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5 YEARS OF CO_2 WATERLESS FRACTURING IN JILIN OILFIELD – WHAT WE HAVE LEARNED

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ABSTRACT

Since the first pilot test of CO_2 waterless fracturing in 2014, a complete system, including equipment, operation and liquid, has been formed. Twenty-three field tests proved the functions of CO_2 waterless fracturing on reservoir energy storage, artificial fracture network and mixed-phase production increase. The effects lead to great water saving and CO_2 storage. A unit volume of CO_2 has the equivalent effect with 2.4 unit volumes of water-based fracturing liquid on oil production. The final storage rate of CO_2 is 76.46%, 30% higher than that of CO_2-EOR technology.

Keywords: CO_2 waterless fracturing; CO_2 storage, water consumption reduction, EOR

1. INTRODUCTION

As the name suggests, CO_2 waterless fracturing uses liquid or supercritical CO_2 instead of water as the fracturing medium to fracture the crude oil reservoir. The technology has the many advantages over traditional hydraulic fracturing, such as damage-free stimulation, crude oil viscosity reduction, higher adsorption strength on coal rock and shale, larger swept volume, and the effect on CO_2 storage.

Since 2014, RIPED (Research Institute of Petroleum Exploration and Development) and Jilin Oilfield have developed whole system for waterless fracturing, including operation technology, kernel equipment, liquid system and management system.

2. CO_2 WATERLESS FRACTURING SYSTEM

2.1 Supporting equipment

The continuity and reliability of equipment is one of the key technologies to realize waterless fracturing. CO_2 is always in the sealed high-pressure state under operation conditions, so the equipment used in the operation is quite different from conventional hydraulic fracturing. Requirements for CO_2 waterless fracturing equipment include CO_2 storage tanks, CO_2 booster pump trucks, sealed sand blenders, fracturing pump trucks, and fracturing manifold trucks.

The sealed sand blender serves as a key device in CO_2 waterless fracturing which is a large sealed pressure vessel and used to mix proppant with liquid CO_2. It requires the pressure of more than 2.2MPa, has a volume of $5m^3$ and sand transport rate of more than 500kg/min (Fig. 1).

Fig. 1 Sealed sand blenders

2.2 Technological process

The basic operation process of CO_2 waterless fracturing includes 5 steps.

(1) Several CO_2 storage tanks are connected in parallel, as shown in Fig. 2. Booster pump trucks, sealed sand blenders, fracturing pump trucks and wellhead devices are connected successively. The measuring truck is connected to monitor their working conditions.

(2) The proppant is loaded into a sealed sand-mixing tank and liquid CO_2 is injected for precooling.

(3) Conduct pump test on high-pressure pipeline and pressure test on low-pressure liquid supply pipeline.

(4) Inject liquid/supercritical CO_2 into the stratum, squeeze the stratum and extend the fracture. Then open the sealed sand-mixing device and inject proppant. After the proppant is injected, the displacement is performed until the proppant has just fully entered the stratum and the pump is shut down.

(5) A series of work such as well soaking and flowback are carried out successively.

2.3 Liquid system

The viscosity of CO_2 under fracturing conditions is only 0.02-0.1cp, and its sand-carrying and filtration properties cannot meet the operation requirements. Therefore, CO_2 thickening, as another key technology for waterless fracturing, directly affects the production-increase transformation effect and even determines whether the operation can be carried out smoothly. Molecular design of CO_2 thickener was carried out based on the following three methods.

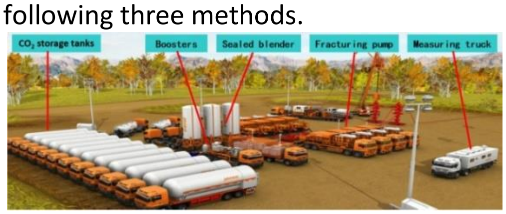

Fig.2 CO_2 waterless fracturing process

(1) Screening non-polar groups soluble in CO_2 and polar groups with high thickening efficiency to synthesize amphiphilic polymer thickener with medium and low molecular weight.

(2) Use small molecule surfactant to form rod-like or worm-like micelles in CO_2.

(3) Develop polymer emulsion thickener system to promote polymer dissolution with a water-in-oil structure.

Based on the methods above, three thickener systems, including lipid amphiphilic copolymers, double-chain surfactant and water-in-oil polymer emulsion, have been formed. Three thickener systems in supercritical conditions with the additive amount of 1wt% have the viscosity of 1-3mPa.s. Among the three, emulsion thickener needs only 2-3mins to realize ample dissolution (Fig. 3). Therefore, it has become the main thickener system in Jilin Oilfield.


Fig. 3 Emulsion thickener and its dissolution

3. WATER CONSUMPTION REDUCTION AND CO_2 STORAGE

By May 2019, Jilin Oilfield has completed the field practice of CO_2 waterless fracturing for 23 wells and achieved good stimulation effect. Typical operation parameters are 400-900m^3 of CO_2 liquid level, 3-8 m^3/min of displacement, and 5-25 m^3 of sand amount. All operation parameters have reached the world's advanced and domestic leading levels. The operation parameters of some operation wells are shown in table 1.

Table 1 Operation parameters for CO_2 waterless fracturing in Jilin Oilfield

No.	Segment m	Liquid m^3	Displacement m^3/min	Sand m^3
1	1584.8-1588	440	4-4.2	8
2	2299.4-2214.6	657	4.5-7.6	11
3	2183.4-2189.2	675	3-6.5	7
4	2292.4-2340.6	582	3.8-4.2	15
5	2793.4-2820	695	3-4	5
6	1935-1942.5	653.5	6-7.4	19.8
7	2268.8-2281.2	696	4-8.0	21
8	1730.8-1757	860	5-6	23
9	2042-2076.8	646	6-7.9	13.5

After field tests, what we have learned are as follows.

