The Study and Practice of the Unconventional Gas Stimulation in China

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Abstract: The amount of unconventional gas (tight gas, coal-bed methane and shale gas) resources in China is very large. However, because "the reservoir can neither be produced at economic flow rates nor recover economic volumes of natural gas unless a special technique is used to stimulate production", hydraulic fracturing treatment has become a key technology to the unconventional gas. Rapid growth of China's natural gas, especially the tight gas, is inseparable from the advance of stimulation technology. The characteristics of the three types of unconventional gas, and the technology progress of stimulation fluid, countermeasures in China were introduced in the paper.

Because low-porosity, low-permeability, sensitivity and easy-damage are the most important characteristics of tight gas in China, the initial well rate is very low, even has no yields. Moreover, the multi-layers and strong heterogeneity also restrict the stimulation effect. How to reduce the formation damage and effectively improve the stimulation profile and efficiency is the key to tight gas stimulation. The ultra-low concentration CMHPG fluid system was developed to decrease the tight gas formation damage. The fracturing fluid system was widely used in the tight gas well, and the field application showed the production can be increased by 20-30%. Besides, based on sand body description and well net, an optimum design method aimed the inhomogeneous tight gas. And a novel water-jet multi-stages isolating fracturing tool without packer was developed for the multilayer formation to efficiently stimulate every layer and increase the production as much as possible.

For coal-bed methane, of the rich joint, low Young's Modulus, low pore pressure, strong adsorption and low production, hydraulic fracturing is necessary for economic development. Coal powder suspending agent for water-based fracturing fluids and low-temperature bio-enzyme breaker and other additive agent were developed to satisfy the fracturing need and decrease the formation damage. Moreover, comprehensive analysis and optimized design methods for the complex fracture were developed. The coiled tubing stimulation was used to increase the efficiency and decrease cost.

The exploration and development of shale gas in China have just been starting. A new continuously mixing fracturing fluid was developed for high rate pumping. Besides, one newly-developed friction reducer has an excellent performance, and the friction reducing coefficient can reach 82%. The fluid system supplies the material basis for the shale gas stimulation. Several pilot field tests were performed in China, and good performance of fracturing fluid was tested. All the shale gas well gained the gas production in vertical well. Then the zipper and horizontal multistage fracturing will be implemented in the future to test the production capacity of shale gas in China.

And the future development tendencies are mainly focused on shale gas "factory fracturing" to realize cost reduction and multi-lateral well fracturing and diagnosis of fracture under the condition of complex multiple fractures, etc. At the same time, to lower formation damage and fluid cost will always be the tendency for research and development of the fracturing fluid.

0. Introduction

There are abundant resources of unconventional gas (include tight gas, coal-bed methane and shale gas) in China. Preliminary estimate shows the technically recoverable unconventional gas resources in China is about 29-36 tcm. However, because "the unconventional gas can neither be produced at economic flow rates nor recover economic volumes of natural gas unless a special technique is used to stimulate production", hydraulic fracturing treatment has become a key technology to the unconventional gas. The rapid development of North American unconventional gas showed that the reservoir stimulation is a vital technology for the 3 types of unconventional gas. Similarly, the growth of China's natural gas, especially the tight gas is closely related to the development of the stimulation technology in recent years, which will be introduced in the paper.

This paper can be divided into three parts: the first part describes the characteristics of the 3 types of gas in China and their challenge in reservoir stimulation; the second part introduce the recent technology development of reservoir stimulation for unconventional gas in China; and the analysis and prospects for future reservoir stimulation technology are included in the third part.

1. Reservoir characteristics and the challenge for reservoir stimulation

In China, the tight gas, CBM and shale gas locate in different areas and reservoir characteristics are quite different, which will be introduced as follow:

(1) Tight gas

According to China's tight gas national standard, the tight gas refers to the air permeability of formation less than 0.1mD in the reservoir condition. The tight gas in China mainly locates in the Sichuan and Ordos Basin.

