EOR Screening and pilot in YCAS Low Permeability Oilfield

Peng Liu
Daqing Oilfield Exploration and Development Research Institute, Daqing, Heilongjiang, 163712, China
*Corresponding author’s e-mail: liupeng5@petrochina.com.cn

Abstract. According to the reservoir characteristics and fluid characteristics of YCAS oilfield, combined with different EOR Process Screening, a method for enhancing oil recovery was selected for this oil field, and the polymer flooding parameters were optimized using numerical simulation software. The pilot test of the oil field shows that polymer flooding can greatly improve the oil recovery rate, which provides a reference for the efficient development of oil fields.

1. Introduction
YCAS oilfield is a multi-fault-block field which is located in the western of depression of ordos basin with edge and bottom water. Ten main hydrocarbon-bearing reservoirs were encountered from bottom to top in this area, with different characteristics. They are CIX-CI with 23 sub-layers. Gross thickness of sand layer ranges from 5.0m to 27.5m, with average of about 18.8m; the net pay of sand layer ranges from 1.5m to 18.9m, with average of about 13.7m; the permeability ranges from 11.5×10⁻³μm² to 102×10⁻³μm², with average of about 83×10⁻³μm²; the porosity ranges from 3.3% to 23.7%, with average of about 15.9%. Most of the sand stones are oil wet.

Reservoir rocks are composed of fine to coarse sandstones and conglomeratic sandstones, with high resistivity and low SP value. The rock composition of reservoir is dominated by detrital grain ranges from 60% to 70%, accounting for about 55% to 73.4% of rock components. Matrix in rock component accounts for 3.4% to 10.3%, ranging from 0% to 43%. The others are authigenic clay cement, heavy minerals and porosity. Among of them, porosity occupies 10.7% to 25% of rock components. It ranges from 2% to 35%. Pores of the reservoirs are dominantly primary intergranular, locally secondary micro-intragranular or moldic due to partial or total dissolution of feldspar.

Capillary analysis data shows that the pore throat size is larger, being more than 0.27 μm when Hg saturation equals to 50%. When pore throat size is more than 1.3 μm, it occupies about 19.4% to 66.6% of all pore throats. Swi ranges from 6.3% to 53.8%, mostly ranging from 13% to 30%.

2. Fluid Property
Totally, 20 oil samples were collected from 13 wells in YCAS oilfield, the reservoir temperature of which ranges from 78°C to 95.2°C and pressure ranges from 16.06MPa to 25.63MPa. The GOR of reservoir oil is very low, just between 0.88m³/m³ and 3.96m³/m³; and bubble point pressure is also very low, just between 0.33MPa and 1.50MPa. The oil FVF is small that distributed in the range of 1.03 to 1.06. Very low bubble point pressure means that no gas will be released during depletion period. The lab data of fluid samples are summarized and shown in table1.
Field-wisely, the fluid viscosity in the upper formation is relatively high, ranging from 21.3 mPa.s to 26.6 mPa.s. In contrast, the fluid viscosity in the lower formation is relatively low, just within the range of 12.3 mPa.s to 16.7 mPa.s, with average of 14.1 mPa.s.

### Table 1. Samples statistic data in YCAS oilfield

|                | 1#  | 2#  | 3#  | Average |
|----------------|-----|-----|-----|---------|
| Depth(m)       | 1007.5 | 1105.6 | 1299.8 | 1137.63 |
| Net Pay(m)     | 1.1  | 7.9  | 16.6 | 8.53    |
| Oil Saturation(%) | 86.3 | 48.1 | 66.6 | 67.23   |
| Porosity(%)    | 6.6  | 20.7 | 16.9 | 14.73   |
| Permeability(×10^{-3}μm²) | 23.3 | 98.6 | 80.3 | 67.4    |
| Reservoir Pressure(MPa) | 18.8 | 21.2 | 24.7 | 21.57   |
| Reservoir Temperature(℃) | 79.8 | 88.8 | 94.4 | 87.67   |
| Viscosity(cp)@reservoir condition | 23.3 | 19.7 | 14.9 | 19.3    |
| GOR(m³/m³)     | 0.66 | 3.12 | 2.89 | 2.22    |
| FVF            | 1.03 | 1.04 | 1.04 | 1.04    |
| Salinity of formation water(mg/L) | 2011.1 | 2676.3 | 3013.2 | 2566.87 |

Six samples were collected from YCAS oilfield for water property lab test, and mineral analysis was conducted for these samples. Total dissolved solids were used to obtain water property parameters. TDS of wells excluding water source wells vary from 1954 mg/L to 3390 mg/L, with an average of 2721.4 mg/L. The average content of Ca²⁺ and Mg²⁺ in the formation is about 97 mg/L and 101 mg/L.

