Analysis of Dry CO_2 Fracturing Technology for Efficient Development of Shale Gas Reservoirs

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Abstract. Shale gas resource potential is tremendous in China, the recoverable resources are 25.08 $\times 10^{12}$ m^3. However, they mainly located in the arid area with lack of water, and clay mineral content of shale reservoir is higher, traditional water-based fracturing fluid used for shale gas development has defects of high water consumption and the serious damage to reservoir, so it is not suitable for stimulation of shale gas reservoir in China. Dry CO_2 fracturing is a fracturing technology using liquid CO_2 as a carrier fluid. For the water sensitivity low permeability tight sandstone gas reservoir, the stimulation effect of this technology is remarkable. CO_2 fracturing technology is proposed innovatively to apply to development of shale gas reservoirs in China with the advantage of no water consumption, no damage to the reservoir and promoting CH_4 desorption. CO_2 fracturing technology applied to shale gas reservoir development involves many key scientific problems. The future research work should mainly focus on three aspects. Firstly, screening and optimizing CO_2 fracturing fluid formulation system suitable for shale gas reservoir of China; Secondly, studying binary CH_4-CO_2 adsorption and desorption on shale; Thirdly, developing CO_2 fracturing matching techniques of low cost.

Introduction

Global demand for energy is increasing with population growth and economic development. For long term, the gap between supply and demand of natural gas in China is big, and foreign dependence ratio of natural gas is over 35.2% in 2015, which bring tremendous pressure to increasing production of natural gas. In recent years, the exploration and development of unconventional gas resources such as shale gas, coal bed gas, natural gas hydrate, etc, has made significant progress. Shale gas, as an important unconventional energy resource, is increasingly becoming a key methane supply resource. For example, in the United States and Canada, gas shales have been considered as natural gas reservoirs with a huge gas potential. The global shale gas resource is $456.2\times10^{12}m^3$, which accounts for about 50% of unconventional gas resources. In fact, China has good conditions of shale gas accumulation with development of many organic-rich shale formations. It is predicted that in China shale gas geological reserves is $134.42\times10^{12}m^3$, including $25.08\times10^{12}m^3$ recoverable resources that is about the same as $28\times10^{12}m^3$ of America. Therefore, the prospects of shale gas exploration and development are bright in China. Accelerating shale gas development can increase natural gas supply and ensure the safety of energy supply. How shale gas resources are exploited effectively in China has become an important subject.

Characteristics of shale gas

Shale gas refers to the natural gas that is mainly generated by thermal maturation or continuous biological action and the interactions between the two and gathered in hydrocarbon source rock. It includes free state (existing in natural fracture and intergranular pore), adsorbed state (existing in clay mineral particles and the surface of kerogen particles) and dissolved state (existing in kerogen and asphaltene) in the main body, which basically covered all possible phase state for the existence of natural gas. Shale gas reservoirs are always some dense rocks such as organic-rich shale and thin interbed of silt-very fine sandstone, marl, etc, which have a very low porosity generally less than 4% to

6.5% and ultralow permeability possessing great change as the degree of fracture development. According to the research of Robert, micron -nanometer pores less than or equal to 0.75 micron are developed in shale gas reservoirs, especially nanoscale pore is the main pore type. Based on the theory of conventional gas reservoir, shale gas reservoirs are very difficult to have economic exploitation value because of the extremely low permeability. Therefore, both the advanced drilling technology and reservoir stimulation technology are needed to achieve the commercial exploitation of shale gas. As is known to all, shale gas development has been a great success in the USA by combing drilling horizontal wells and stimulated reservoirs volume technology. This greatly alleviated natural gas demand of the USA. However, this development way has also caused a series of problems, for example, environmental pollution resulting from a large number of return liquid after fracturing, water consumption, etc.

The difference of shale mineral composition leads to the difference of adsorption ability and brittleness. The composition of clay minerals and their microporous structure affect the adsorption capacity of the shale. Brittle mineral such as the quartz, feldspar, etc, can improve the brittleness of rock, making it easy to form fracture network by fracturing. The shale mineral composition in different regions also shows significant variations. For example, the clay mineral content of shale reservoirs in major shale gas basin in the U.S is low and the content of brittle mineral is higher, which is very conducive to drilling and fracturing in the late. Taking Barnett shale in the U.S as an example, the average content of clay mineral is less than 30%. Compared with the United States, the main shale gas reservoirs in China have a higher content of clay mineral, especially clay mineral content of continental shale gas reservoirs is even more than 60%. In China, the pressure in the shale gas reservoir is generally low. In addition, there are abundant water resources in major shale gas basin in the U.S. According to the investigation of China Water Resources and Hydropower Research Institute, the Tarim Basin, Sichuan Basin, the North China Plain, Liaoning, Shanxi, Tianshan Mountain, the Hexi Corridor, etc, are all serious water shortage districts, which are just the favourable areas of shale gas exploration and development in China.