The low-porosity, low-permeability, low- pore-pressure, sensitivity and easy-damage are the most important characteristics of tight gas in China. Because of the above conditions, the initial tight gas well rate is very low, even has no yields. Moreover, due to the reservoir is the fluvial deposits, the sand body of formation is often lens-shape, unconnected, and laminated in vertical direction. Thus, the multi-layers and strong heterogeneity will significantly restrict the stimulation effect.

The main challenge for tight gas stimulation in China is how to reduce the formation damage and how to effectively improve the stimulation profile and efficiency. So the development of new low-damage fracturing fluid, stimulation effective tools and technology is the solution for the tight gas.

(2) Coal-bed Methane (CBM)

The CBM is rich in China, and has been realizing the industrially development. The CBM is mainly distributed in the North, Northwest, South, Northeast and Yunnan-Tibet of China, such as Qinshui, Ordos, Junggar Basin, etc.

The main reservoir characteristic of China's CBM include: a) low permeability Most of the CBM permeability is less than 0.1mD in China, while the permeability of developed CBM field is often more than 10mD; b) low pore pressure Most of the CBM in China is low pressure while the other developed field is overpressure; c) low Young's Modulus The Young's Modulus for CBM is often less than 10GPa; d) strong adsorption The gas in CBM is mainly the adsorption gas.

All of the conditions make the CBM production very low in China, and the successful stimulation is necessary to increase the production. The main challenges for CBM stimulation

include the serious proppant embedment, formation damage, and low-yielding. This has strict requirements on the fracturing fluid and the low cost stimulation.

(3) Shale Gas

According to the U.S. Energy Information Administration (EIA) resource assessment results data from the 48 shale gas basin in 32 countries, the shale gas reserves in China is about 100 tcm[1], and the recoverable resources can be 36 tcm. But the exploration and development of shale gas in China have just been starting. The shale gas in China mainly locates in the marine shale in Southern of China[2].

China's special geological conditions make shale gas in China special. The storage conditions, permeability & porosity, gas-bearing properties and pore pressure are all worse than the shale gas in North America. At present, referencing to the successful practice in North America, the main shale gas stimulation technology in China is the large scale slicker water fracturing and multi-stage horizontal well fracturing. But the production of gas well is not very optimistic. Based on the specificity of shale gas in China, it's necessary to selected right and targeted stimulation technics and fracturing fluid system.

2. Development of unconventional gas stimulation in China

According to the reservoir characteristics and technical requirements, some developments in stimulation technology for the 3 types of unconventional gas have been gained in recent years. The developments of three types of gas are described below.

(1) Tight gas

According to the difficulty and technical requirement for tight gas stimulation, the main development includes 3 parts: low-damage fracturing fluid system, multi-layer/ multi-stage stimulation tools and the optimizing design method.

Ultra-low Concentration CMHPG

The formation of tight gas in China, representing as Sulige Gas Field, has the features of low permeability, small pore throat radius, and low pressure coefficient, which makes the formation be prone to be seriously damaged by fracturing fluid. Through the development of cross-linking agent, a ultra-low concentration carboxymethyl guar gum fracturing fluid system was formed. The system has several advantages as follow:

a) Ultra-low amount of polymer: The polymer in new system is about 0.18-0.2% for 100℃ formation, which is about half the amount of conventional HPG (0.4-0.5%).

b) Low water insoluble substance: The water insoluble substance of new system decrease 89% comparing to the conventional HPG system, and decrease 33% comparing to the super HPG system, which will remarkably reduce the damage of fluid.

c) Low residue: The residue of new fluid system is about 118-211mg/L, which is the 30-50% of the conventional HPG system.

d) Low damage: All above advantages determine the low damage of new system, and the damage ratio of formation rock decreased about 25% comparing with the conventional system.

e) Low frictional resistance: The friction factor of new system is only about the 70% of conventional system, which makes the high-rate pumping in possible.

To solving the serious spurt loss of new CMHPG system, a leakoff reducer was developed and added into the system, and the leakoff coefficient C_{III} of fluid with reducer is about 4.55×

10^{-4}m/min$^{0.5}$, which is about half of the C_{III} of HPG. This can effectively prevent sand screen-out during hydraulic fracturing [3-5].

