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Research of Improving Super Heavy Oil Properties Through Flue Gas

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ABSTRACT

Flue gas capacity of improving super heavy oil properties was investigated by laboratory experiment, and the experimental results showed that flue gas could play a role of swelling and reducing viscosity after being dissolved in super heavy oil. Within the experiment temperature range, flue gas maintained smaller solubility and volume factor in super heavy oil, and the viscosity of oil and gas mixture appeared a sharp fall after flue gas being dissolved in super heavy oil, meanwhile the viscosity reduction rate fundamentally appeared a linear increase. Flue gas assisting SAGD feasibility was analyzed, and the results showed that flue gas could obviously enlarge the steam chamber extension in the transverse direction and slow down the rate of increase in the longitudinal direction after being injected with steam. As a result, it could play a very good effect of adjusting steam chamber shape and temperature distribution. Therefore flue gas assisting SAGD is feasible, which is also an important means of improving development effect and enhancing oil recovery for super heavy oil reservoir SAGD in the middle and later periods.

Key words: Super heavy oil; Flue gas; Solubility; Volume factor; Viscosity

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INTRODUCTION

Super heavy oil is alternatively named natural asphalt, which refers to the crude oil with the degassing oil viscosity greater than 50000 mPa·s and density greater than 0.98 g/cm^3 under the condition of formation temperature[1]. As the super heavy oil has special high viscosity and high freezing point features, currently the vast majority of these reservoirs uses steam heating to improve the way to exploit crude oil rheology[2-3]. Moreover, conventional steam stimulation mining is poor, which even can't form an effective use. How to develop such reservoirs has been a worldwide problem, and the key point of solving the problem is to improve the physical properties of super heavy oil, reduce oil viscosity, and improve the flow capacity of crude oil. By simplifying the flue gas component, I considered it as a mixture of nitrogen and carbon dioxide with 85% the proportion of nitrogen, and 15% the proportion of carbon dioxide, carried out experiment to modify the physical properties of super heavy oil using flue gas, provided guidance for the development of super heavy oil, and offered new solutions to deal with greenhouse gases, which fit the national energy saving requirements.

1. LABORATORY EQUIPMENT

High pressure PVT experimental device was used to make flue gas sufficiently dissolved in crude oil. There is a rotor at the bottom of the high-pressure PVT barrel, which plays a certain role of stirring when turning and can shorten the time to reach equilibrium dissolution. The entire device was placed in the incubator, whose highest temperature can reach 150 ℃. All experiments were performed in the incubator for 4 hours or more thermostat with maximum operating gauge pressure of 50MPa, and the data was collected by the pressure sensor.

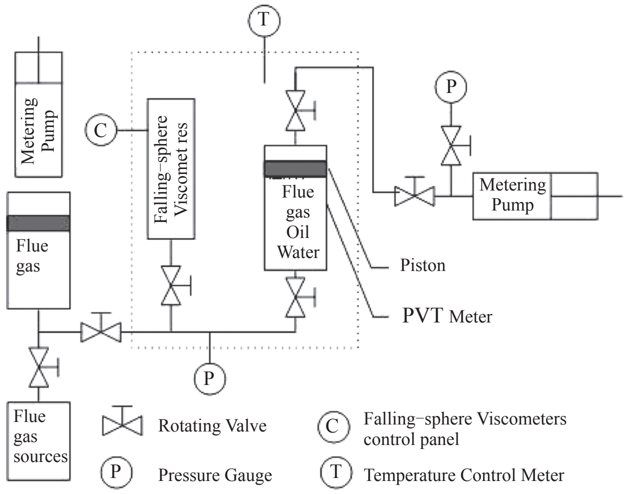

Figure 1
High Temperature and High Pressure PVT Experimental Device

2. RESERVOIR OVERVIEW AND SUPER HEAVY OIL PROPERTIES

The crude oil mentioned in this essay came from Liaohe Oilfield DU 84 Block super heavy oil reservoirs with the depth between 530 m and 649 m, the thickness between 150 m and 210 m, the original reservoir temperature is 30 ℃ and the original reservoir pressure is 6.02 MPa. The average porosity is 36.2% and the average permeability is 5.539 μm^2.

