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CO_2 Flooding in Ultra-low Permeability Reservoir – Fang 48 Block of Daqing Oilfield

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Summary

CO_2 flooding is a process whereby carbon dioxide is injected into an oil reservoir in order to increase output when extracting oil. Since 1952, Wharton obtained the patent concern CO_2 flooding, CO_2-EOR(CO_2 Flooding Enhance Oil Recovery) has been one of research hot-spot around the world. According to the statistical data of 2006, there are total of 94 global CO_2-EOR projects, including 65 low permeability oilfield projects(79%of the total)[Leena Koottungal, 2008]. Daqing Oilfield is the largest one of China, after more than 50 years of continuous development, oilfield comprehensive water cut has reached over 90%, the difficulty of oilfield development has been gradually increasing. In recent years, low and ultra-low permeability reservoirs development have played an more and more important role accompany with low permeability reserves in proportion of the total reserves have been increasing year by year. But water-flooding recovery of low permeability reservoir is very low under the influence of reservoir poor properties and heterogeneity. As a kind of greenhouse gas, CO_2 flooding can obtain good results for the low permeability reservoir in which the water flooding has proven ineffective. Fang 48 block CO_2 flooding Pilot Test was conducted under such background since Dec.2002, Practice has proved that CO_2 flooding is a effective method to improve the development effect, all experience during the mechanism study and field test should present important references for further larger-scale CO_2 flooding projects.

Introduction

Low permeability reservoir are characterized by small reservoir pore, fine throat, high filtration resistance, fluids flow is not coincident with Darcy law which has been influenced by Start-up Pressure Gradient, etc. All these factors lead to high injection pressure and small water absorption capacity, low production and decline rapidly[Li Li, Pang Yanming, 2006]. Therefore, the key to improve the development effect of low permeability reservoir is to improve fluid flow capacity by using both physical and chemical means. CO_2-EOR are suitable through the process of primary, secondary oil production, it's also can be an ideal tertiary recovery method. It is particularly effective in reservoirs deeper than 600m where CO_2 will be in a supercritical state, the viscosity of any hydrocarbon will be reduced and hence will be easier to sweep to the production well.

Reservoir properties of Fang 48 Pilot block

Fang 48 Pilot block is located at ZhaoZhou nose structure of SanZhao depression in SongLiao Basin Northeastern China, there are total of 6 wells in field pilot block, including one injection well and five production wells. Fuyu reservoir is the main production layers(QuanTou formation of lower Cretaceous), reservoir buried depth is about 1880m, original formation pressure is 20.4MPa, formation temperature is 85.9℃. Oil bearing area of Pilot test well group is about 0.43km^2, OOIP is 16×10^{4}t. Based on core analysis result, Fuyu reservoir's physical property is poor due to the experience of intense diagensis, average porosity is 14.5%, average air permeability is 0.681×10^{-3}μm^2, it belongs to ultra-low permeability reservoir. Crude oil density is 0.815t/m^3, freezing point is 33℃, wax content is about 25.6%.

According to PVT data, oil viscosity is 6.6mPa.s, original saturation pressure is 5.3MPa, crude oil volume factor is 1.089, initial gas-oil ratio is 17.5m^3/t.

CO_2-EOR Mechanism

CO_2 will easy to be in a supercritical state when temperature higher than critical temperature or pressure exceed the threshold value, CO_2 properties will be changed, its density is close to the liquid and viscosity is close to the gas, diffusion coefficient of CO_2 is 100 times of the liquid and very easy to dissolve[D. Abdassah, S. Siregar, 2000].