The field cases of new fluid system application showed that the increasing yield effect is very remarkable. The production of fractured well with new CMHPG system can increase about 30%, and the long-term effect is more obvious. This proved the applicability of ultra-low concentration CMHPG system in tight gas. And the system is being rapidly expanding in all tight gas fields in China.

Water-jet Multi-layer/Multi-stage Isolating Fracturing Tool

Because the lens-shape sand body in tight gas is often unconnected and laminated, the multi-layer/multi-stage isolating fracturing is necessary to improve the vertical stimulation profile or the horizontal well production as high as possible. The fracturing supporting tools is critical for successful treatment and effective isolating fracturing.

A novel suite of multi-layer/multi-stage isolating tool was developed to fulfil the stimulation requirement. This tool can isolate each layer/stage with not packer but water-jetting. The water jet can form a low pressure area near the targeted layer/stage according to the Bernoulli's equation to separate other layer/stage. At the same time by using different sizes of ball-seat and dropping ball to realize the one-trip multi-layer/multi-stage fracturing system. It can be used in all kinds of well completion system, such as open hole, casing or screen. Every year this tool can be used in field for more than 50 times in tight gas well, and become the main tool for horizontal well multi-stage fracturing except for the open-hole packer + sliding sleeve system. It significantly improve the treatment efficiency, and decrease the cost.

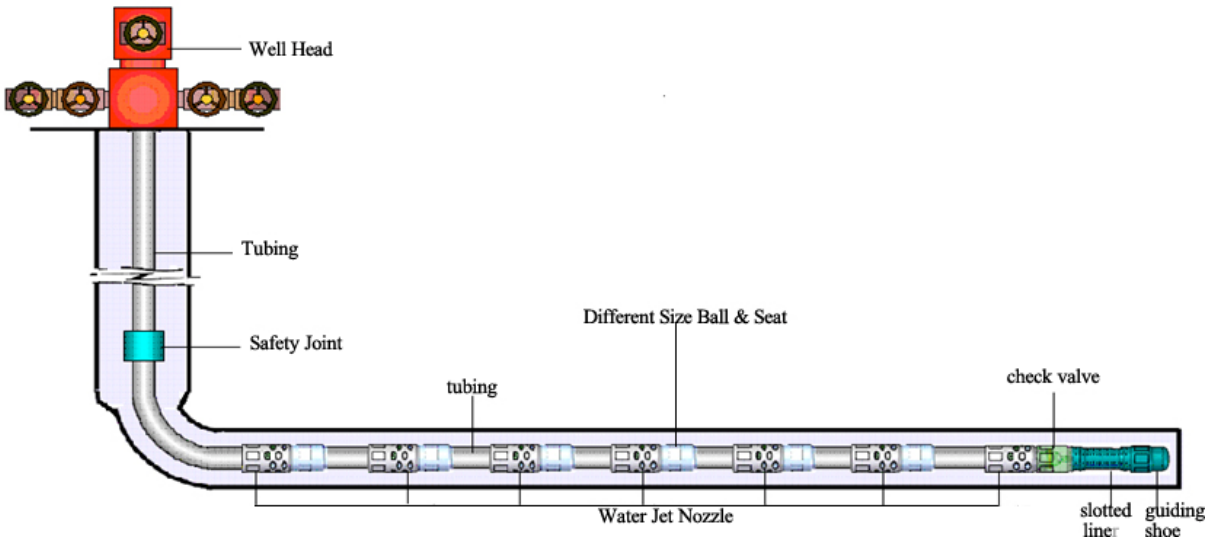

Fig. 1 The structure of one-trip water-jet multi-layer/multi-stage isolating fracturing tool

Optimizing Fracturing Design Method

The unconnected lens-shape sand body decides that the conventional fracturing design method for homogeneous formation can't fit for the fluvial facies tight gas in China. A new design method was proposed for the inhomogeneous formation. In this method, the well pattern, sand body distributing morphology and the in-situ stress direction were comprehensively analysed, which makes the optimal fracture length and conductivity more reasonable. Moreover, the proppant conductivity measuring with gas not water, long-term conductivity, and non-Darcy effects parameter were introduced into the design method. This makes the design result consistent with the field to guide the fracturing treatment effectively.