The oil samples used in the experiments were taken from Guanping 12 Well in the block. This type of crude oil was solid-state under normal temperature, and it was very difficult to develop. The properties of Guanping 12 Well crude oil were shown in Table 1.

Table 1
Super Heavy Oil Crude Oil Properties

Crude oil density /g/cm^3	Crude oil viscosity /mPa·s	Colloid + asphaltene /%	Wax content /%	Solidifying point /℃
1.007/20 ℃	231910/50 ℃	52.9	2.44	27

3. ANALYSIS OF EXPERIMENTAL RESULTS

3.1 Heavy Oil Viscosity Stability Characteristics

Guantao oil layer dehydration super heavy oil viscosity-temperature curve was measured by Brook Field RVDV-III digital rheometer. Semi-logarithmic viscosity-temperature curve and double logarithmic viscosity-temperature curve were made based on the experimental data as shown in Figure 2.

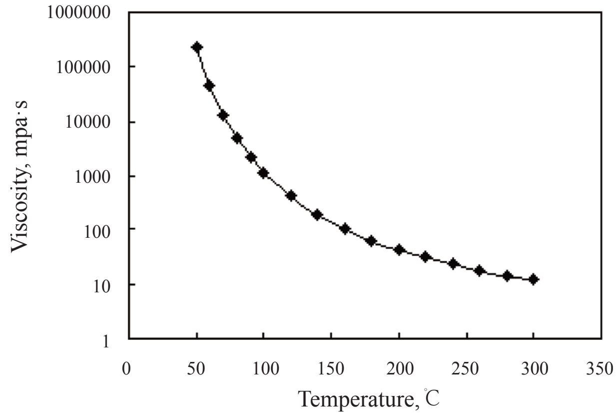

Figure 2
Experimental Zone Viscosity-Temperature Curve of Crude Oil Dehydration

When the temperature is 50 ℃, the oil viscosity is 232294 mPa·s; when the temperature is 80 ℃, the oil viscosity is 4981 mPa·s. As the temperature increases, a significant reduction in oil viscosity appears. Oil viscosity is greatly affected by temperature, and their relationship is close to linear semi-logarithmic, which also shows that using heat in the exploitation of super heavy oil to reduce viscosity and increasing the super heavy reservoir temperature are the main ways to improve oil recovery for this type of oil reservoir .

3.2 Flue Gas Swelling Effect on Super Heavy Oil

Flue gas can be dissolved in super heavy oil and make it swell. With stronger dissolving capacity and greater coefficient of expansion, the solution gas drive energy will be greater[4-5]. According to different solubility of the flue gas, there are corresponding gas-oil mixture saturation pressure and volume factor, which were measured by the experimental apparatus of high temperature and high pressure PVT physical property analysis. The experimental results are shown in Table 2.

From Table 2 we can see that the solubility capacity of the flue gas was influenced by pressure and temperature. At the same temperature, the solubility increased while the pressure was increasing; under the same solubility condition, the higher the temperature was, the higher the saturation pressure would be. When the gas-oil ratio increased from 1 sm$^{3/}$m^3 to 8 sm^3/m^3, under 60 ℃ condition, the saturation pressure increased from 1.03 MPa to 5.31 MPa; under 80 ℃ condition, the saturation pressure increased from 2.03 MPa to 8.42 MPa; under 100 ℃ condition, the saturation pressure increased from 3.03 MPa to 11.53 MPa. As is considered, the reason is that under low pressure the crude oil has larger molecule gap, and the flue gas molecules' movement affects the solubility a lot. The higher the temperature is, the more intense the gas molecules' movement will be, the more likely the gas will be evaporated, and therefore it's not conducive for it to be dissolved in the crude oil. At a certain temperature, as the pressure increases, the solubility capacity of the flue gas is enhanced again.

