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Exploration and Practice of CO2 Huff-N-Puff Combined CO2 Flooding in Shale Oil Well Cluster Group

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Abstract. Shale oil production wells in Dagang Oilfield in China are put into production by means of horizontal well and segmented multi-cluster massive volume fracturing. The production characteristics are that the output is high in the initial phase of production, the output decreases rapidly with the continuous production, and there are no effective measures to increase production. There is an urgent need for stimulation technology to improve the recovery of shale reservoir. In the field of oilfield development, CO_2 has multiple advantages such as easy injection, viscosity reduction and energy increase. For the shale oil well cluster group with good inter well connectivity, the author designs an implementation mode of "CO_2 huff-n-puff combined CO_2 flooding" to improve shale oil production. This implementation mode can play the dual role of CO_2 huff-n-puff combined CO_2 flooding and CO_2 drive to realize the efficient production increase of shale oil well group. After two phases of implementation of the test well group, the cumulative oil increase of the well group has reached 3864 tons, and the comprehensive oil change rate has reached 1:1.22, which has achieved good stimulation effect. This implementation method can effectively improve the production of shale oil reservoirs and provide a new technical measure for improving production and efficiency of similar shale reservoirs.

Key words: Shale oil, CO_2 huff-N-puff, CO_2 Enhanced oil recovery, CO_2 flooding

1. Introduction

The thickness of shale oil reservoir in Dagang Oilfield is 150-200m and the buried depth is 3000-5000m; Dagang shale oil reservoir has poor producability and difficulty in development， which is characterized by higher proportion of nanometer pore throats and rather minute pore throats，and the flow capacity mainly comes from sub-micro pore throats with higher displacing pressure and lower maximum mercury-injection saturation． Shale oil production wells are put into production by means of horizontal well and segmented multi-cluster massive volume fracturing, and most of them have no artificial energy supplement. In the initial phase of self spraying production, the output is high, but the self spraying period is short and the decline is fast; Artificial lifting can rapidly increase production, but it is still in the dilemma of short high production period and rapid decline. There is an urgent need for the replacement technology of increasing production and efficiency to improve the recovery of shale reservoir.

2. Stimulation mechanism of CO_2 injection into shale oil

The multiple advantages of CO_2 in oilfield development, such as easy injection, viscosity reduction and energy increase, make use of the miscibility of CO_2 and shale oil to reduce the viscosity of shale oil, increase the fluidity of shale oil and improve the output of shale oil; At the same time, after entering the shale reservoir, CO_2 can diffuse, dissolve and extract shale oil in the matrix and supplement formation energy by volume expansion, which can further improve the recovery of shale reservoir.

Hawthorne divides carbon dioxide entering shale fracture matrix system into four steps: (1) Carbon dioxide passes through the crack quickly under the action of high pressure. (2) When the shale matrix is exposed to carbon dioxide, carbon dioxide penetrates into the matrix under the action of differential pressure. In this process, the carbon dioxide entering the matrix expands, forcing some shale oil to flow out of the matrix and enter the fracture, but at the same time, some carbon dioxide will also carry shale oil into the matrix. (3) Carbon dioxide entering the matrix is dissolved in shale oil while supplementing matrix energy, resulting in the expansion and viscosity

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reduction of some shale oil. (4) When the pressure system of matrix and fracture reaches equilibrium, shale oil enters the fracture from the matrix under the action of diffusion. Miscible flooding can also occur under appropriate conditions.

For shale matrix, Pierre et al. Pointed out that compared with methane, carbon dioxide is easier to be adsorbed in porous media with organic matter, which can replace the methane adsorbed on the surface of the media. Therefore, the mechanism of enhanced oil recovery of carbon dioxide in shale reservoir mainly includes pressurization, dissolution, extraction, expansion, adsorption and replacement, reducing capillary force and diffusion.

3. Well cluster group selection principle and implementation mode design

Combined with the stimulation mechanism of carbon dioxide injection in shale oil and the production status of Dagang shale oil wells, an implementation mode of "carbon dioxide swallowing drive" is designed for the shale oil well group that can establish displacement relationship, and the well selection principle is given. This embodiment can play the dual roles of huff and puff of injection wells and inter well displacement. CO_2 huff-n-puff combined CO_2 flooding can recover the remaining oil around the injection well from the wellhead, and CO_2 flooding can displace the remaining oil between wells near the production well and recover it.