(2) Coal-bed Methane (CBM)

Similarly, the key for reservoir stimulation of CBM is the low-damage fracturing fluid, high-performance fracturing tools and distinctive fracturing design method.

Low-damage Fracturing Fluid for CBM

The damage for the CBM is mainly from the fracturing fluid and the coal powder dispersed form formation. So the research and development work also have centered on the two aspects.

Firstly, during the CBM stimulation there is much coal powder produced which will block the fracture causing the production less. According to the adsorption and wetting mechanism of non-ionic surfactant, coal powder suspending agent was developed. It can make coal powder dispersed quickly, and has excellent suspension performance. And the flow experiments show that it can carry coal powder out of the fracture and wellbore efficiently to eliminate the settlement and blocking of coal powder. The damage ratio is only 9.45% with the active water with this agent, while the damage can reach 10-30% without the agent [8].

Secondly, the CBM reservoir formation temperature is often very low (20-30℃), which make the cross-linked gel extremely hard to completely break. A low-temperature bio-enzyme breaker was developed to satisfy the gel-breaking in CBM. Application of this efficient ultra-low-temperature enzyme gel breaker reduces the damage rate of coal from 80-95% to 7-38% with the cross-linked gel.

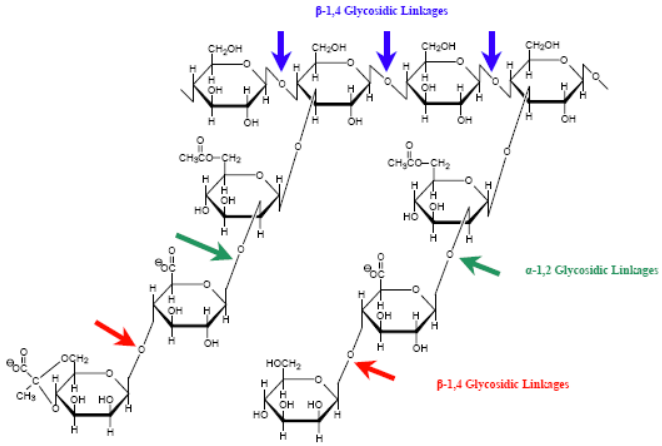

Fig. 2 Cellulose structure and gel-breaking mechanism of enzyme

Fracturing Tool and Design Method

Draw lessons from foreign mature coal-bed methane development technology, the main vertical well stimulation technology for medium/high rank coal in China is coiled tubing with water jetting and proppant fracturing through the annulus. 90% of CBM in China was stimulated with this technology. Unlike the shale gas stimulation, the pumping rate is relatively low (4-8m^3/min), and fluid volume relatively less (several hundreds of cubic meters), but the proppant concentration must be high enough to overcome the impact of embedding and ensure the fracture conductivity.

According to the pressure analysis of fracturing, tiltmeter monitoring data, the fracture in CBM is very complex, and diverse from one to the other. Based on this, special CBM fracture models were established and design software was being under development considering the T-shape, horizontal or mixture fracture geometry.

(3) Shale Gas

The preliminary exploration of shale gas in China has just begun. The national petroleum companies, including CNPC, Sinopec, CNOOC, Yanchang and Shell, have fractured several shale gas wells in China. Most of the fracturing fluid, fracturing tools and design concept were from the North America shale gas, especially the Barnett Shale Gas. The main hydraulic fracturing technology is the large scale slicker water fracturing in horizontal well with high rate, low proppant concentration and small-size proppant.

At present, a new continuously mixing fracturing fluid was developed for high rate pumping based on the development of the friction reducer and micro- emulsion cleanup additive. The newly-developed friction reducer has an excellent performance, and the friction reducing coefficient can reach 82% when the pumping rate is 16m^3/min. The fluid system supplies the material basis for the shale gas stimulation. Several pilot field tests were performed in China, and good performance of fracturing fluid was tested. All the shale gas well gained the gas production in vertical well and horizontal multistage fracturing.