Table 2
Flue Gas Solubility-Saturation Pressure-Volume Factor Results

Solubility sm^3/m^3	60 ℃		80 ℃		100 ℃	
	Saturation pressure MPa	Volume factor	Saturation pressure MPa	Volume factor	Saturation pressure MPa	Volume factor
1	1.03	1.011	2.03	1.015	3.03	1.019
2	1.64	1.014	3.09	1.017	4.54	1.021
3	2.4	1.016	4.2	1.020	6	1.024
4	3.33	1.019	5.5	1.023	7.67	1.027
5	4.03	1.022	6.55	1.026	9.07	1.029
6	4.4	1.024	7.27	1.028	10.14	1.032
7	4.82	1.027	7.9	1.031	10.98	1.035
8	5.31	1.030	8.42	1.034	11.53	1.038

With the gas-oil ratio increased from 1 $sm^{3/}m^3$ to 8 sm^3/m^3, under 60 ℃ condition, the volume factor increased from 1.011 to 1.030; under 80 ℃ condition, the volume factor increased from 1.015 to 1.034; under 100 ℃ condition, the volume factor increased from 1.019 to 1.038. At a certain temperature, after the super heavy oil dissolving the flue gas, the volume factor of the oil and gas mixture appears linearly increases as the flue gas solubility increases. Meanwhile, in certain solution gas-oil ratio conditions, the crude oil volume factor slightly increases as the temperature rises. With the increase in the amount of flue gas injection, oil formation volume expansion increases.

After dissolving the flue gas, the volume expansion of the super heavy oil can increase the elastic energy for the oil reservoir. For the gradually formed steam chamber as a result of steam injection, the flue gas undissolved in the super heavy oil and formation water plays a role of occupying the steam chamber and generates displacement effect. The injected flue gas can do better in pushing the steam to the leading edge of the steam chamber, which can make better use of latent heat of vaporization of the steam. In addition, the flue gas dissolved in the remaining oil of steam chamber affected area can reduce the residual oil saturation to some extent, but in the steam chamber the residual oil itself is low, such reduction doesn't have great impact on the ultimate recovery. Overall, the volume expansion amount of crude oil caused by flue gas dissolving in super heavy oil is not big, the volume factor is still lower than 1.04 when reaching the maximum solubility capacity in the experiment.

3.3 Flue Gas Viscosity Reduction Effect on Super Heavy Oil

Flue gas dissolved in the crude oil can reduce the viscosity of super heavy oil, improving its liquidity. The viscosity reduction magnitude depends on the solubility of the flue gas in the super heavy oil[6-7]. According to different flue gas solubility, corresponding oil and gas mixture viscosity was measured respectively by the falling ball viscometer at 60 ℃, 80 ℃ and 100 ℃, and the viscosity reduction was calculated as well. The experimental results are shown in Table 3.

Table 3
60 ℃, 80 ℃, 100 ℃ Flue Gas - Super Heavy Oil Mixture Viscosity Experiment Results

Solubility sm^3/m^3	60 ℃		80 ℃		100 ℃	
	Viscosity mPa·s	Viscosity reduction ratio%	Viscosity mPa·s	Viscosity reduction ratio%	Viscosity mPa·s	Viscosity reduction ratio%
1	44747	3.36	4841	2.81	1119	2.44
2	43106	6.91	4694	5.76	1090	5
3	41517	10.34	4551	8.63	1061	7.5
4	39978	13.66	4412	11.43	1033	9.93
5	38486	16.89	4276	14.15	1006	12.31
6	37040	20.01	4145	16.79	979	14.63
7	35638	23.04	4016	19.37	953	16.9
8	34279	25.97	3891	21.88	928	19.11

The experimental results show that, at the same temperature, as the solubility of the flue gas increases, the viscosity of the gas-oil mixture appears a sharp fall, which embodies that the viscosity ratio increases linearly with the increase of temperature. At 60 ℃,the viscosity reduction ratio increases from 3.36% to 25.97%; at 80 ℃, the viscosity ration increases from 2.81% to 21.88%; at 100 ℃, the viscosity ration increases from 2.44% to 19.11%. As the reason is analyzed that the contact of flue gas and super heavy oil can extract the light components from the crude oil, forming or approaching the pseudo mixed phase, and acts as a continuous phase in the oil and gas mixture, separating colloid, asphaltene and other heavy components into non-continuous phase, and has greatly weakened their influence on the viscosity of the whole system.