Technological requirements for domestic exploitation

According to the exploitation experience of USA, the slick-water fracturing is an effective shale gas stimulation technology. While this technology needs to consume a huge amount of water and brings pollution to environment. Based on the data of the U.S. Environmental Protection Agency (EPA), in 2010 the average water consumption of one shale gas well is between 0.76×10^4 and 2.39×10^4t (depending on the well depth, horizontal section length and fracturing scale). Taking Marcellus shale gas field in the U.S as an example, the average water consumption of single-well reaches $1.41\times10^4 m^3$ in fracturing. About 60 percent of slick water is detained in the well after fracturing, which not only damages reservoirs but also threatens underground water[1]. As mentioned above, there are abundant water resources that can approximately satisfy the exploitation demand in the USA. Conversely, China lack water relatively and in most of the shale gas enrichment areas there are long-term or seasonal water shortage. Therefore, the water resources consumption caused by large-scale shale gas development can bring severe test to the local ecological environment and people's life. The clay mineral content is high in shale reservoirs of China, especially in continental shale gas reservoirs, so when the water-based fracturing fluid, slick water, invades shale reservoirs, the swelling of the clay minerals meeting with water can lead to serious damage to permeability of the shale reservoirs. The fracturing fluid flowback is not easy attributed to low gas reservoirs pressure, and a lot of residual fracturing fluid makes formation damage be exacerbated. Taken together, both the water resources shortage and shale reservoirs feature make it more difficult to exploit shale gas in China. Thus, for shale gas development in China, copying foreign technology simply may not be appropriate and the advanced fracturing technology with little water consumption (or even no water), no pollution to environment, little damage to reservoirs is desiderated.

The feasibility and advantages of dry CO_2 fracturing

Dry CO_2 fracturing is a stimulation technology using pure liquid CO_2 as a carrier fluid to perform fracturing treatment. The CO_2/sand stimulation operation is unique in that no liquids remain in the reservoirs in the process of the treatment, and therefore the damage created by retained stimulation liquids is eliminated[2]. The fracturing fluid, carbon dioxide is pumped as a liquid and then vaporizes at reservoir conditions, and no chemicals, gels, or water are used. It is very effective in reservoirs where the gas permeability is damaged by the introduction and/or the retention of stimulation liquids. The first treatments containing CO_2 appeared in the 1950s. The first publicly reporting use of this CO_2/sand stimulation process was in 1982, and its early field testing demonstrated greatly successful for gas well applications. As early as 1986, and by 1987, more than 450 treatments had been performed in Canada. The CO_2/sand fracturing technology had widespread commercial acceptance by operators in Canada. This technology had yet to be fully proved beyond some early testing in the U.S. in the mid 80s. The first demonstrations of the CO_2/sand stimulation process were initiated through a DOE sponsored project involving two operators, and were conducted in eastern Kentucky's Big Sandy gas field in January, 1993. They were identified as a target opportunity for the CO_2/sand stimulation process primarily. Burlington Resources initiated a well stimulation study in the Lewis shale interval, San Juan Basin in the spring of 1999, for establishing the operational feasibility of CO_2/sand stimulation in the Lewis shale, and comparing production response of wells stimulated with CO_2/sand to those stimulated with aqueous based systems[3]. The post-fracture pitot gauge rates and 30 day cumulative gas volumes indicate the two stage liquid CO_2 and sand treatments out-perform the two stage nitrogen foam treatments.

Based on the previous study, it is proposed that dry CO_2 fracturing can be applied to the development of shale gas reservoirs of China. This technology has the advantage of no water consumption, no damage to the reservoir, rapid flowback and environment friendly. The content of the adsorbed gas in shale gas reservoirs has a wide range of 20%-85%. The early production of the shale gas well is mainly decided by free gas, and the period of stabilized production of gas well is mainly decided by adsorbed gas. The gas desorption effect is an important mechanism of production of shale gas. Therefore, when CO_2 enter the shale reservoirs, CO_2 molecules can effectively replace CH_4 and can be restricted in shale surface with a stronger adsorption or forced to stay in reservoir pores. Using CO_2 fracturing to develop shale gas reservoirs can not only enhanced the recovery of shale gas, but also has the effect of energy saving and emission reduction at the same time.

Trends of research and development

(1) Based on deep research of characteristics of the main shale gas reservoirs, optimizing and screening out dry CO_2 fracturing fluid formulation system that is suitable for the stimulation of shale gas reservoirs in China is crucial. Conducting experimental and theoretical study of the CO_2 dry fracturing fluid such as the rheological properties, proppant transport and filtration characteristic in detail is also necessary. The mechanism of fracture extension should be analyzed when CO_2 dry fracturing is operated. Making optimization for the CO_2 fracturing technology and forming the corresponding fracturing construction technology is final objectives.
(2) For evaluation of yield after fracturing, it is necessary to study the adsorption and desorption mechanism of CO_2 and CH_4 in shale gas reservoirs and analyze factors and displacement efficiency of CO_2 by dynamic simulation experiments of CO_2 displacing, which also can provide theoretical basis for injecting CO_2 for strengthening shale gas exploitation.
(3) We have to study low-cost matching technology of dry CO_2 fracturing for exploiting shale gas reservoirs. At present, the cost of transportation of CO_2 is still high, therefore, the CO_2 dry fracturing technology can be applied to CO_2-rich shale gas field (Jilin) or shale gas field near large coal chemical factories/coal power plants firstly, CO_2 capture and storage technology related to it needs further research.

Conclusions

In conclusion, considering domestic shale gas reservoirs and the exploitation environment, we can't copy foreign technology simply and must form the exploitation technology system with characteristics of China on the basis of reference and learning according to domestic facts. Based on systematic study, the dry CO_2 fracturing used in development of low-permeability gas and oil reservoirs is put forward to develop shale gas in China, with the advantage of no damage to reservoirs, no water consumption, rapid flow back and being in favour of shale gas desorption. Compared with conventional fracturing technology, CO_2 fracturing technology is relatively complex. And a further detailed research is needed combined with the characteristics of domestic shale gas reservoirs. In view of domestic shale reservoir characteristics, optimizing CO_2 fracturing fluid formulation system which is applicable to China's typical shale gas reservoirs by the experimental and theoretical study and forming corresponding fracturing construction technology are the main work in the future.

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