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Original article

Feasibility study on application of volume acid fracturing technology to tight gas carbonate reservoir development☆,☆☆

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ABSTRACT

How to effectively develop tight-gas carbonate reservoir and achieve high recovery is always a problem for the oil and gas industry. To solve this problem, domestic petroleum engineers use the combination of the successful experiences of North American shale gas pools development by stimulated reservoir volume (SRV) fracturing with the research achievements of Chinese tight gas development by acid fracturing to propose volume acid fracturing technology for fractured tight-gas carbonate reservoir, which has achieved a good stimulation effect in the pilot tests. To determine what reservoir conditions are suitable to carry out volume acid fracturing, this paper firstly introduces volume acid fracturing technology by giving the stimulation mechanism and technical ideas, and initially analyzes the feasibility by the comparison of reservoir characteristics of shale gas with tight-gas carbonate. Then, this paper analyzes the validity and limitation of the volume acid fracturing technology via the analyses of control conditions for volume acid fracturing in reservoir fracturing performance, natural fracture, horizontal principal stress difference, orientation of in-situ stress and natural fracture, and gives the solution for the limitation. The study results show that the volume acid fracturing process can be used to greatly improve the flow environment of tight-gas carbonate reservoir and increase production; the incremental or stimulation response is closely related with reservoir fracturing performance, the degree of development of natural fracture, the small intersection angle between hydraulic fracture and natural fracture, the large horizontal principal stress difference is easy to form a narrow fracture zone, and it is disadvantageous to create fracture network, but the degradable fiber diversion technology may largely weaken the disadvantage. The practices indicate that the application of volume acid fracturing process to the tight-gas carbonate reservoir development is feasible in the Ordovician Majiagou Formation of lower Paleozoic, which is of great significance and practical value for domestic tight-gas carbonate reservoir development and studies in the future.

☆ Volume Acid Fracturing: Volume acid fracturing technology is a new technology which apply to stimulate tight reservoir, it is a combination of SRV fracturing and multistage alternating injection acid fracturing, complex fracture network is created by SRV fracturing, fracture conductivity is created by multistage alternating injection acid fracturing.

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1. Introduction

The rapid development of unconventional natural gas has drawn the attention of the world, and caused significant effect on the global energy structure. As the leader of the exploration and development of unconventional natural gas, the United States made a major breakthrough in the early 1980s. According to the statistics of the U.S. Energy Information Administration (EIA), the production of unconventional gas has reached 1690×10^8 m^3 in 2011, which accounts for about 26% of the US natural gas output. Predictably, the proportion will continue to rise in the next period of time.

Unconventional natural gas reserves of China are rich as well, among which the amount of tight gas prospective resources reaches to $(12–100) \times 10^{12}$ m^3 [1]. Consequently, domestic related work for the exploration of the tight gas has been carried out and made substantial progress. The tight oil and gas resources have been discovered in Ordos basin, Sichuan basin, Junggar basin, Tarim basin, Songliao basin, and almost all the petroliferous basins, mainly concluding three types of reservoirs, like lacustrine carbonate rocks, deep lake delta sandstone and deep lake gravity flow sandstone, with a more than 20×10^4 km^2 of total favorable exploration area and approximately $106.7–111.5 \times 10^8$ t of total geological resources. There are great differences between the geological features of the tight oil and gas reservoir and conventional oil and gas reservoir. Generally, the former one has low porosity (less than 10% generally), low permeability (less than 0.1 mD generally), various types of reservoir, complex lithology, high calcium content (about 40% generally, in addition to the Yanchang Group of Ordos Basin and the cretaceous system of Songliao Basin), mostly proximal accumulation, low natural deliverability, developed natural fractures and essentially control the production of oil and gas reservoirs, and so on.

Currently, to develop fractured tight-gas carbonate, conventional acid fracturing mode is generally used around the world. Although this mode can obtain a certain degree of original stimulation, it results in rapid decline of production and difficulty in obtaining stable production [2,3]. Furthermore, this mode connects little of the natural fracture system and offers acid very small swept volume. Therefore, there is a need in further exploration, study and field practice for this kind of gas reservoir. Until now, acid fracturing for high-calcium tight oil and gas reservoir hasn't been seen all around the world, but the volume acid fracturing pilot tests for tight-gas carbonate reservoir have been carried out in China, and it creates acid etched complex fracture network with the conductivity (HFM microseismic monitoring of adjoining wells have indicated that the volume acid fracturing creates multiple branch non-planar complex fracture network). The results of practice have indicated that the effect of volume acid fracturing is very similar with SRV sand fracturing and the volume acid fracturing has a good application prospect.

In this paper, tight-gas carbonate reservoir in the Ordos Basin is investigated by using many theoretical methods such as the mechanics, the probability statistics, scanning electron microscope (SEM), X-ray diffraction (XRD) techniques, well logging, and using technical means of combination of laboratory experiment with field practice. The research results will promote the theoretical development of volume acid fracturing in the future.

2. Stimulation mechanism and technical ideas

2.1. Stimulation mechanism

Horizontal well drilling technology increases reservoir contact area, slick water fracturing creates hydraulic fractures and reopens most natural fractures or makes part of them slippage, the hydraulic fractures communicate with the natural fracture, which creates initially fracture network; using the degradable fiber diversion agent to overcome the disadvantage of large horizontal principal stress difference, increasing SRV, at this moment complex fracture network is created initially; acid is an important factor for creating complex fracture network, first, acid heterogeneously etches fracture walls and increases their roughness, and so fracture obtains conductivity after fracture close; second, natural fracture conductivity is created by acid leak-off, and simultaneously the formation of a small amount of acidizing wormhole makes fracture network further complex; A massive slick water is injected to reduce reservoir temperature, which makes acid–rock reaction velocity slow down and acid effective time increase. Meanwhile the phenomenon of acid fingering in preflush also increases the distance of acid penetration, and acid is pushed to fractures in the remote by overflush fluid, which improves the stimulation rate of the fracture in the remote.

Table 1
Comparative table of shale gas reservoir attributes and objective gas reservoir attributes.

Parameter	Shale-gas reservoir	Carbonate gas reservoir	Comparative results
Stress	<2000 psia net lateral stress	3626 psia net lateral stress	
Reservoir temperature	>230 °F	221 °F	×
Pressure	>0.5 psi/ft	0.416 psi/ft	×
Mineralogy	>40% quartz or carbonates	>96% carbonates	√
	<30% clays	No clays	√
	Low expandability	Low expandability	√
Fracture fabric and type	Vertical vs. horizontal orientation	Horizontal orientation	√
	Open vs. filled with silica or calcite	Filled with authigenic carbonate	√
Internal vertical heterogeneity	Less is better	Less	√
Seals	Fracture barriers present top and base	Fracture barriers present top and base	√
Gas type	Thermogenic	–	–
Gas composition	Low CO_2, N_2 and H_2S	Low N_2 and some layers contain H_2S, CO_2	√
Thermal maturity	Dry gas window > $1.4R_o$	Dry gas window is $1.6–4.5R_o$	√
Total organic content	>2%	0.1–24	√
Permeability	>100 nd	<1 md	√
Young's modulus	>3.0 MMPSIA	4.93×10^6 MMPSIA	√
Poisson's ratio (static)	<0.25	0.22	√