3. EOR Process Screening

![Figure 1. Appropriate EOR process for different reservoir conditions](image)

Generally, most of EOR methods are common used in the worldwide including ① chemical flooding such as Micellar, Polymer flooding, SP (Surfactant + Polymer) injection, ASP (Alkaline + Surfactant + Polymer) flooding. ② gas injection such as miscible or immiscible CO₂, Nitrogen gas, Flue gas. ③ thermal method such as Huff-Puff cycling, steam flooding, combustion in situ. Recently, the more complex processes such as foam method, foam + ASP, even Micro-bacteria method as the quaternary process for EOR. Except the reservoir depth, oil viscosity, reservoir temperature, formation
heterogeneity, formation water salinity and other requisites should be considered before EOR process screening, every process has its suitable range corresponds to the reservoir condition.

(1) Based on the Criteria on EOR Process Screening in 1984 by Natl. Petroleum Council (NPC) reports[1], there are some conditions for appropriate EOR method, as shown in figure 1.

(2) Based on the EOR screening criteria revised[2], concerning current oil price, oil-displacement mechanisms and results of EOR field projects. Depth, oil gravity, and oil production from hundreds of reports[1], there are some conditions for appropriate EOR method, as shown in figure 1.

(3) Based on the experiences of Polymer Flooding in Daqing Oilfield [4-6], Daqing oil field concluded a set of criteria (Multi-parameter) for polymer flooding through abundant successful tests and applications (table 3).

| Table 2. Summary of screening criteria for EOR methods |
|---------------------------------|
| **Oil Properties** | **Reservoir Characteristics** |
| **Gas Injection Method(Miscible)** |  |
| Nitrogen and flue gas | $>$50°C | $<$0.4 MPa | High percent of $\text{C}_7$ to $\text{C}_1$ | $>$40% | Sandstone of carbonate | Thin unless dipping | Not Critical | $>$6,000 | Not Critical |
| Hydrocarbon | $>$21°C | $<$0.8 MPa | High percent of $\text{C}_7$ to $\text{C}_1$ | $>$30% | Sandstone of carbonate | Thin unless dipping | Not Critical | $>$4,000 | Not Critical |
| CO$_2$ | $>$22°C | $<$1.5 MPa | High percent of $\text{C}_7$ to $\text{C}_1$ | $>$20% | Sandstone of carbonate | Wide range | Not Critical | $>$2,500 | Not Critical |
| Immiscible gases | $>$12 | $<$600 | Not Critical | $>$35% | Sandstone | Not Critical | NC if dipping and/or good vertical permeability | Not Critical | $>$1,800 | Not Critical |
| **Enhanced Waterflooding** |  |
| Micellar Polymer, ASP, and Alkaline Flooding | $>$20°C | $<$35°C | Light, intermediate, some organic acids for alkaline floods | $>$35% | Sandstone preferred | Not Critical | $>$100°C | $>$9,000 | $<$2,500 | $>$200°F |
| Polymer Flooding | $>$15 | $<$150, $>$10 | Not Critical | $>$50% | Sandstone preferred | Not Critical | $>$100°C | $>$9,000 | $<$2,500 | $>$200°F |
| Combustion | $>$10°C | $<$5,000 | Some asphaltic components | $>$50% | High porosity Sandstone | Not Critical | $>$10°C | $<$50°F | $<$1,500 | $>$100°F |
| Steam | $>$8 to 15°C | $<$200,000 | High porosity Sandstone | $>$20 | High porosity Sandstone | Not Critical | $>$200°C | $>$240°F | $<$4,500 | $>$1,500 | Not Critical |
| Surface mining | 7 to 11 | Zero cold flow | Not Critical | $>$8 wt% Sand | Mineable tar sand | Not Critical | $>$10°C | $>$3:1 overburden sand ratio | Not Critical | |

