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Case Study：Gas-Cap Reservoir Injection Polymer Barrier to Develop the Buffer Zone Test

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Abstract. This article introduced the application of forming polymer barrier technology on Daqing Lamadian oil field. Demonstrated the feasibility of polymer injection formed barrier wall to develop the buffer zone through the experiments of polymer injection on gas sand and on low water cut formation. The test results show: the cumulative oil increased 4650t and the stage recovery efficiency increased 12.4% after 39 months' production. The polymer barrier separates the oil and gas zone effectively and ensures the normal production of the buffer zone. The success of this test offers a new method on developing the bedded sand reservoir to control the gas cap and increase the development effect.

Keywords : Gas-cap, Buffer zone, Polymer injection to form barrier wall, Test

1. Introduction

Lamadian is a bedded sand reservoir controlled by structure and with a gas cap, the biggest gas-cap area is 32.3km^2. In order to prevent the oil and gas mutual cut, there was a 450m-600m oil ring not been perforated has been left as a buffer zone, which primary oil reserves is 3100×10^4t， is the important potential production area. In order to find an effective method for gas cap development and study the feasibility of developing the buffer zone without developing the gas cap， the injection polymer barrier wall to develop the buffer zone test was done.

2. Technology study

2.1. Parameters of the reservoir

The test site is located at the south of Lamadian oilfield axial part, composed with 3 parts: gas cap, buffer zone and the oil producing zone (figure 1). The gas reserves in place of the target zone SaⅡ2+3 is 1.05×10^8m^3 , the oil reserves in place of the buffer zone is 179.8×10^4t.The porosity of oil reservoir is 28.0% and of gas reservoir is 27.0%, original oil and gas saturation is 78.5% and 75.0%. The average air

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permeability in the gas cap, buffer zone and the oil production zone is 910,236 and 298mD. The effective pay thickness in the buffer zone is 5.1m and in the oil producing zone is 5.2m.

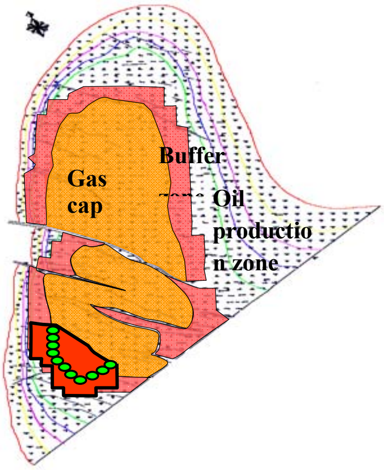

Figure 1 The test site in Lamadian oilfield

2.2. Laboratory experiments about forming polymer barrier wall and developing the buffer zone

In order to study the feasibility of forming polymer barrier wall and developing the buffer zone, laboratory experiments of polymer injection on gas sand and on low water cut formation were done to study the seepage flow mechanism.

Experimental conditions: The simulation geological conditions should be same as which during developing. Simulation formation temperature is 45℃; the max formation pressure is 14 MPa; the gas back pressure is 8.6 MPa; the salinity of the formation water is 7249ppm. The injected water is from Lamadian oilfield water station, the experiment oil is indoor formulating, which viscosity is 10.23mPa.s at 45℃. The molecular weight of the polymer is 19000000, the solution concentration is 1000mg/L and 2000mg/L, the gas is N_2, the core is from the SaⅡ2+3 layer, the air permeability grade is 200, 500 ~ 800, 1200mD.

2.2.1. Laboratory experiment about forming polymer barrier wall

Experiment purpose: study the feasibility of forming polymer barrier wall when injecting polymer to SaⅡ2+3 gas sand layer in no mining condition; the pressure gradient change of layers with different permeability after injecting polymer solution; the breakthrough of gas pressure and the gas flow after forming the polymer barrier wall; the time, pressure and injection rate which the positive rhythm reservoir integral need to form the polymer barrier wall, etc.