4. FLUE GAS ASSISTING SAGD FEASIBILITY ANALYSIS

To carry out flue gas assisting SAGD feasibility analysis on the basis of the history matching, in which the flue gas (85% nitrogen, 15% carbon dioxide) physical parameters (such as density, viscosity, etc.) and gas-liquid equilibrium constants were exported after using CMG-Winprop module to achieve fitting phase to ensure the reliability of the simulation parameters.

When SAGD is assisted by gas, the amount of steam injection can be appropriately reduced. Research results from scholars home and abroad show that in the process of gas assisting SAGD, an appropriate reduction of steam can extend production time and dramatically increase the oil-steam ratio, thus making sure the sum of injected steam and flue gas is the same as steam injection alone, both are 50 m^3/d when conducting flue gas assisting SAGD feasibility analysis; the injection speed of flue gas and steam is consistent, namely the ratio of steam and flue gas is 1:1.

When conducting flue gas assisting SAGD numerical simulation, the steam injection speed of all five injection wells was cold water equivalent rate of 25 t/d. The flue gas was injected from injection wells along with the steam at the injection speed of 25 m^3/d.

Feasibility analysis was conducted between the SAGD stage and consider production time. The evaluation indexes are cumulative oil production, daily oil output, oil and gas ratio and oil/gas+ steam ratio.

Table 4
Flue Gas Assisting SAGD Feasibility Analysis

	Production time (d)	Cumulative steam injection (t)	Cumulative gas injection (m^3)	Cumulative oil production (t)	Oil and steam ratio	Daily oil output (t/d)
Pure steam	3093	897091	0	289682	0.323	93.66
Flue gas + steam	5346	995967	464372	403765	0.276	75.53

From Table 4 we can see that, under the condition of flue gas injection with steam, SAGD production time was extended by 2253 days and the cumulative oil production increased by 114083 tons, despite slight decline of oil and steam ratio and sharp fall of daily oil output. The effect of oil production increase was obvious. Therefore flue gas injection with steam is feasible.

CONCLUSIONS

(1) The flue gas swelling experiment shows that, as the pressure increases, the solubility of the flue gas in the super heavy oil is increasing gradually, the formation oil volume expands, and the volume factor increases with the increase of dissolved flue gas. Within the experimental temperature range, flue gas solubility in the super heavy oil is small, and the volume factor is small. Corresponding to the original reservoir pressure, the solubility is less than 8 sm^3/m^3 while the volume factor is less than 1.04.

(2) The flue gas viscosity reduction experiment shows that, within the experimental temperature range, the oil and gas mixture viscosity declines dramatically after the flue gas being dissolved in the super heavy oil, and the viscosity ratio fundamentally appears a linear increase. When the solubility reaches 8 sm^3/m^3, the viscosity reduction ratio can reach 25.97% at the maximum.

(3) The physical properties of the super heavy oil can be improved by flue gas swelling and viscosity reduction, and flue gas swelling can increase the elastic energy for the oil reservoir. For the gradually formed steam chamber as a result of steam injection, the flue gas undissolved in the super heavy oil and formation water plays a role of occupying the steam chamber. The injected flue gas can do better in pushing the steam to the leading edge of the steam chamber, which can make better use of latent heat of vaporization of the steam. In addition, viscosity reduction can improve the liquidity of the super heavy oil.

(4) The injection of the flue gas has reduced the amount of steam to some extent, reducing the temperature in the steam chamber. Under the steam chamber temperature and pressure conditions, the flue gas distributes in the upper portion of the steam chamber to form a thermal barrier, slowing the longitudinal heat conduction, thus relatively slowing down the expansion of the steam chamber in the longitudinal direction and enhancing the expansion in the transverse direction, slowing the top water breakthrough

time and extending the time of SAGD stage, meanwhile making the temperature distribution in the steam chamber more uniform. Therefore flue gas injection assisting SAGD is feasible.

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