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EXPERIMENTAL STUDY OF ENHANCE OIL RECOVERY USING GREENHOUSE GASES

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***Abstract*—CO_2 as the main cause of global warming is threatening the circumstance of human being living. So the geological storage of CO_2 becomes one of the hot topics. By physics simulation experiments, the feasibility study of enhance oil recovery (EOR) using CO_2 is studied. The results show that CO_2 can not only enhance the recovery percent, but also can be stored in reservoir effectively. CO_2 can greatly increase oil recovery percent compared with water flooding. Water alternating CO_2 should given priority by using CO_2. In case of water alternating CO_2, the optimum gas water ratio is 1:1 and the optimum plug volume is 0.1 times of pore volume (PV), earlier water alternating CO_2 will makes better development effect.**

***Index Terms*—Greenhouse gases, CO_2, Enhance oil recovery, Physics simulation**

I. INTRODUCTION

Because of the over-reliance on fossil fuels (coal, oil and natural gas), the emission of CO_2 by industry and living has been increased, which has destroyed the environment more and more seriously. Among many greenhouse gases, more than 65% is CO_2 [1,2]. The storage of CO_2 mainly chooses depleted reservoir, deep brine reservoir, unworkable coal bed and deep sea etc, which is an efficient way to avoid the global warming [3-6]. The ARI company study three CO_2 gas reservoirs show that CO_2 can storage for millions of years. In July 2005, the feasibility study of CO_2 storage by IEA in the Weyburn oil field show that only 0.02% of CO_2 used to drive displacement is escaped from the reservoir in 5000 years, most of them get into the cap rock and can not invaded the drinking water aquifers, escaped quantity from the oil and water Wells is lower than the 0.001% of the original reserves [7-9]. The results suggest that CO_2 flooding can greatly enhance the oil recovery efficiency [10-12]. Due to the well sealing, the reservoir can realize CO_2 geological storage for a long time. Using CO_2 as a drive force can not only increase the crude oil recoverable reserves, also realize long-term CO_2 geological storage, which realizes the social benefit of CO_2 emission reduction and enormous economic benefits.

Since 1952 Whorton got the first patent of carbon-dioxide flooding-"EOR by CO_2 flooding" has been thought much by the practical operators as a secondary method to improve oil recovery after water flooding. The CO_2 EOR technology is getting innovated and matured depend on the sustained and stable air supply which contain a lot of CO_2 in USA. Holm summarized the CO_2 flooding mechanism systematically for dissolved gas flooding, immiscible flooding, first and multiple contact miscibility etc. CO_2 can evaporate and extract C_5-C_{30} components from crude oil, completely eliminate interfacial tension between fluids. Elimination of interfacial tension can increase capillary number, accordingly, reduce the residual oil saturation, and enhance ability of oil recovery [13]. During practical production, due to heterogeneity, the viscosity of CO_2 is 10 to 50 times less than the original in the conditions of the reservoir, viscous fingering caused by adverse mobility ratio let gas early breakthrough and get high gas oil ratio that make the CO_2 can easily get into high permeability layers and greatly reduce the oil displacement effect. On the other hand, CO_2 and oil are separated according to the different density, low-density gas floating and can only be spread in parts of reservoir [14]. To different physical properties of reservoir, it is necessary to determine the best way of CO_2 injection by laboratory tests. This paper discusses the feasibility of CO_2 to improve oil recovery and the parameter optimization of indoor experiments for a low permeability reservoir.

II. EXPERIMENTAL SECTIONS

A. Experimental Conditions

Oil sample used in this study was prepared by using dead oil and natural gas. The purity of CO_2 used in these experiments is 99.999% (Beiwen, China). The simulating formation water with the same ion concentration as the underground fluid in the oilfield is used as the displacing fluid. Five natural cores are used in this study, which are sequenced follow a certain order. The assembled core has a length of 29.23cm and a porosity of 14.15%. Diameter of the assembled core is 2.5cm and the permeability is 1.76×10-3μm^2. Experimental temperature is set as 85 ^{o}C.

