |

It can be seen from Figure 4 that with the decrease of fracture spacing, the gas production of horizontal wells after segmented fracturing increases significantly. When the fracture spacing is shortened to 130–160 m, the increase of gas production of fractured wells does not become obvious. Therefore, the optimal fracture spacing of horizontal wells in Sichuan Basin is 130–160 m.

**2.2. Temporary Plugging Segmented Fracturing Technology.** The hole size of ultradep wells in Sichuan Basin is generally small, and for those wells with reservoir vertical depth more than 7000 m, the hole size is usually only 127 mm. In the early stage of production, some wells were completed by open hole packers in sections. In the process of running open hole packers, there were some accidents such as blocking and setting in advance, which seriously affected the operation time. Temporary plugging and segmented acid fracturing is a new efficient stimulation method. Its technical principle is to inject a temporary plugging material to block the fracture after fracturing a fracture, increase the bottom hole pressure, and force the subsequent acid hydraulic to open another fracture so as to achieve the purpose of segmented fracturing.

The reservoir in Sichuan Basin is highly heterogeneous, and the rupture pressure at each point on the horizontal section is very different. Therefore, it requires high plugging performance of the temporary plugging agent, and a plugging layer with a strength of more than 15 MPa can realize the secondary diversion of acid solution. At present, the plugging pressure of temporary plugging materials commonly used is only 5–10 MPa, which is difficult to meet the requirements of segmented acid fracturing of horizontal wells in Sichuan Basin.

Fiber and granule are common temporary plugging materials. In this paper, we use a three-dimensional fracture sealing ability tester to evaluate the bearing capacity of the sealing layer formed by a single material and a composite material. We place the fibers and particles in clean water in a certain proportion, use a precision pressure pump to displace the temporary plugging material into the simulated fracture at a constant speed, and observe the change of displacement pressure after the temporary plugging material enters the simulated fracture.

It can be seen from Figure 5 that the plugging ability of fiber to acid fracturing fracture is very poor. We use fiber with a solution concentration of 0.5–1.5% to conduct plugging experiments for fracture with a width of 4 mm, and the maximum plugging pressure is only 3.8 MPa. Such low plugging pressure cannot effectively plug fracture.

It can be seen from Figure 6 that the plugging ability of 100 mesh granules to acid fracturing fracture is also poor. Compared with the fiber temporary plugging agent, the sealing pressure of 100 mesh granules is higher than that of fiber, and the maximum plugging pressure is increased to 5.7 MPa, which still cannot meet the requirements of Sichuan Basin segmented fracturing.
The sealing pressure of 10/40 mesh granules to the fracture with a 4 mm width can reach 9.2 MPa (Figure 7), and the sealing effect is obviously better than that of fiber and 100 mesh granules, but the sealing pressure is still unable to reach the target of more than 15 MPa. We consider using the combination of fiber and particle to carry out the sealing experiment to judge whether it can achieve the sealing target.

It can be seen from Figure 8 that after adding 10/40 mesh granules into 100 mesh granules, the pressure-bearing capacity of the plugging layer is significantly improved; especially, when the solution concentration of 10/40 mesh granules is increased to 1.5%, the pressure-bearing capacity of the plugging layer can be increased to 13.9 MPa. We consider adding fiber into the temporary plugging granules to further enhance the pressure-bearing capacity of the plugging layer. The granules quickly accumulate in the fracture to form a plugging layer, and the fiber fills the gap between granules of different sizes so that the plugging layer is very dense.

Figure 4. Comparison of cumulative gas production by segmented fracturing in horizontal wells with different fracture spacings.

Figure 5. Comparison of the sealing ability of fiber to fracture.

Figure 6. Comparison of the sealing ability of 100 mesh granules to fracture.
It can be seen from Figure 9 that after adding fiber into 100 and 10/40 mesh granules, the pressure-bearing capacity of the plugging layer is increased from 13.9 to 20 MPa. At the same time, the fiber and granules form long dense slugs in the fracture (Figure 10). The results show that 1% fiber + 0.5% 100 mesh granules + 0.5% 10/40 mesh granules can meet the requirements of segmented fracturing for horizontal wells in Sichuan Basin.