3.1 Well selection principle

(1) There is a certain production in the early phase of the well group, and the production in the early phase of the well group is high, indicating that the shale reservoir has a certain reserve scale and has the potential of EOR;
(2) The production of the well group decreases rapidly, and the current low production shows that the well group meets the problem of low production and low efficiency, so it is necessary to take measures to increase production;
(3) The target formation of the well group has good connectivity and can establish displacement relationship. This is conducive to the realization of CO_2 flooding between wells and the production of remaining oil between wells.

3.2 Implementation mode design

According to the number of wells contained in the well cluster and the connectivity between wells, taking three well clusters as an example, the design and implementation methods are as follows:
(1) Implementation mode 1, Injection of intermediate wells and production of wells on both sides, as shown in Fig. 1. Shut in the wells on both sides and carry out pressure bearing treatment. Inject CO_2 into the intermediate well. When the three wells meet the well opening conditions at the same time, start the well for oil production at the same time. Until the oil production is lower than that before the measures, it is determined that the first round of measures has failed, and subsequent rounds can be implemented.
(2) Embodiment 2: Injection on both sides and intermediate production, as shown in Fig.2. Shut in the intermediate well and carry out pressure bearing treatment, and inject CO_2 into the wells on both sides. When the three wells meet the well opening conditions at the same time, start the well for oil production at the same time. Until the oil production is lower than that before the measures, it is determined that the first round of measures has failed, and subsequent rounds can be implemented.

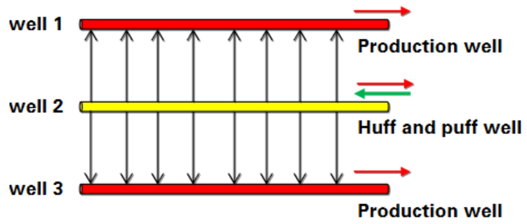

Fig. 1 Implementation mode 1

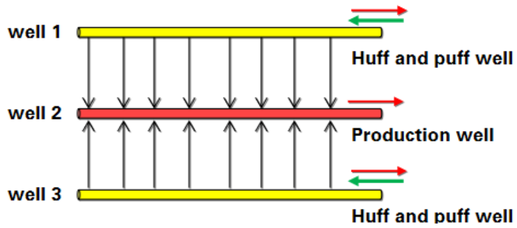

Fig. 2 Implementation mode 2

During the implementation process, in combination with the structural location and production requirements of each well, implementation mode 1 and implementation mode 2 can be carried out alternately to optimize and adjust the sequence. For multi well groups, the implementation methods are not limited to the above two, and the injection wells and production wells can be rotated according to the production needs. Considering the continuous reduction of shale oil near the well, it is necessary to increase the consumption of CO_2 round by round to expand the swept volume of CO_2,so that more remaining oil between wells and edges can be started and flow to the wellhead.

4. Field application effect and understanding

According to the principle of well selection, well group G1 of shale oil in Dagang Oilfield is selected to carry out field test of CO_2 huff-n-puff combined CO_2 flooding. The well cluster includes three horizontal wells arranged in parallel, all of which are put into production by segmented multi-cluster massive volume fracturing without artificial energy supplement. During fracturing, all adjacent wells react, and the well spacing is close, only 130m, with good connectivity between wells. The schematic diagram of test well group is shown in Fig. 3.

Fig. 3. Schematic diagram of test well group

In the early self-injection production of the well group, the maximum daily liquid production reached 172m^3 , and the maximum daily oil production reached 50t. However, the high-yield period was short, the decline was rapid, and the liquid production and oil production decreased significantly. In the later phase, artificial lifting was selected, and the liquid production and oil production recovered, but there was still a problem of rapid decline in development. The production dynamic curve of well group before test is shown in Fig. 4.

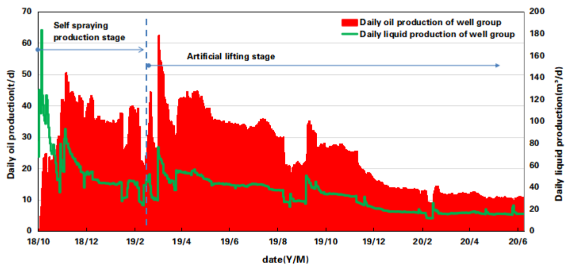

Fig. 4. Production dynamic curve of well group before test

4.1 Determination of implementation mode

The well group has good connectivity. The field test of CO_2 huff-n-puff combined CO_2 flooding is carried out in the well group by the combination of implementation mode 1 and implementation mode 2. Implemented in two phases:

(1) In the first phase, Well G1 and well G3 were subjected to pressure treatment, and CO_2 was injected into the well G2. After the three wells reached the blow off conditions at the same time, the self-injection production was carried out, and the oil recovery was resumed according to the original lifting process.

