Study and Application of Novel Cellulose Fracturing Fluid in Ordos Basin

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Abstract. Due to low gas saturation, less than 10% porosity, around 0.05 mD permeability and below 0.85 pressure coefficient, stimulation treatments are necessary in order to get economic production. Development speed of this block had been seriously affected because of significantly lower single well production than other parts of the Sulige Gas Field. Low concentration crossed-linked guar fracturing fluid is now commonly used in this area. As small size pore throat, high clay content and water lock, this gas deposit is sensitive to treatment fluid, thus the flowback time of fractured well is very long and production is generally low. In this paper we introduce a new fracturing fluid which can be crossed-linked in acidic water-based fluids. This fluid contains a kind of cellulose, which is completely soluble with no residue. Cellulose was used as additive agent in drilling and completion fluid twenty years ago, therefore, its application was greatly limited as poor stability of performance. New cross-linked agent and additives could solve this problem. Because of being compatible well with the reservoir fluids, the damage of fracturing fluid is relatively low. Proppant carrying capacity of this new fluid can be compared with low concentration crossed-linked guar fracturing fluid. The new fluid has been used in 6 vertical wells, with 100% treatment success-rate and 8.6×10^4 m^3/d average production rate. Compared with the nearby wells which had the same pay formation and were fractured with the similar fracture treatment scale by low concentration guar fracturing fluid, the flowback time was shortened by 53% and gas production was doubled. In conclusion, this new fracture fluid can reduce treatment time and cost, but increase gas production.

1. Introduction
The Sulige East II Block, with an area of 1945 km^2 and proven reserves of 207 billion m^3, is located in the northern part of the Eastern Sulige Gas Field. This block belongs to typical tight sandstone gas reservoirs with low porosity, low permeability and low pressure [1] [2]. Compared with the Sulige Central and Sulige South Blocks, it has larger reservoir heterogeneity, smaller effective sand body scale, lower pressure coefficient (about 0.85), higher shale content of reservoir, finer pore throats, generally longer flowback cycle after fracturing and lower individual well production. In addition, its reservoir is more sensitive to fracturing fluid [3], where sandstone is obviously interbeded with...
mudstone. Based on the reservoir features of the Sulige East Block, this study deals with a new type of fracturing fluid with low damage. It has shown good stimulation performance in the Sulige East Block. The main pore type is intergranular dissolved pore (88%), followed by kaolinite intercrystalline pore (10%), and intragranular dissolved pore (2%). The results of core laboratory analysis also indicate that the pore throat radius of the reservoirs in this block is small and the pore volume controlled by the pore throat with radius of less than 0.1µm accounts for more than 70% of total pore volume. The petro-physical analysis of coring data indicates that the samples with conventional permeability of less than 0.1mD account for 80% of total samples. The mean value of permeability cumulative probability is one order of magnitude smaller than that of the Sulige Central and Sulige East Blocks (Fig.1). In addition, the reservoir samples with overburden pressure permeability of less than 0.1mD account for 87.2%, representing typical tight reservoirs. Another typical feature of the reservoirs in this block is low pressure coefficient. Statistical comparison and analysis indicate that, compared with the large tight sandstone gas reservoirs in China and abroad, the fluid pressure coefficient of the Sulige East II Block is about 40% lower than that of average value (Fig.2); the reservoirs is at normal temperature, with gradient of 2.95°C/100m.

Fig. 1 Conventional permeability distribution of Sulige East II Block, Sulige East Block and Sulige Central

Fig. 2 Pressure coefficient comparison of tight sandstone gas reservoirs in China and abroad

In summary, the tight sandstone reservoir in the Sulige East II Block has high clay content, where the clay particles within intergranular pores and around pore throats can easily expand, migrate and block pore throats, resulting in reservoir damage. Moreover, the reservoirs are prone to be damaged by fracturing fluid due to their poor petro-physical properties, low pressure coefficient, small pore throat radius and large displacement pressure.

1.1. Fracturing fluid analysis
Formation damage refers to the permeability decrease when formation fluid and/or solid intrudes into near-bore sections (sometimes it may extend to a certain distance from wellbore). Permeability decrease will constrain the channel flow in any types of reservoir rocks and reduce or stop oil and gas from flowing into wellbore. It may occur in all exploitation stages of underground oil and gas
reservoirs and are unavoidable. Formation damage can usually be divided into natural damage and induced damage according to its generation mechanism. Natural damage refers to the first damage when hydrocarbon liquid is produced. Induced damage is caused by external operations when well operations are conducted, such as well drilling, well completion, well workover, stimulation and water injection. Moreover, some well completion operations, induced damage and design problem may lead to natural damage. Natural damage includes: (1) fines migration; (2) expanded clay; (3) scale; (4) organic sediments, such as paraffin or asphalt; (5) mixed organic or inorganic sediments; and (6) emulsion matter. Induced damage includes: (1) blockup resulted from the solids or aggregates within injected liquids entering into particles; (2) wettability change resulted from injected liquid or oil-based drilling fluid; (3) acid reaction; (4) acid byproduct; (5) iron precipitate; (6) iron catalyst; (7) bacteria; and (8) incompatibility of fluid liquids.