Materials: 3 groups of total 36 different cores. The experimental results are list as follows:

1) Irreducible water saturation in cores with medium-high permeability is higher (26.01%-30.79%), the wettability of formation core is slightly water-wet, so it can form polymer barrier wall in the buffer zone .

2) The gas sand under the reservoir state (output back pressure of cores is 8.5 MPa) can inject into the water or polymer solution with low differential pressure, and the inject pressure is relatively stable. The inject pressure gradient reduce with the permeability increase for the same medium, the pressure into the polymer solution is higher than into the aqueous solution for different medium, the injection pressure gradient of 1000 mg/L polymer solution compare with 2000 mg/L polymer solution are not obvious different.

3) Use gas drive the cores full of aqueous solution or polymer solution with constant pressure, the barrier wall can be gassed out (breakthrough) when the high pressure reaches a certain value; the bearing capacity of 2000mg/L polymer solution is good, which can bear 0.95MPa. The bearing capacity of cores with medium permeability is inferior to cores with high permeability or with low permeability [8]。.

2.2.2. Laboratory experiment about Polymer flooding in low water cut formation

Experiment purpose: study the oil displacement efficiency of the buffer zone (low water cut) with polymer injection. Material: 18 cores. The experimental results are list as follows:

1) The final oil displacement efficiency by polymer injection into the low water cut cores is 68%-70%.

2) The final oil displacement efficiency with 0.8PV consumption is 1-2% higher than that with 0.6PVconsumption.

3) The oil displacement efficiency of the polymer solution increases with the core porosity and the air permeability, and has a relationship with the pore structure.

2.2.3. Study on numerical simulation of forming polymer barrier wall and polymer flooding to develop the buffer zone

Use Eclipse simulation software to set up a fine numerical model: the total simulation test area is 7.8 km^2, 2 layers are SaⅡ2+3 and SaⅡ4. In order to study the plane and vertical integral closure of the polymer barrier wall, selects 27 wells continuously in the strip where to build the polymer barrier wall, interprets the well logging curve through subdividing the target layer SaⅡ2+3 into 3 structure units (a, b and c layers). Grid width and length are 25m, 69888 nodes, can meet the demand of fine simulation. Calculation conditions are: the location of barrier wells are in the gas cap, well spacing are respectively 150m and 75m, injecting polymer has the same molecular weight, concentration and average daily individual-well injection rate. Results see table 1.

TABLE 1 Parameters of Forming Polymer Barrier in Real Gas Cap Reservoir Model

Item	Plan 1	Plan 2
Well spacing（m）	150	75
Distance to the oil-gas interface（m）	100	150
Total wells	21	34
Forming barrier wall time （month）	5	3
Polymer molecular weight	1900	1900
Polymer solution concentration（ppm）	1000	1000
Wellhead injection pressure（MPa）	10～13	8～12
Average daily single well injection volume（t）	161	161
Total amount of polymer（$\times 10^4$ t）	51	49
Maintenance of barrier average daily single well injection volume （t）	44	36
Width of polymer barrier(m)	150～200	100～150

From table 1, the plan 2 to form polymer barrier wall need shorter time, smaller dosage, with right width and uniform distribution in the vertical and horizontal than plan 1, so plan 2 is recommended.(results compare with b layer for example with 2 plans see fig.2)