2.3. High-Temperature-Resistant and High-Performance Stimulation Working Fluid. The temperature of the ultradeep carbonate reservoir in Sichuan Basin is as high as 160 °C, and the reaction rate between acid and rock is accelerated under high temperature, which leads to a greatly shortened action distance of the working fluid. Meanwhile, the burial depth of the reservoir is up to 7300−7500 m, and the acid friction caused by the long pipe string is large, which seriously affects the acid fracturing effect. In view of the problems of fast reaction rate between acid and rock, large friction of conventional acid, and the difficulty in the lifting of displacement in the ultradeep and high-temperature reservoirs, high-temperature-resistant authigenic acid and gelling acid systems were formed after research, which can meet the acid fracturing stimulation requirements of the ultradeep carbonate reservoir in Sichuan Basin.

Authigenic acid is an acid system that uses the parent acid to produce active acid in situ through chemical reaction under formation conditions. It can not only avoid the rapid reaction of acid at high temperature but also slow down the corrosion of acid to the downhole pipe string. This paper developed high-temperature-resistant authigenic acid using the principle that organic esters can be hydrolyzed in water to form acids, and an authigenic acid thickener with hyperbranched fraction structure was synthesized. With the aid of the acid produced by organic ester hydrolysis, the rock is dissolved, and the fracture conductivity is improved. At the same time, using zirconia chloride, citric acid, diethanolamine, glycerol, polyhydroxyalcoholamine, and other materials as the main raw materials, a citric acid polyhydroxyalcoholamine organic zirconium cross-linking agent was synthesized. The viscosity of authigenic acid can be higher than 150 mPa s after shearing for 60 min at 160 °C and 170 s⁻¹, and the highest acid generation concentration is 4.05 mol/L. The formula of autogenous acid is 0.5% thickener + 2.0% drainage aid + 10% acid generator + 1.0% clay stabilizer + 0.6% cross-linking agent. The acid basically generates acid below 120 °C and gradually generates acid above 120 °C, and the reaction rate is a quarter of the reaction rate of conventional gelling acid. Meanwhile, authigenic acid forms deep etched grooves on the rock wall surface that can avoid fracture closure failure caused by the increase of the pressure difference in production (Figure 11).

Conventional gelling acid thickener is mainly composed of linear polymers, which affect the viscosity and friction properties of the gelling acid due to intramolecular repulsion resulting in loose and irregular clusters. This study adopts the cationic monomer methyl acryloyl oxygen ethyl trimethyl ammonium chloride as the main monomer, which significantly improves the high-temperature resistance performance of the molecular main chain. We add a small amount of an acrylate-type chain extender and replace the acrylamide in the molecular structure. While increasing the temperature and the number of acid-resistant groups, multiple series of cationic homopolymer units make it easier to intertwine between polymer molecules to improve the heat-resistant performance of acid, and the thickener macromolecules can inhibit the displacement of the barium of the acid.
vortex of energy dissipation and greatly reduce the friction in the process of the acid system in pump injection. The formula of gelling acid is 20% HCl + 3.0% high-temperature corrosion inhibitor + 1.0% high-temperature corrosion inhibitor synergist + 2.5% gelling agent + 1.0% iron ion stabilizer + 1.0% drainage aid + 1.0% clay stabilizer, and the viscosity of the formed gelling acid is 24−30 mPa s after shearing for 60 min at 160 °C and 170 s⁻¹. The order of the magnitude of the reaction rate between the acid and rock can be controlled in the range of 10⁻⁴ to 10⁻⁵. The resistance reduction rate of the high-temperature-resistant gelling acid measured in the laboratory can reach more than 70%, and the acid fracturing displacement can be increased to more than 8 m³/min.

2.4. Deep Penetration and High Conductivity Acid Fracturing Technology. In the early stage of production, gelling acid fracturing is the main stimulation technology of the ultradeep carbonate reservoir in Sichuan Basin. After fracturing, the fracture length provided by the well test is about 38 m, and the average gas production per well is only 30 × 10⁴ m³/day, which is far from reaching the high-yield target. We use the fingering effect achieved by alternating injection of two liquids with different viscosities, and this can reduce the liquid filtration to improve the efficiency of acid, form nonuniform etching grooves on the fracture wall surface, and increase the fracture length and the conductivity.²⁶

In this paper, according to the actual size of the acid-etched fracture, a three-dimensional fracture model with a length of 100 m, height of 60 m, and width of 0.008 m is established. The fingering effect of different-viscosity liquids is simulated using CFD simulation software. At the same time, the corrosion morphology of the fracture wall under different acid injection rates is analyzed using an acid-etched fracture conductivity test device. The deep penetration and high conductivity acid fracturing technology suitable for ultradeep carbonate reservoirs in Sichuan Basin has been developed.