B. Materials & Conditions

In this paper, a self-developed experimental platform is established, and the schematic diagram of the experimental flow system，as is shown in Figure 1, consists mainly of the following devices: (1) Three high pressure stainless-steel cylinders (0-70MPa; ≤150^{o}C; 200-1000mL; Huaan, China) were used to store and deliver oil, water and CO_2 samples. (2) A date acquisition system was used to get the temperature date and pressure date for real-time. (3) A back pressure pump and a confining pressure pump were used to maintain the pre-specified pressure inside the cell during the tests (Huaan, China; pressure range, 0−5800 psi; pressure accuracy, 0.1%). (4) A syringe pump (ISCO, flow range, 0.001-60 mL/min; flow accuracy, 0.5%; pressure range, 0-10000 psi; pressure accuracy, 0.1%) was used to displace samples (oil, CO_2 and water). (5) A core holder (0-100MPa; ≤150^{o}C; Huaan, China) was used to realize the core which can be compressed same as reservoir conditions. (6) A wet type gas flow meter (volume, 2 liters per revolutions; volume accuracy, 1%； Changchun, China) was used to measure the volume of a gas.

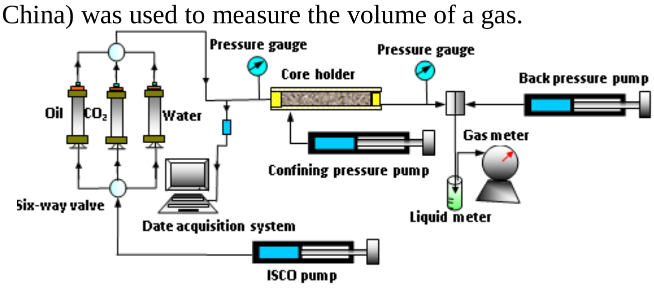

Fig. 1. Schematic of the experimental setup

C. Experimental Procedures

Experimental studies were carried out using three different driving methods, which were water flooding, CO_2 flooding and WAG respectively. Three different driving methods share the same experimental procedures as follows: (1) The cores were cleaned and dried at first. Then they were assembled to a long core. (2) To remove the gas in the core by pulling a vacuum on it, and then it was saturated by simulating formation water. (3) Oil displacing water was carried out at the speed of 0.5cc/min last for 20PV. The irreducible water saturation was calculated based the date which come from the above experiment. (4) Experiments were carried out using different driving methods. Fluid volume (oil, water and gas) and upstream/downstream pressure were recorded. (5) The cores were cleaned and dried after the experiment. Repeat the above-mentioned steps to perform different experiment.

III. RESULTS AND DISCUSSION

A. Water Flooding Experiment

It is clear from Figure 2 that water breakthrough when the injection volume reaches 0.31 times of pore volume (PV), the water breakthrough recovery percent (RP) is 39.34%. After water breakthrough, water cut shows rapidly increase and it costs 0.35PV to make the water cut reaches 90%. The ultimate recovery percent (URP) of water flooding is 51.56%.

It can be seen from Figure 3 that the experimental core has high injection pressure, which is 39.09MPa on average. The injection pressure increases as the injection volume increase, after the injection volume reaches 0.6 PV, the injection pressure falls with a slow rate. Therefore water injection is difficult to carry out in the target reservoir.

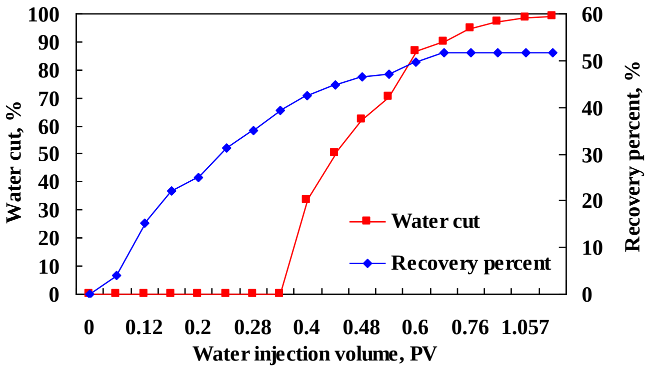

Fig. 2. Water flooding RP and water cut curve

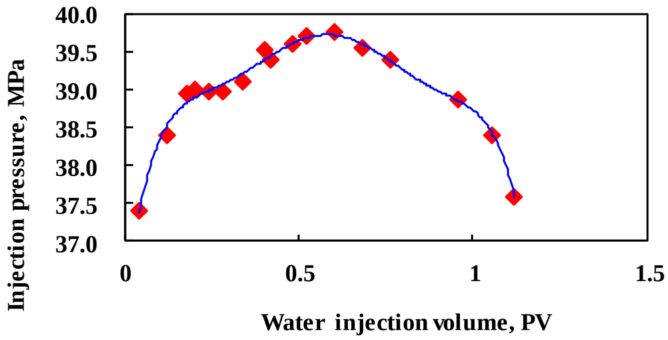

Fig. 3. Water injection pressure curve

B. CO_2 Flooding Experiment

As seen in Table 1, the injection volume at gas breakthrough, RP at gas breakthrough and URP increase along with the injection rate increase.