| Table 3. Favourable condition for applying polymer flooding in Daqing oilfield |
|---------------------------------|
| **Advantages** | **Daqing** |
| Variation coefficient | 0.7±0.1 | 0.5-0.8 |
| Average permeability($\times 10^{-3}$µm$^2$) | $>$10 | 100-600 |
| Reservoir temperature(°C) | $<$100 | 45 |
| Formation water salinity(mg/L) | $<$1000 | 3000-7000 |
| Makeup water salinity(mg/L) | $<$1000 | 600-1200 |
| Water cut(%) | Low water cut | 90-96 |
| Oil viscosity (mPa.s) | $<$100 | 8-20 |
| Recovery percentage(%) | Low | 35-45 |
| Well spacing (m)/well pattern | 150-300/5 spot | 150-300/5 spot |
4. Demonstrability of Screened EOR
Based on table 1 to table 3 and initial screening results, Polymer flooding is suggested as the EOR methods in the future in YCAS low permeability oilfield under the necessary measurements adopted. However, YCAS oilfield is a kind of multi-fault-block field with edge and bottom water. The average reservoir temperature is 86.67℃, average oil viscosity ranges from 16.3 mPa.s to 26.6 mPa.s, total salinity of the formation water varies from 1954 mg/L to 3390 mg/L, average permeability is about $8.3\times10^{-3}\text{μm}^2$ (compares to the 3nd class oil strata of Daqing).

The key factors of polymer formula are $1600\times10^4$ Dalton of polymer molecular weight, 1000 mg/L of concentration and 0.14PV/a of injection rate. The polymer injection formula and relative laboratory data referred to Daqing oil field. 5-spots well pattern is employed and the well spacing is about 210m in pilot oilfield. Polymer slug injection is supposed to be started at the water cut is 92% of the well pattern.

![Simulation model for well pattern](image1)

Polymer Module of Eclipse is employed when polymer process screening to be carried on, the simulation model can be seen as the figure 2. The OOIP within this 5 wells pattern estimated by Volumetric methods is about 4569529.9 stb; the porous volume is about 5.683296 Rb; grid numbers are $27\times29\times14$, area is about 0.3132 Km². The history match average relative error is about 0.33%.

![Simulation model for well pattern](image2)

Figure 2. Simulation model for well pattern

Figure 3. Simulation model for well pattern

Figure 3 provides the oil recovery factor and oil increment per ton polymer by different polymer loadings. When the water cut reaches 98%, the recovery factor of polymer flooding increases with the
polymer loading, but the increase rate decreases. Considering the economic benefits, the polymer loading should be selected 500 mg/LPV to 800 mg/LPV, which is increased by 10.37 to 12.64 percentage points of production. The oil increment per ton polymer is about 1123 stb/t to 977 stb/t.

5. Pilot of YCAS Low Permeability Oilfield

Polymer flooding is selected for EOR in YCAS low permeability oilfield. Parameters optimization in polymer flooding are carried out by Eclipse, but the evaluation is only based on limited information and Daqing oilfield successful experiences (figure 4), so if YCAS low permeability oilfield wants to implement polymer project, lots of experimental evaluations and reservoir simulations are needed.

![Figure 4. History of polymer flooding in Daqing](image)

YCAS low permeability oilfield was put into production in Jul, 2008. Square well pattern with 600m well spacing was adopted initially. In May 2010, local infilling was implemented with well spacing of 200m to 300m and the minimum well spacing is about 180m. In Sep 2013, many experiments of polymer flooding were done and then pilot tests was conducted in this oilfield. The performance of pilot oilfield is shown in figure 5.

![Figure 5. Comparison curves of polymer flooding in YCAS low permeability oilfield](image)

Figure 5 shows that water cut of YCAS low permeability oilfield decreased dramatically and oil production increased rapidly. The lower water cut of do nothing is about 95.98%, of polymer is about 70.54%, of prediction is about 68.39%, which decreased 25.44 percentage point, daily oil production increased from 126.6 stb to 367.9 stb, cumulative oil production increased $58.3 \times 10^4$ stb, accounting for 12.76% OOIP.

The pilot test of polymer flooding in YCAS low permeability oilfield has been very successful, which could be expected to be widely promoted under economic conditions.

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