(1) The technology can reduce water consumption greatly.

Tight oil reservoir is the most widely used fracturing transformation object of CO_2 waterless fracturing technology in Jilin Oilfield at the present. According to statistics, 31 fracturing wells in tight reservoir are fractured, among which 23 conventional hydraulic fracturing wells have an average injection volume of 380 m^3, and an average daily oil production of 0.6t after fracturing. The average injection amount of fracturing fluid in 8 CO_2 waterless fracturing wells is 630 m^3, and the average daily oil production is 2.4t after fracturing (Fig. 4). That is, in tight reservoirs, a unit volume of CO_2 oil production is equivalent to 2.4 unit volumes of water-based fracturing liquid.

(2) CO_2 waterless fracturing can effectively realize CO_2 storage.

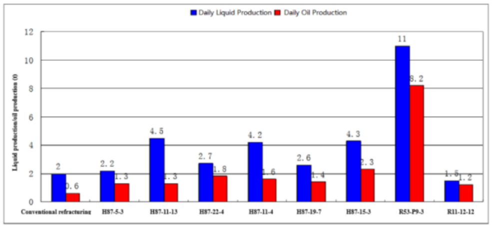

Fig. 4 Production comparison between CO_2 waterless fracturing and refracturing

Field monitoring data of CO_2 waterless fracturing shows that, in the operation, soaking, and discharge process of waterless fracturing, CO_2 is in a supercritical state for a long time (Fig. 5), and the deeper the reservoir is buried, the greater the geothermal gradient is, and the higher the proportion of CO_2 in a supercritical state is. Under a supercritical state, CO_2 density is close to that of liquid, but its migration capacity is similar to that of gas, therefore, it is easy to diffuse in reservoirs and has stronger dissolution capacity in crude oil, creating an advantageous condition for effective CO_2 storage.

To evaluate the storage effect of CO_2 waterless fracturing, Block H87 has been selected as the research object to establish the geological model of the whole well area, as shown in Fig. 6. The simulation area, with an area of 4.45km^2, covers all production and water injection wells within the research area. The curves of CO_2 recovery percentage over time for the three wells are shown in Fig. 7. The final storage rates of wells H87-11-4, H87-5-3, H87-7-7 are respectively 83.87%, 71.57% and 73.77%, with an average storage rate of 76.46%. Compared with CO_2-EOR technology, the storage rate of CO_2 waterless fracturing has increased by about 30%.

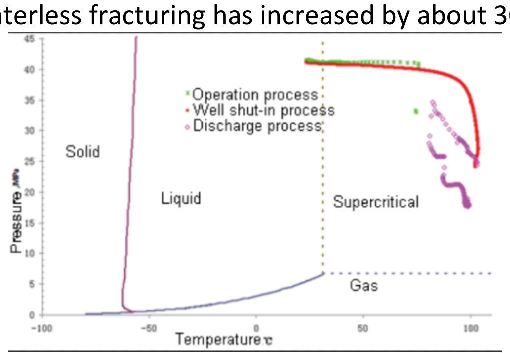

Fig. 5 Downhole CO_2 phase change during the operation, soaking, and discharge

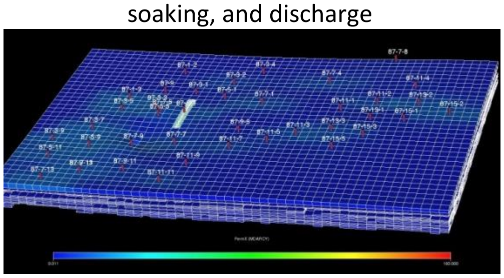

Fig. 6 The geological model of well area

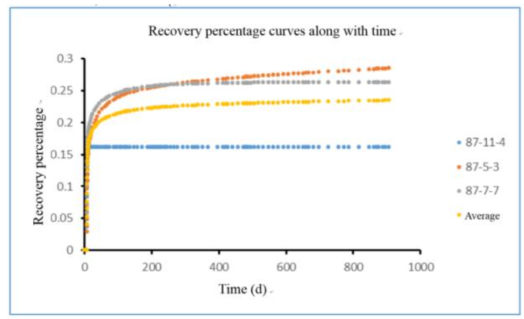

Fig. 7 CO_2 recovery percentage curves along with time in three wells

The main reason for CO_2 waterless fracturing technology has higher storage efficiency than that of CO_2 - EOR technology is that the injection pressure of waterless fracturing (30-70MPa) is higher, and injection displacement is greater (3-8m^3/min). Thus, CO_2 under the effect of high pressure and high displacement has further enhanced penetrability and diffusion ability, being able to enter micro-nano sized pores that CO_2 can't enter in displacement, and greatly increasing the spread range.

CO_2 also has obvious advantages over water for energy storage, and can increase swept volume and production greatly.

4. CONCLUSION

As a new type of fracturing technology, the field practice of CO_2 waterless fracturing in Jilin Oilfield shows that the technology has a broad market prospect, as it can achieve multiple goals including CO_2 storage, water resource conservation, increased single well production and ultimate recovery rate. In the future, we will further research the mechanism on fractures caused by CO_2 to open up new roads for carbon emission reduction and CO_2 resource utilization.

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