As shown in Figures 12 and 13, with the increase of the viscosity ratio between the injection liquids, the acid breakthrough coefficient and the coefficient of variation gradually increase, and the liquid differentiation fingering phenomenon increases. When the viscosity ratio between the injection liquids is greater than 8, the advance of the liquid front tends to be stable, the acid breakthrough coefficient and the coefficient of variation decrease rapidly, and the fingering phenomenon is weakened accordingly. When the viscosity ratio between authigenic acid and gelling acid is greater than 8, the effect of the fingering phenomenon is ideal, which is beneficial to improve the length and the conductivity of the acid-etched fracture.

As shown in Figures 14 and 15, it is difficult to achieve the fingering effect when the injection displacement of acid is 3 m³/min, the gelling acid forms uniform etching on the fracture wall, which results in excessive consumption of the gelling acid near the wellbore and reduces the action distance of the acid. When the injection displacement of the acid is 6 m³/min, authigenic acid and gelling acid give rise to a differentiation fingering phenomenon, and the gelling acid forms banded etching grooves on the fracture wall surface, which reduces acid consumption near the wellbore and improves the etched fracture length and flow conductivity. In the field application of acid fracturing, the injection rate should be increased as much as possible under the condition of the limited pressure of the wellhead to improve the differential acid etching effect.

Figure 9. Comparison of the fracture sealing ability of granules and fiber combination.

Figure 10. Distribution of temporary plugging materials in simulated fracture.
2.5. Field Application. For well SY001-X8 located in Guangyuan (Sichuan province, China), the drilling finished well depth is 8300 m, the horizontal section length is 785 m, the bottom hole temperature is 163 °C, the average reservoir porosity is 3.3%, and the average permeability is 0.32 mD. In the early stage of production, gelling acid fracturing was used in adjacent wells, and the gas production was small after acid fracturing. In February 2021, stimulation of segmented acid fracturing by temporary plugging in well SY001-X8 was completed. During the stimulation, 420 m³ of authigenic acid and 1480 m³ of gelling acid were injected into the formation, with the maximum injection capacity of 8.1 m³/min (Figure 16). At the same time, the temporary plugging agent is added three times for segmented acid fracturing, and the wellhead pressure rises by 15−20 MPa after the temporary plugging agent enters the formation, which shows that a good segmented effect of temporary plugging is achieved. Compared with those of conventional acid fracturing, the length and the conductivity of acid-etched fracture fitting after fracturing are, respectively, increased by 80% and 45%. The test daily gas production is 175 × 10⁴ m³/d, which is 2−3 times higher than the test daily gas production of the adjacent wells. The production of well SY001-X8 has been stable for more than 6 months, and there has been no formation damage caused by the temporary plugging agent during production.

3. CONCLUSIONS

(i) Authigenic acid has the characteristic of gradually producing acid at the reservoir’s temperature, and the highest acid generation concentration is 4.05 mol/L, which can effectively etch the front end of the fracture. Meanwhile, gelling acid has the characteristics of high-temperature resistance and low friction resistance, which can be used for acid fracturing of the ultradeep carbonate reservoirs in Sichuan Basin.
Figure 14. Corrosion morphology of the fracture wall when the acid injection rate is 3 m$^3$/min.

Figure 15. Corrosion morphology of the fracture wall when the acid injection rate is 6 m$^3$/min.
The combination of fiber with different particle sizes and particles forms a tight sealing layer, and the temporary plugging agent with the formula of 1% fiber + 0.5% 100 mesh granules + 0.5% 10/40 mesh granules can achieve a maximum sealing pressure of 20 MPa, which can be used for ultradepth horizontal wells in Sichuan Basin.

Alternate injection of authigenic acid and gelling acid can greatly improve the conductivity and the length of acid-etched fractures, and the field application effect is good.