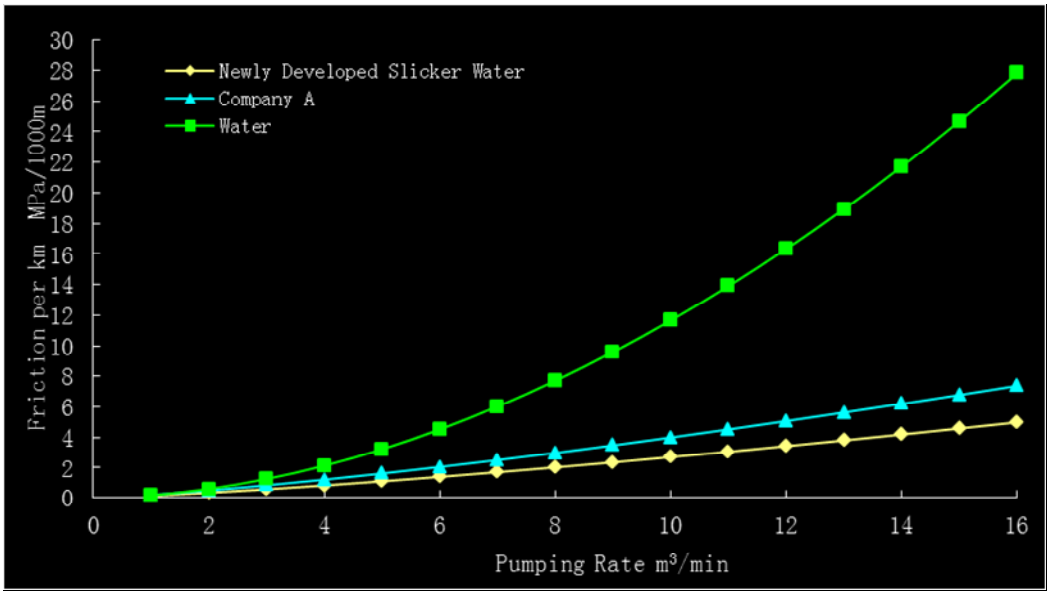

Fig. 3 The friction comparison of newly developed slicker water with other fluid

3. Prospect of Unconventional Gas Stimulation Technology in China

The different levels of these 3 types of gas stimulation technology determine their future directions differ. But because of the low production of unconventional gas, the low cost and low damage are the common goals. Based on the current situation, the unconventional gas stimulation technology direction in the future can be divided into two stages:

(1) The stage of tight gas/CBM stimulation improvement & shale gas stimulation reserving

In this stage, the key research is the localization of related fracturing tools (such as multi-layer/multi-stage isolating mainstream tools) and treatment facilities (such as skid-mounted high power fracturing pump), which will greatly reduce the treatment cost. This will lower the recoverable economic limit of tight gas/CBM. Meanwhile the development of lower-cost and lower-damage fracturing fluid is necessary in the next few years.

With the establishment of shale gas demonstration area in China, all the tools and facilities will be able to be used in the shale gas development and fulfil the elementary application.

(2) The stage of new technology breakthrough and the achieving economic development of shale gas in China

The shale gas in China mainly locates in Sichuan Basin, the region of east Hubei and west Chongqing and lower Yangtze area where the surface conditions are very complex, based mainly in mountainous and hills (fig. 4) [8]. Besides, the water resource is relatively scarce in these regions. This makes the development of shale gas with conventional techniques very difficult, which needs wide broad treatment site and abundant water resources. Under this condition, revolutionary high efficiency low cost stimulation technology is necessary for the development of shale gas in China. In the global, the shale gas stimulation and development are transforming to environmentally friendly and low cost, but considering the difficulty of development these new technologies. This stage will extend 10 years or longer[7].

Fig. 4 The surface condition of shale gas in China (Left) and North America (Right)

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