TABLE 1 CO_2 flooding experimental results

Injection rate (cc/min)	Injection pressure at gas breakthrough (PV)	RP at gas breakthrough (%)	URP (%)
0.2	*0.61*	*17.21*	*72.91*
0.5	*0.72*	*18.34*	*76.23*
1.0	*0.73*	*22.45*	*78.32*
1.5	*0.76*	*24.44*	*79.74*
2.0	*0.81*	*30.67*	*80.24*

It can be seen from Figure 4 that the RP increases along with the increase of CO_2 injection volume and injection rate. That is mainly because higher injection rate will lead to higher injection pressure, thus more CO_2 is dissolved in oil, due to which the oil viscosity and the interface tension reduces and the flooding is much more close to miscible flooding. Figure 5 shows that CO_2 breakthrough when the injection volume reaches 0.6PV and the gas-oil ratio (GOR) begin to increase slowly. GOR shows rapidly increase after the injection volume reaches 1.2PV. It can be seen from Figure 6 that injection pressure increases as the increase of injection volume before CO_2 breakthrough. CO_2 injection pressure shows significant decrease after CO_2 breakthrough. Higher injection rate can lead higher injection pressure. It can be seen from Figure 7 that in case of higher injection rate, more CO_2 injection volume is needed to make CO_2 breakthrough and the breakthrough RP is higher as well.

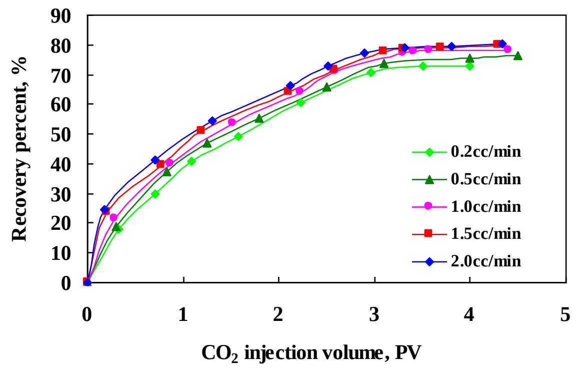

Fig.4. CO_2 flooding RP curves at different injection rates

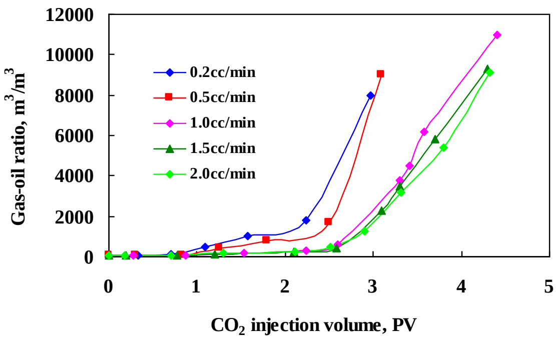

Fig. 5. GOR curves at different injection rates

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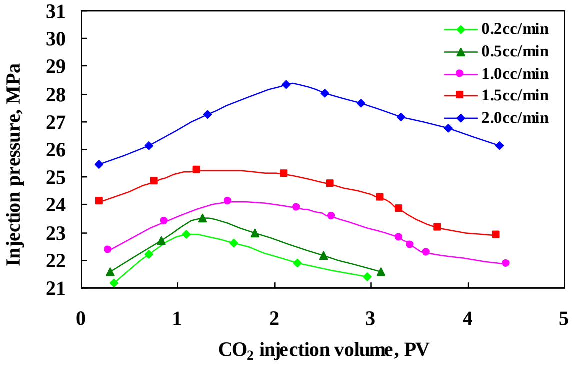