AUTHOR INFORMATION

Corresponding Author
Yang Wang — Engineering Technology Research Institute of Southwest Oil & Gas Field Company, PetroChina, Chengdu 610017, China; orcid.org/0000-0001-9074-1758; Email: wangyang0996@petrochina.com.cn

Authors
Yu Fan — Engineering Technology Research Institute of Southwest Oil & Gas Field Company, PetroChina, Chengdu 610017, China
Changlin Zhou — Engineering Technology Research Institute of Southwest Oil & Gas Field Company, PetroChina, Chengdu 610017, China
Zhieng Luo — State Key Laboratory of Oil and Gas Reservoir Geology and Exploitation, Southwest Petroleum University, Chengdu 610500, China
Weihua Chen — Engineering Technology Research Institute of Southwest Oil & Gas Field Company, PetroChina, Chengdu 610017, China
Tingting He — Engineering Technology Research Institute of Southwest Oil & Gas Field Company, PetroChina, Chengdu 610017, China
Hongming Fang — Engineering Technology Research Institute of Southwest Oil & Gas Field Company, PetroChina, Chengdu 610017, China

Notes
The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This work was financially supported by the project of the PetroChina Southwest Oil and Gas Field Company (grant nos. 20200302-14 and 20210302-19).

REFERENCES

(1) Liu, Z.; Guo, J.-C.; Ma, H.-Y.; Zhou, C.-L.; Gou, B.; Ren, J.-C. Simulation study of the approach to enhance acid penetration distance in high temperature gas well: Case study of Qixa Formation, western Sichuan Basin. Nat. Gas Geosci. 2019, 130, 1694—1700.
(2) Wang, Y.; Zhou, C.; Yi, X.; Li, L.; Chen, W.; Han, X. Technology and Application of Segmented Temporary Plugging Acid Fracturing in Highly Deviated Wells in Ultradeep Carbonate Reservoirs in Southwest China. ACS Omega 2020, 39, 25009—25015.
(3) Chen, Z.; Wang, Z.; Zeng, H. Status quo and prospect of segmented fracturing technique in horizontal wells. Nat. Gas Ind. 2007, 27, 78—80.
(4) Zhang, H.; He, Y.; Liu, J.; Zhang, H. Current conditions and development trend of foreign phased fracturing technology for horizontal well. Oil Forum 2012, 31, 47—52.
(5) Li, G.; Sheng, M.; Tian, S.; Huang, Z.; Li, Y.; Yuan, X. Multistage hydraulic jet acid fracturing technique for horizontal wells. Pet. Explor. Dev. 2012, 39, 100—104.
(6) Mu, D.; Jia, W.; Yao, Y.; Yang, C.; Wang, C.; Jia, J. Study on the Integration of Gelled Acid and Crosslinked Acid to Form High Temperature Retarded Acid. Drill. Fluid Compl. Fluid 2019, 36, 634—638.
(7) Li, D.; Yi, X.; Wang, Y.; Li, Q.; Liu, H. Research situation of the new acid fracturing acid system applying to deep carbonate reservoir. Petrochem. Ind. Appl. 2017, 36, 7—11.
(8) Wang, Y.; Zhou, C.; Yi, X.; Li, L.; Zhou, J.; Han, X.; Gao, Y. Research and Evaluation of a New Autogenic Acid System Suitable for Acid Fracturing of a High-Temperature Reservoir. ACS Omega 2020, 33, 20734−20738.

(9) Pournik, M.; Nasr-el-din, H. Effect of acid spending on etching and acid fracture conductivity. SPE Prod. Oper. 2013, 28, 46−54.

(10) Ye, J. W.; Yang, J.; Geng, S. Y.; Li, Y. Development and evaluation of a new type of self-generated acid fracturing fluid. Petrochem. Ind. Appl. 2019, 9, 8−13.

(11) Antelo, L. F.; Zhu, D.; Hill, A. D. Surface Characterization and Its Effect on Fracture Conductivity in Acid Fracturing. In Paper Presented at the SPE Hydraulic Fracturing Technology Conference, Paper SPE 119743 MS, The Woodlands, Texas, Jan 19, 2009.