- CO_2 is easy to dissolve in crude oil, the oil solubility is 3-9 times than that in water, in the flooding process, can greatly reduce the oil-water interfacial tension and lowering residual oil saturation.
- CO_2 dissolution can lowering crude oil viscosity of 1/10 or so, lower viscosity can improve crude oil flow capacity .
- According to the Canada Manorville oilfield Lab study results, CO_2 dissolution can make oil volume expansion 28-50%, crude oil volume increase improved the crude oil flow capacity and greatly reduce the capillary resistance.
- CO_2 dissolution can lead to formation water acidizing and dissolved part of pore jams, make the reservoir permeability increased.
- Miscible Effect under a certain pressure. Miscible Effect refers to two kinds of fluid can dissolve each other and eliminate the interfacial tension, it can not only extracted the light hydrocarbon component from crude oil, but can form a mixed belt, oil belt movement is one of the most effective way in process of oil displacement, the recovery ratio can even reach above 90%.

CO_2 Flooding Mode

- Minimum Miscible Pressure(MMP)

CO_2 flooding can be classified into two kinds: Miscible flooding (when the displacement pressure is higher than MMP) and Immiscible flooding. The domestic and foreign research data shows that oil displacement efficiency of miscible flooding is much higher than that of immiscible flooding. MMP not only depends on the purity of CO_2 and reservoir properties, but also depends on crude oil components. According to Lab study result of the Slim-tube test and Interfacial tension method, MMP of Fuyu reservoir in Fang 48 pilot block is determined to be about 30-32MPa which is far higher than oil displacement pressure in field. Crude oil properties in Fang 48 pilot block is characterized by high wax and pectin content and high freezing point, Higher original heavy components content（＞C5 components) result in higher minimum miscibility pressure. Therefore, Fang 48 pilot block CO_2 flooding belong to immiscible flooding.

- Injection Capacity Analysis

Long core gas displacement experiment has been conducted to simulation and determined the physical properties under reservoir condition. All the samples are from coring well in Fang 48 block, average sample diameter is 2.5 cm, sample permeability is 0.2-5.9$\times 10^{-3}\mu m^2$, oil saturation is 49.7%- 58.7%. In order to meet the requirement of experiment, select samples with similar properties joining together into five long core models. Lab study results shows that:

- ✓ Injection capacity is closely related with rock permeability and injection pressure.
- ✓ Gas injection capacity is far higher than water injection capacity. Gas injection capacity is over 100 times larger than water injection capacity. In addition, Injection water easy to cause clay swelling, injection capacity will become more and more low.
- ✓ When gas breakthrough, gas injection capacity increase sharply, because injection gas mainly go through by the breakthrough channels, the gas displacement efficiency will be reduced

greatly as well. Therefore when undesirable gas channeling happened, it's better to consider other displacement mode.

- Water Alternating Gas injection(WAG)

Gas flooding effect depends on oil sweep efficiency increases. In most cases, gas fingering and channeling will happen in an undesirable stage by reservoir heterogeneity influence. Therefore, retard gas channeling is the key to improve gas flooding effect[Li XiangLiang, Li Zhenquan, 2002]. WAG is a good choice to solve the problem. Through Water Alternating Gas injection, on the one hand, injection water will reduce gas relative permeability and retard gas fingering; On the other hand, it's availably to decrease oil-water mobility ratio and residual oil saturation, so as to improve both sweeping volume and displacement efficiency.

According to the study result of long core WAG experiment, gas displacement recovery of core sample ($K=5.9\times10^{-3}\mu m^2$) is only about 29.22% because of early gas channeling. When oil content is very low in output fluid, Stop gas injection and change into water injection. By the end of WAG experiment, recovery reach 42.86% which is increased by 13.64%. It is obvious that WAG is greatly improve the development effect.