Fig. 6. CO_2 injection pressure curves at different injection rates

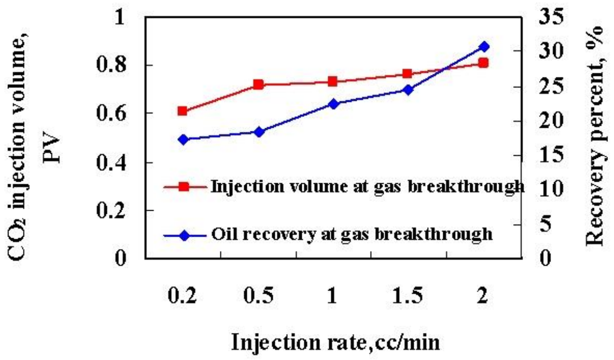

Fig. 7. RP and injection volume at gas breakthrough at different injection rates

C. Water alternating Gas (WAG) Flooding Experiment

(1) Water-gas ratio (WGR) Optimization Experiment

WGR refers to the volume ratio between injection water and injection gas under reservoir conditions in the WAG process. In this experiment, the injection rate is 0.5cm^3/min, and the injection slug is 0.2PV. Five WGRs (1:3; 1:2; 1:1; 2:1; 3:1) are performed.

TABLE 2 WAG experimental results at different water gas ratio

WGR (m^3/m^3)	Injection volume at water breakthrough (PV)	RP at water breakthrough (%)	URP (%)
1:3	*2.92*	*50.24*	*78.32*
1:2	*1.37*	*55.17*	*77.71*
1:1	*1.13*	*52.46*	*79.91*
2:1	*0.92*	*32.03*	*76.40*
3:1	*0.88*	*9.34*	*75.41*

(2) Slug Size Optimization Experiment

In this experiment, the injection rate is 0.5cm^3/min, and the WGR is 1:1. Five slug sizes (0.05PV; 0.1PV; 0.2PV; 0.3PV; 0.4PV) are designed.

As seen in Table 3, the injection volume at gas breakthrough and the injection volume at water breakthrough decreases along with the slug size increase. The slug size is 0.2PV with the maximum URP.

TABLE 3 WAG experimental results at different slug size

Slug size (PV)	Injection volume at water breakthrough (PV)	RPy at water breakthrough (%)	URP (%)
0.05	*1.93*	*54.21*	*62.55*
0.1	*1.38*	*55.53*	*78.95*
0.2	*1.13*	*53.56*	*80.21*
0.3	*1.06*	*29.34*	*77.58*
0.4	*0.81*	*8.45*	*74.77*

(3)Alternating Timing Optimization Experiment

In this experiment, the injection rate is 1.0 cm^3/min, and the WGR is 1:1. The slug size is 0.1PV. The alternating timing refers to the volume of CO_2 which have been injected in the core before WAG experiment.

TABLE 4 WAG experimental results at different alternating timing

Alternating timing	Injection volume at water breakthrough (PV)	RP at water breakthrough (%)	URP (%)
0.1	*1.11*	*43.25*	*83.68*
0.2	*1.38*	*37.89*	*82.77*
0.3	*1.55*	*35.56*	*85.68*
0.4	*1.81*	*31.47*	*81.65*
Breakthrough	*2.13*	*32.95*	*86.21*

At first, in this experiment, the core was injected CO_2 with the volume of 0.1PV, 0.2PV, 0.3PV, 0.4PV and CO_2 breakthrough respectively as five different alternating timings. As seen in Table 4, the earlier the alternating timing is, and the latter gas breakthrough and the earlier water breakthrough. The URPs of different alternating timings are close.

IV. CONCLUSIONS

1) Environmental problems caused by CO_2 emissions have caught much attention worldwide. Combining CO_2 storage with EOR can not only make profit for oil companies but also lead to a contribution to the environment. Thus further researches on CO_2 flooding in oil extraction are strongly needed.
2) URP of water flooding is 51.56%, and that of CO_2 flooding is 72.91%-80.24%.
3) RP of CO_2 flooding increases along with the increase of injection CO_2 volume. Increasing rate of CO_2 flooding recovery slows down after the CO_2 breakthrough. CO_2 flooding RP increases as the increase of injection rate. Once the injection rate increases, the CO_2 breakthrough time delays and the breakthrough recovery increases. CO_2 injection pressure increases as the increase of injection volume, the injection volume increases and injection pressure significantly reduces after CO_2 breakthrough. CO_2 flooding reaches better development effect under high injection rate and pressure.
4) Earlier water alternating CO_2 leads to higher injection pressure and production rate, the water breakthrough time also become earlier while the CO_2 breakthrough time delays, and higher recovery percent will finally made.
5) Water alternating CO_2 should given priority when using CO_2 flooding. In case of water alternating CO_2, the

optimum WGR is 1:1 and the optimum plug size is 0.1PV, earlier water alternating CO_2 will makes better development effect.

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