In summary, the invasion of external fluids will cause severe damage to reservoir. Therefore, more efforts should be made in the study on the compatibility between external fluid and reservoir. Moreover, the soaking time of reservoir in external fluid should be minimized. Specifically, it is to shorten the time interval between perforation and operation and reduce the number of well killing, in order to speed up the flowback of external fluid through nitrogen containing liquid or foam liquid.

At present, conventional low concentration guar gum fracturing fluid is predominantly used in the block, which has been proved successful in the Sulige South and Sulige Central Blocks due to its low cost and fast preparation rate. However, since the reservoir features of the Sulige East II Block are significantly different, the fracturing fluid technology needs to be further improved.

Based on the analysis on the advantages and disadvantages of fracturing fluids commonly used in this block, a new type of non-residue, low damage cellulose fracturing fluid is developed. It uses a type of plant cellulose as gelling agent and improves the dissolution efficiency of cellulose gelling agent through modification technology. Furthermore, it introduces a substituent to make this plant cellulose generate etherification reaction, in order to improve its hydrophilicity and enhance its dissolving capacity. On this basis, a new FAC-201 crosslinking agent is developed. It has strong proppant carrying capacity and can ensure the success of construction since it is compatible with the base fluid of cellulose fracturing fluid system and can form the gel with good elasticity after crosslinking. In addition, the foaming agent and highly efficient cleanup agent, which are compatible with this fracturing fluid system and reservoir fluid, are developed depending on reservoir features.

1.2. Formula of cellulose fracturing fluid

Formula: 0.35%FAG-500 (gelling agent)+0.2%FAZ-1 (thickening agent)+0.3%DL-16 (cleanup agent)+0.5%FL-90 (foaming agent)+1%FAJ-305 crosslinking conditioning agent (conditioning agent); crosslinking agent: FAC-201 crosslinking agent; crosslinking ratio: 100: 0.5. The concentration of FAG-500 gelling agent is 0.3-0.4%, corresponding to base fluid viscosity of 20-50mPa·S; the PH of base fluid is 4.5-5.5.

The fracturing fluid is prepared in laboratory according to the formula of cellulose fracturing fluid system mentioned above. According to SY/T 5107-2005 “Water-based fracturing fluid performance test method”, using the RS6000 rheometer, the temperature/shear resistance performance test is conducted for fracturing fluid (Fig.3). The results indicate that the fracturing fluid formula has good temperature/shear resistance and rheological performance and can meet the needs for (fracturing treatments) use.
Fig. 3 Temperature/shear resistance performance at 120°C after adding gel breaker

Fig. 4 Laboratory gel breaking liquid and well site flowback liquid

Table 1. On-site implementation comparison of fracturing fluids

| Fracturing fluid types | Well          | Horizon | Sand volume (m³) | Liquid volume (m³) | Operating displacement (m³/min) | Proppant concentration (%) | Open flow capacity (10⁴m³/d) | Flowback cycle time (h) |
|------------------------|---------------|---------|------------------|-------------------|---------------------------------|----------------------------|-----------------------------|------------------------|
| Cellulose fracturing fluid | Sudog 022-A   | Shan1   | 42.8             | 356               | 3.4-3.5                         | 20.3                       | 2.9                         | 36                     |
| Low concentration fracturing fluid | Sudog 020-B |          | 35.0             | 323               | 2.8-3.1                         | 21.6                       | 1.2                         | 150                    |
| Cellulose fracturing fluid | Sudog 014-A   | He7, He8, Shan1 | 96.5             | 772               | 3.0-3.5                         | 20.1                       | 10.4                        | 8                      |
| Low concentration fracturing fluid | Sudog 014-B | He6, He7, He8 | 79.6             | 705               | 2.1-3.8                         | 19.5                       | 4.2                         | 26                     |
| Cellulose fracturing fluid | Sudog 02-A    | He6, He7, He8 | 90.0             | 713               | 2.3-2.8                         | 21.2                       | 3.4                         | 23                     |
| Low concentration fracturing fluid | Sudog 02-B  |         | 85.6             | 617               | 3.0-3.5                         | 23.6                       | 2.3                         | 47                     |
Fig. 5 Comparison between the operations of cellulose fractured wells and their neighboring wells

Laboratory test results indicate that the subsidence rate of cellulose fracturing fluid is low, which is almost unchanged before and after heating (90 ℃), indicating that fracturing fluid has good proppant-carrying capacity.

The static filtration performance of cellulose fracturing fluid is tested using US Bariod high pressure and high temperature static filtration device. The results show that the fluid loss performance of this fracturing fluid is almost the same with that of low concentration fracturing fluid and carboxymethyl fracturing fluid. Thus, the fluid loss control measures can be selected according to field conditions [8] [9].