(12) Rodrigues, V. F.; Campos, W.; Medeiros, A. C.; Victor, R. A. Acid-Fracture Conductivity Correlations for a Specific Lime-stone Based on Surface Characterization. In Paper Presented at the SPE Annual Technical Conference and Exhibition, Paper SPE 145298 MS, Denver, Colorado, USA, Oct 30, 2011.

(13) Jiang, T.; Zhou, J.; Jia, W.; Zhou, L. Deep penetration acid fracturing technology for ultra-deep carbonate oil & gas reservoirs in the Shunbei oil and gas field. Pet. Drill. Tech. 2019, 47, 140−147.

(14) Gou, B.; Zhan, L.; Guo, J. C.; Zhang, R.; Zhou, C. L.; Wu, L.; Ye, J. X.; Zeng, J. Effect of different types of stimulation fluids on fracture propagation behavior in naturally fractured carbonate rock through CT scan. J. Pet. Sci. Eng. 2021, 201, 108529.

(15) Yue, J.; Duan, Y.; Chen, W.; Wang, S.; Liu, Q. Study on productivity performances of horizontal fractured gas well with many vertical fractures. Pet. Geol. Oilfield Dev. Daqing 2004, 23, 46−48.

(16) Gou, B.; Wang, C.; Yu, T.; Wang, K. J. Fuzzy logic and grey clustering analysis hybrid intelligence model applied to candidate-well selection for hydraulic fracturing in hydrocarbon reservoir. Arabian J. Geosci. 2020, 13 (975), 1−13.

(17) Liu, H.; Yuan, X.-F.; Guo, W.; Liu, J.; Liu, J.-Y.; Zhang, H. Practice of Stage Acid F Frac in Cased Horizontal Well in Ultradeep Carbonate Reservoir. Drill. Prod. Technol. 2016, 36, 33−35.

(18) Gou, B.; Guo, J. C.; Yu, T. Modeling of quantifying proppants for stimulation reservoir volume fracturing in a shale hydrocarbon reservoir. Journal of Geophysics and Engineering 2018, 15 (5), 2297−2309.

(19) Solares, J. R.; Al-Harbi, M.; Al-Sagr, A. M. In Successful Application of Innovative Fiber-Diverting Technology Achieved Effective Diversion in Acid Stimulation Treatments in Saudi Arabiandep Gas Producers. In Paper Presented at the SPE Asia Pacific Oil and Gas Conference and Exhibition, Paper SPE-115528-MS, Perth, Australia, Oct 20−22, 2008.

(20) Cohen, C. E.; Tardy, P. M. J.; Lesko, T. M. Understanding Diversion with a Novel Fiber-Laden Acid System for Matrix Acidizing of Carbonate Formations. In Paper Presented at the SPE Annual Technical Conference and Exhibition, Paper SPE-134495-MS, Florence, Italy, Sept 19−22, 2010.

(21) Gou, B.; Zeng, M.; Wang, K.; Li, X.; Guo, J. Effect of fiber on the rheological properties of gelled acid. J. Pet. Explor. Prod. Technol. 2021, 11, 2207−2215.

(22) Zhou, F.; Yi, X.; Yang, X.; Liu, X.; Wang, D. Dynamic Filtration Experiment of Fiber Temporary Plugging Artificial Fracture. Drill. Prod. Technol. 2014, 83−85.

(23) Hou, F.; Xu, Y. Y.; Zhang, A.; Lu, J. Research and application of self-generated acid deep penetration acid pressure technology for ultra-deep high temperature carbonate rock. Drill. Prod. Technol. 2018, 41, 35−37.

(24) Wang, Y.; Yuan, Q.; Li, L. I. Deep Penetrating Acid Fracturing Involving Self-Generated Acid in Carbonate Reservoirs of the Tahe Oilfield. Pet. Drill. Technol. 2016, 5, 90−93.

(25) Gou, B.; Guan, C. C.; Li, X.; Ren, J. C.; Zeng, J.; Wu, L.; Guo, J. C. Acid-etching fracture morphology and conductivity for alternate stages of self-generating acid and gelled acid during acid-fracturing. J. Pet. Sci. Eng. 2021, 200, 108558.

(26) Zhan, L.; Zhou, F.; Mou, J.; Xu, G.; Zhang, S.; Li, Z. A new method to improve long-term fracture conductivity in acid fracturing under high closure stress. J. Pet. Sci. Eng. 2018, 171, 760−770.