Field Pilot Test

- Fang 48 pilot well group started production in Dec. 2002, then oil production decline rapidly and water cut increase. Due to the insufficient gas source, CO_2 injection started until April 2003. There are total of 6 wells in pilot area, including one gas-injection well and five production wells. Contrast performance with nearby similar reservoir , CO_2 injection pressure is lower than water injection pressure 1.0- 4.0MPa, CO_2 injection intensity is 3.0 times of water injection intensity. CO_2 injection soon come into effect, production began to rebound quickly and tends to be stable.
- After two years of CO_2 flooding, Fang 48 pilot area began to in trouble of gas channeling problems. In generally, Continental sedimentary heterogeneous is more serious. Based on core analysis data, Fuyu reservoir Interlayer heterogeneity is very strong, vertical permeability contrast is 297.5, mutation coefficient is about 5.7. After gas channeling, oil-gas ratio increased rapidly, average oil-gas ratio reached $450m^3/t$. Suffer gas channeling influence, some oil production wells were forced to periodic shut and total oil production began to decline.
- In order to control gas channeling problems, WAG was started in Nov.2009. Through the implementation of WAG, oil-gas ratio begin to decrease and oil production rebound obviously and remain stable. By the end of 2012, cumulative CO_2 injection is 3.23×10^4t, cumulative water injection $3400m^3$, cumulative oil production is 1.32×10^4t, recovery percentage of OOIP reached 8.24%, development effect is obviously better than that of similar reservoir with water-flooding, with cumulative incremental oil production of 58.5%.

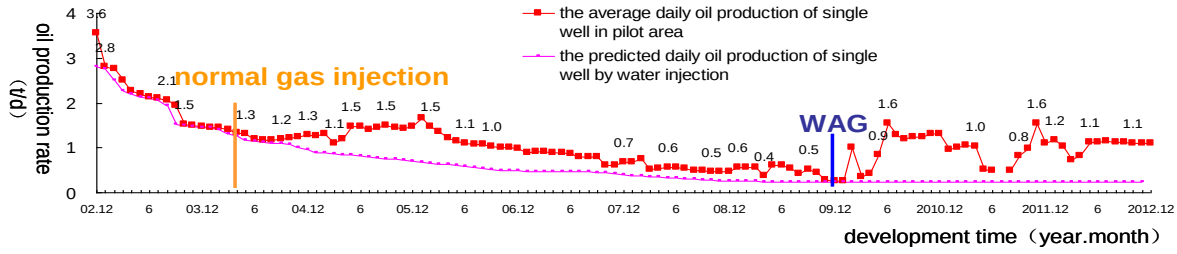

Figure1. Average daily oil production of single well in Fang 48 pilot area

Conclusions

In the middle-late period of oilfield development, development object will gradually turn to low and ultra-low permeability reservoirs. Practice has proved that CO_2 flooding is a effective method to improve the development effect of low permeability reservoir, all experience during the mechanism study and field test should present important references for further larger-scale CO_2 flooding projects.

- In the process of CO_2 dissolution, CO_2 will be in a supercritical state, the oil-water interfacial tension and the viscosity of oil can be reduced and fluid flow capacity greatly increased. Gas injection capacity is much higher than water injection capacity.
- Crude oil properties of Fang 48 pilot block is characterized by high wax and pectin content and high freezing point, which causes the higher miscibility pressure. According to the long-core experiment study result, MMP is determined for about 30-32MPa which is much higher than displacement. Therefore, Fang 48 block CO_2 flooding is a kind of immiscible flooding.
- Interlayer heterogeneity of continental sedimentary reservoir are relatively serious. In addition, the network of natural fractures and artificial fractures by higher injection pressure are easy to formed channels for gas breakthrough, thus lowering the sweep efficiency. Gas channeling treatment should be strengthened in the future.
- According to field pilot test result, WAG is a good choice to control gas channeling problems, through the implementation of WAG, oil-gas ratio can be decreased and oil production rebound obviously.
- Fang 48 field pilot test shows that CO_2 flooding can obtain good results for the low permeability reservoir in which the water flooding has proven ineffective. But there are still many problems should be solved before a wide range application of CO_2 flooding, e.g. corrosion and scaling problems when injection CO_2 produced carbonate acid, looking for sufficient gas source and control of gas channeling etc.

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