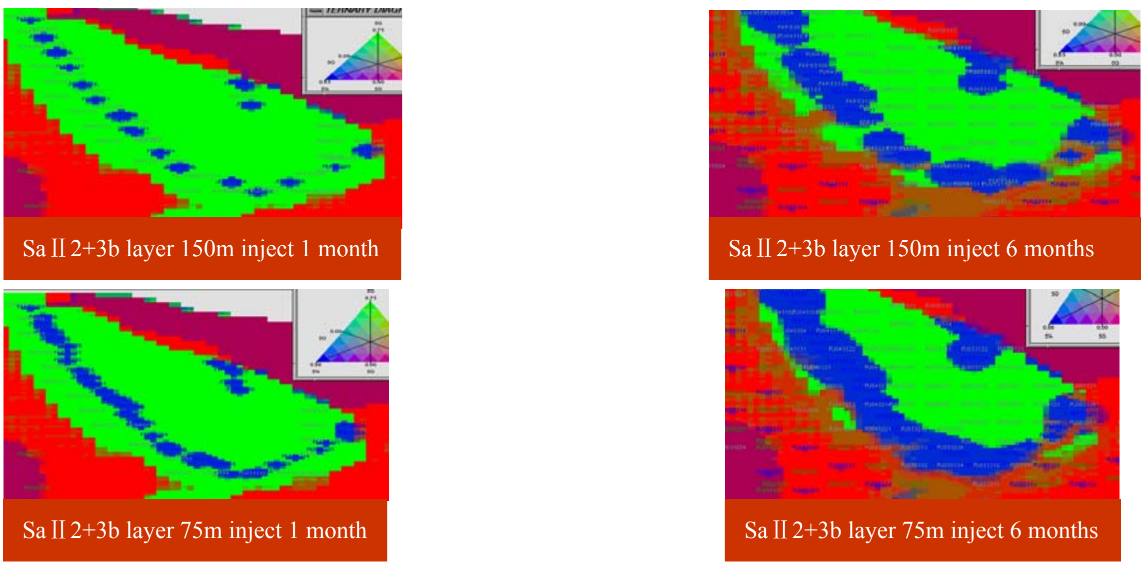

Figure 2 Comparison chat of 150m and 75m well space forming polymer barrier wall

The simulation results show that vertical heterogeneity have on much influence on the formation of polymer barrier wall, 3 layers can form the wall at the same time; the wells to form barrier should be located at about 100m in the gas side; 75-100m well spacing have some advantage on forming barrier wall: short forming time (4-5 months), narrow barrier width, less polymer consuming and favoring local adjustment; 3 layers have almost the same wall width about 100m; the buffer zone can't produce when forming the barrier wall, the formation pressure is 0.5-1.0MPa lower than which in the gas cap; the injection pressure should lower than the fracture pressure; maintenance must done to supplement the polymer dispersion and recovery after forming the barrier wall, the average daily single well injection volume is $15m^3$.

3. Field test and effect evaluation

3.1. Pilot scale

Total wells 168(new wells 163, substitute wells 5), among them 81 injectors (forming barrier wells 34, polymer injectors 45, water injector 2) and 87 producers.

3.2. Test process sketch

3.2.1. Inject polymer to form barrier wall with no producing the gas cap

The average daily single well injection volume is $80m^3/d$, the polymer molecular weight is 19000000 and the polymer concentration is 2000mg/L.Forming stable barrier wall to isolate the oil and gas area, no producing the gas cap, the maintenance stage come when producing the buffer zone, then the average daily single well injection volume cut to $15m^3/d$, the forming barrier wall wells turns to be water injectors at the subsequent water flooding stage of the buffer zone, the average daily single well injection volume is $15m^3/d$.

3.2.2. Polymer flooding the buffer zone

Use the polymer flooding well pattern to develop the buffer zone after forming the polymer barrier wall. The average daily single well injection volume is $30m^3/d$, the polymer molecular weight is 19000000, the polymer concentration is 2000mg/L and the injection rate is 0.15PV/a.

3.2.3. Old field adjustment

Use the existing well pattern to develop the old field, avoid to influencing the developing effect of the buffer zone through adjusting the working system [6].

3.3. Effect evaluation

34 wells in the test site were perforated and developed at September and injecting polymer at November, 2007, the polymer barrier wall was formed at May, 2008 then turn to maintenance stage. 128 new wells in the buffer zone producing in batches from the outer ring to the gas cap.

3.3.1. Production variation of the buffer zone

The average single well inject pressure of the 45 new injectors is 9.2MPa and the daily injection volume is 39 m^3 at the initial stage, the number of working injectors is 43 until November, 2010, the average injection pressure is 11.3MPa, daily injection volume is $50.4m^3$, cumulative injection is $189.10\times10^4 m^3$ and the average concentration is 1923mg/L.