If 0.2-0.5/ten thousand of gel breaker is added, the cellulose fracturing fluid can achieve gel breaking in 2 hours, indicating good gel breaking performance. If more gel breaker is added appropriately, gel breaking can be achieved quickly and thoroughly and formation damage will be reduced. The flowback liquid obtained from well site after fracturing in one hour can also prove that cellulose fracturing fluid can achieve gel breaking thoroughly, which is very conducive to flowback after fracturing and enhance fracturing effect [10] [11].

In accordance with the evaluation criteria for water-based fracturing fluid, the interior damage evaluation of cellulose fracturing fluid is conducted. Cores are sampled from the reservoirs of the Sulige East II Block and cellulose fracturing fluids are allocated using 0.35% gelling agent, based on which, the core damage at normal temperature and 70 ℃ is evaluated. Moreover, low concentration conventional guar gum (0.30% powders) is selected in order to evaluate the core damage at the temperature below 70 ℃. The results show that the cellulose fracturing fluid has light damage on reservoir, which is significantly smaller than that of low concentration guar gum.

1.3. On-site implementation
Based on laboratory research and development, cellulose fracturing fluid system is used in the fracturing of 6 wells in Sulige East II Block. In order to compare and analyze the effects of fracturing fluid of this type and other types, low concentration guar gum fracturing fluid is used in three neighboring wells for fracturing. All the wells have same fracturing horizon and similar fracturing scale (table1).

By strengthening the supervision of liquid allocation and quality control on well site, the operation success rate of the six cellulose fractured wells reach 100%. The average open flow capacity of the six cellulose fractured wells is $8.6 \times 10^4 \text{m}^3/\text{d}$, 95.6% higher than the average value of this block and 117% higher than the average value of the three neighboring wells, which are fractured by low concentration guar gum, indicating predominant stimulation effect. The flowback cycle of the six cellulose fractured wells shortens by 50%, which has significantly reduced labor intensity on well site and saved
operation cost. It is also proved that this fracturing system can break gel completely and flow back easily. In addition, its secondary pollution on reservoir and the proppant within fracture is slight. The operation curves indicate the fracturing fluid has low friction, about 25% lower than that of low concentration guar gum fracturing fluid (Fig 5), which is helpful for reducing fracturing pressure and risk.

2. Conclusion
(1) New fracturing fluid technology is required in order to effectively promote the exploration and development of the Sulige East II Block, where physical properties are poor, pressure coefficient is low and reservoirs are sensitive to fracturing fluid.

(2) New cellulose fracturing fluid has stable performance and good proppant carrying capacity, which is well compactable with formation fluid after acidic crosslinking. Its gelout time is controllable and it has no residue after gel breaking. This could significantly reduce secondary pollution on reservoir. Moreover, its cost is low and its preparation time is short, which can meet the online compounding operations of large-scale.

(3) The new cellulose fracturing fluid is tested in the Sulige East II Block and obvious stimulation effect has been achieved. The open flow capacity increases over one time after fracturing, showing obvious economic value. The new cellulose fracturing fluid shows a good prospect for tight gas reservoir fracturing.

References
[1] Ran Xinquann, Li Anqi, Sulige gas field development [M] Beijing: Petroleum Industry of society, 2008: 15-17.
[2] Yang Hua, Xi Shengli, Wei Xinshan, et al., Gas exploration potential analysis of Sulige region. [J]. Natural Gas Industry, 2006, 26 (12): 45-48.
[3] Kuuskraa VA, Ammer J. Tight gas sands development: How to dramatically improve recovery efficiency [J]. Gas TIPS, 2004 (Winter): 15-20.
[4] Lei Bianjun, Liu Bin, Li Shilin, et al., Tight sandstone diagenesis and its effect on reservoir [J] Southwest Petroleum University: Natural Science, 2008,30 (6): 57-62.
[5] National Energy Board. SY / T 6832-2011 Oil and gas industry standards of People's Republic of China: tight sandstone gas geological evaluation method [S] Beijing: Petroleum Industry Press, 2011.
[6] Tong Xiaoguang, Huang Fuxi. Comparative study on the similarities and differences between the distribution of the tight sandstone gas reservoirs of China and America and its significance [J]. China Engineering Science, 2012, 14 (6): 9-15.
[7] Holditch S A. Tight gas sands [R]. SPE103356, 2006.
[8] Kang Yili, Luo Yaping. Key engineering technical status and prospect for the exploration and development of the tight sandstone gas reservoir of China [J]. Petroleum Exploration and Development, 2007, 34 (2): 239-245
[9] Zeng Xiaohui, Guo Dali, Wang Zuwen, et al., calculation method study on fracturing fluid comprehensive filtration coefficient [J]. Southwest Petroleum Institute: 2005, 27 (5): 53-57.
[10] Wang Yonghui, Lu Yongjun, Li Yongping, et al., Unconventional reservoir fracturing technology progress and application, Acta Petrolei Sinica,2012, supplement 1, 149-158.
[11] Surdam R C.A new paradigm for gas exploration in anomalously pressured “tight gas sands” in the Rocky Mountain Laramide Basins[M]//Surdam R C.AAPG Memoir 67: Seals, traps, and the petroleum system. Tulsa: AAPG, 1997: 283-289.