(2) In the second phase, the well G2l was subjected to pressure treatment, and CO2 was injected into well G1 and well G2. After the three wells reached the blow off conditions at the same time, the self-injection production was carried out, and the oil recovery was resumed according to the original lifting process.

4.2 Design of CO_2 injection amount

The CO_2 injection amount is determined according to the thickness of shale reservoir, fracturing volume of single well, horizontal section length, free hydrocarbon content, organic carbon content and other reservoir parameters of the test well group, as well as the process parameters such as CO_2 action radius and CO_2 solubility with shale oil under reservoir conditions. In the first phase of design, the CO_2 injection volume of G2 well is 1560 tons; In the second phase, 780 tons of CO_2 is injected into well G1 and 840 tons of CO_2 is injected into well G3.

4.3 Test effect

In the first phase, the total oil increment of the well group was 2087t, of which 922t were increased in well G2, 551t were increased in well G1, and 614t were increased in well G3, and the oil exchange rate in this phase was 1:1.34. In the second phase, the well group increased oil by 1777t, including 525t in Well G1, 645t in Well G3 and 607t in Well G2. The oil exchange rate in this phase was 1:1.10. Through the implementation of the two phases, the cumulative oil increase of the well group was 3864t, and the comprehensive oil exchange rate reached 1:1.22, which achieved good oil increase effect. The test results are shown in Table 1.

Table 1. Statistical table of field test results of CO_2 huff-n-puff combined CO2 flooding

Well number	First phase			Second phase		
	CO_2 injection amount(t)	Soaking time (d)	Oil increment(t)	CO_2 injection amount(t)	Soaking time (d)	Oil increment(t)
Well G1	0	28	551	740	25	525
Well G2	1560	20	922	0	29	607
Well G3	0	28	614	810	25	645
total	1560		2087	1550		1777

4.4 Understanding of the test

(1) The oil layer has good gas absorption performance. At the beginning of gas injection, the injection displacement is increased by stages, and the suction indicator curve is drawn according to the injection displacement and injection pressure. The test results show that the injection displacement is positively correlated with the injection pressure, indicating that the shale reservoir has a strong gas absorption capacity for CO_2.

(2) The mobility of shale oil increases. The viscosity and density of shale oil were tested before and after the test, as shown in Table 2. The test results show that the viscosity and density of shale oil decrease after the test, indicating that the injection of CO_2 can effectively reduce the viscosity and density of shale oil, improve the liquidity of shale oil, and facilitate the migration of shale oil in the reservoir and the lifting in the wellbore.

Table 2. Statistics table of shale oil viscosity and density test results before and after test

Well number	Test phase	Pre-test	Initial of the first stage	The middle of the first stage	Initial of the second stage	The middle of the second stage
Well G1	Density (g/cm^3)	0.882	0.866	0.878	0.869	0.871
	Viscosity (mPa·s)	96.31	65.72	67.69	66.15	68.22
Well G2	Density (g/cm^3)	0.873	0.859	0.862	0.865	0.864
	Viscosity (mPa·s)	67.92	60.94	49.54	52.47	50.31
Well G3	Density (g/cm^3)	0.875	0.867	0.872	0.859	0.87
	Viscosity (mPa·s)	106.31	61.33	65.67	64.39	68.42

(3) Formation energy is supplemented. According to the monitoring data, the energy of all wells has been fully supplemented. In the first stage, the flowing production of G2 well will last for 35 days, and the flowing production of G1 well and G3 well will last for 25 and 28 days. In the second stage, the flowing production of G2 well will last for 30 days, and the flowing production of G1 well and G3 well will last for 26 days and 23 days;The dynamic liquid level of each well was tested. In the first stage, the dynamic liquid level on both sides of the well changed from no display before the test to 469M and 825m before blowout in the middle of the first stage; At the same time, the indicator diagram of each well shows that the liquid supply is sufficient.

5. Application prospect

The potential resources of shale oil in the world are considerable, with a total amount of 1.1×10^{13}~1.3×10^{13}t,mainly distributed in the United States, Russia, China, Australia and other countries. According to the statistics of the US energy information administration, the shale oil reserves of the United States, Russia and China account for 47.8% of the world's shale oil reserves.CO_2 huff-n-puff combined CO_2 flooding implementation mode can be implemented in shale reservoir well groups with good inter well connectivity or displacement relationship. It can significantly increase shale oil production and has broad application prospects.

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