The average daily production is 1154t, daily oil production is 167t, combined water cut is 79.1%, daily gas production is $317m^3$ and the GOR is $63m^3/t$ at the initial stage; the number of working producers is 81 until November, 2010, the average daily production is 1653t, daily oil production is 504t, combined water cut is 69.5%, the GOR is $35m^3/t$. The average daily production increased 499t, daily oil production increased 337t, combined water cut dropped 9.6%, the GOR dropped $28m^3/t$ compare with the initial stage. The cumulative production of 83 producers is 140.43×10^4t, the cumulative oil production is 39.85×10^4t, the oil increment is 4650t. Enhanced the recovery efficiency 12.4% periodically, recovery percent of reserves is 45.1%.

3.3.2. Stability and reliability of the polymer barrier wall

1) Water-intake capacity of the target zone in polymer barrier wells

TABLE 2 Absorbent layers & Sandstone Thickness of the Target Layer

Item	Number	The second class sandstone(m)	The first class sandstone (m)
All layers	112	244.6	190.3
Absorbent layers	108	240.7	189.1
Absorbent ratio（%）	96.4	98.4	99.4

From table 2， absorbent ratio is high in vertically, absorbent layers for all layers of the ratio is 96.4%, this establish a geological foundation for the forming of the polymer barrier wall.

2) Micro seismic frontal test

Micro seismic frontal test result of 2 adjacent polymer barrier wells show: the frontal of the 2 wells are coincident, the polymer barrier wall has already connected. See fig. 3.

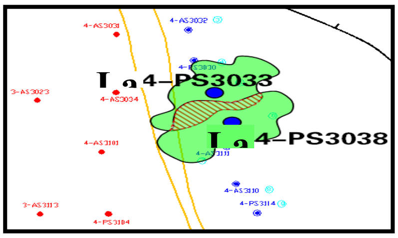

Figure 3 well La4-PS3033, La4-PS3038 displacement frontal

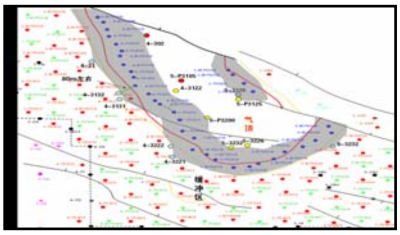

Figure 4 Neutron-neutron monitor results on both strip sides

3）Stability Test of the polymer barrier wall

TABLE 3 Neutron Count Down in Different Displace Monitoring Wells

Distance to polymer barrier (m)	Wells	Average neutron count (API)	Neutron count down value (API)
30-40	3	169	15
40-50	5	172	24
50-60	1	166	12
60-70	1	168	14
70-80	1	168	11

Table 3 shows: the average count of thermal neutron density in monitoring wells which 35-75m distance to the polymer barrier had all count down, illustrate that gas production rate decline, gas in target zone barrier strip is separated by the polymer.

Fig. 4 shows that polymer barrier forms a relatively uniform, the width is 150- 200 m, and the polymer barrier frontals continue extends to both sides.

Gas composition monitoring results show: methane content in the first row of producers at the gas cap external is less than 95%, the average value is 86.4%, illustrate that the produced gas in the first row of producers is mainly dissolved gas; gas in the gas cap has not cut into the buffer zone through the barrier.

Static pressure data shows (test every half a year): the pressure has increased to 10.60MPa at 2011 from 9.13MPa at the initial stage, illustrates the pressure raised slowly and gradually stabilized.

Above test results show that the polymer barrier separates the oil and gas zones effectively, all wells in the buffer zone are in normal production without gas and oil out.

4. Conclusion

- The success of forming polymer barrier to develop the buffer zone technology in gas cap reservoir innovate the development mode in domestic similar oilfield.
- The polymer barrier separates the oil and gas zone effectively, buffer zone development effect is apparent; stage recovery efficiency increased 12.4%.
- During the buffer zone development process, the formation pressure in gas cap, buffer zone and old field tend to be stable and keep in a balance state through adjustment the production system.

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