Energy and Power Engineering, 2009, 44-49
doi:10.4236/epe.2009.11007 Published Online August 2009 (http://www.scirp.org/journal/epe)

Study of the Law about Water-Cut Variation for the Fractured Metamorphic Reservoir of Buried Hill with Bottom Water

——A Case study at Budate Reservoir in Beir Depression, Hailar Basin

Shenggao QIN [1], Yanling SUN [2], Zhenqi JIA [1], Dagang YANG [1]
[1]*Key Laboratory of Enhanced Oil and Gas Recovery of Education Ministry, Daqing Petroleum Institute, Daqing, China*
[2]*Information Center of No.1 Oil Recovery Company, Daqing Oilfield Co. Ltd., Daqing, China*

Abstract: Aiming at the complex flowing environment including the buried hill of Metamorphite, the active bottom water and the fracture at Budate Reservoir within Beir Depression of the Hailar Basin, combining the laboratory studies and based on analysis of its drive mechanism, field wells' parameters were used to analyze the effects of different conditions of the fractured metamorphic reservoir with bottom water on its law of water-cut variation and the waterflooding efficiency. The results show that for the Budate buried hill reservoir with bottom water, the gravity should be taken into consideration to determine reasonable perforation ratio and production pressure difference. And because of the acid sensitivity of the buried hill reservoir, application of proper clay stabilizer will enhance the field oil recovery to a satisfactory extent.

Keywords: metamorphic reservoir, bottom water, buried hill reservoir, water-cut

1 Introduction

Currently majority of the discovered buried hill reservoirs home and abroad belong to the type of carbonate reservoir [1][2], in which there are complex types of pore canals always including solution crevice, fracture and so on. Thereby the fluid flowing inside shows the unique features. Many scholars home and abroad have made progressive advance in this area with the reservoir engineering method, numerical simulation and others [3-5]. However, Budate Reservoir in the Beir depression of the Hailar Basin is the buried hill reservoir with bottom water, where it is very complicated of the fluid flowing laws that have not been reported academically. So it is a new topic to perform the study of the law of fluid flowing in this kind of reservoir and the fruits acquired will have positive reference value for the same kind of reservoirs.

2 Reservoir Features of Budate Buried Hill

Budate Reservoir lies in the bottom of the Hailar sedimentary basin. It developed from the Trias and was composed mainly of the carbon siltpelite, a slightly metamorphite and the unequigranular feldspar rock-fragment sandstone. Due to the dissection of many faults, each faulted-block is a buried hill reservoir with its independent oil-water interface.

Budate Reservoir has geological reserve about 1811×10^4t, but very poor physical properties such as the average effective porosity of 5.3%, the average gas permeability of $0.14\times10^{-3}\mu m^2$ and water-sensitivity coefficient of 0.64 which shows a bit strong water sensitivity. The fractures developed plus the pores make the formation a fracture-pore reservoir.

3 Drive Mechanism of the Buried Hill Reservoir

3.1 Principle of Bottom Water Coning

Because of the active energy of bottom water, when an oil well produces at a certain rate after perforation of an oil well, a pressure drop funnel would form at the bottom

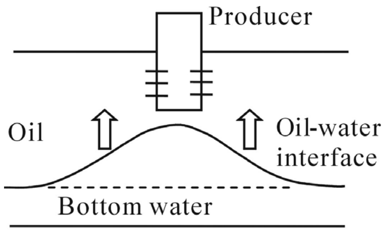

Figure 1. Schematic of the water core

of the well (see in Figure 1). The original horizontal oil-water interface before production transforms to the shape of a core under the well by the oil-water potential gradient. If the well produces at a certain stable rate the formed water core would stay at an certain altitude; if the production rate increases the core altitude grows until the bottom water flows into the oil well which would produce water.

By the difference of the core's advance speed there are two types of bottom water drive: lifting and coning. Lifting denotes that in the process of bottom water displacement, the front edge of the displacing water (oil-water interface) move upwards slowly, smoothly in a big area; while coning indicates the displacing bottom water rushes into oil wells along local zones of high permeability. So lifting is favorable for oil displacement by bottom water with good oil displacement efficiency, long anhydrous production period and high ultimate field recovery; while coning which happens always near wellbores, would results in quick water breakthrough, short anhydrous production period and low ultimate field recovery. The flooding pattern of bottom water is dependent on two types of factors. One type corresponds to factors such as the geological features of the reservoir, the relationship between oil layers and water layers, interlayers' development and distribution, physical properties of the subsurface oil and water and so on, and the other corresponds to man-made development program, perforation positions and ratio, production rate and so on.

Hence, it is a key technological problem to control the bottom water coning in the development process of this kind of reservoirs. For the field, to control coning of the bottom water to extend the anhydrous production period a reasonable production rate should be adopted; for a single well the output should not overcome a special number which is called critical yield. Finally the detailed regulatory measures for the yield, production pressure difference and the perforation ratio should be used to control the bottom water coning. And to control the yield should be realized by the variables as perforation ratio and production pressure difference, which are the major measures to control bottom water coning to displace the overall reservoir upwards in the type of lifting.

Because the displacement energy source underlies the oil reservoir, at the oil-water interface below, the bottom water should firstly overcome the gravity itself then to displace crude oil bottom-up. In this process the action of gravity should be taken into consideration.

3.2 Mathematical Model of the Water-Cut Variation

In the development program of bottom water reservoir, perforation is always done at the top of the reservoir to avoid early water breakthrough. In contrast with the total reservoir thickness, the fluid flowing in the porous media could be presumed as the combination of the horizontal flowing at the top layers perforated and the vertical flowing in the sub-layers [7][8]. Hen the equation about the water-cut variation could be derived as following:

$$f_w = \frac{Q_w}{Q_o + Q_w} = \frac{\dfrac{K_{rw}}{\mu_w}}{\dfrac{K_{rw}}{\mu_w} + \beta' \dfrac{K_{ro}}{\mu_o}} \tag{1}$$

$$\beta' = 1 + \frac{\left(\gamma_w - \gamma_o\right)H}{\dfrac{25\Delta p}{\ln\dfrac{R_e}{R_w} - 0.5} - \left(\gamma_w - \alpha'\right)H} \tag{2}$$

4 Analysis of Law on Water-Cut Variation at Budate Buried Hill Reservoir

Now take well D112-227, D108-229 and B28-1 as examples for Budate Reservoir to appraise the laws of water variation with different parameters that are listed at Table 1.

Table 1. Parameters from three wells of Budate Reservoir

Well	μ_w(mPa.s)	μ_o(mPa.s)	γ_w	γ_o	h(m)	H(m)	x	Re(m)	Rw(m)	α
D112-227	0.65	4.68	1	0.7761	176	155	0.1193	300	0.1	0.97
D108-229	0.65	4.32	1	0.745	110.4	95.6	0.1341	300	0.1	0.97
B28-1	0.65	4.32	1	0.745	64	8.4	0.8688	300	0.1	0.97

4.1 Effects of Reservoir Thickness, Perforation Ratio and Production Pressure Difference on Water-Cut Curves

Considering strong water sensitivity of the Beir Depression, in the lab three groups of relative permeability curves were measured as in Figure 2, one displacing fluid is water, the others are two kinds of clay stabilizer solutions(CS-05 and CS-07).

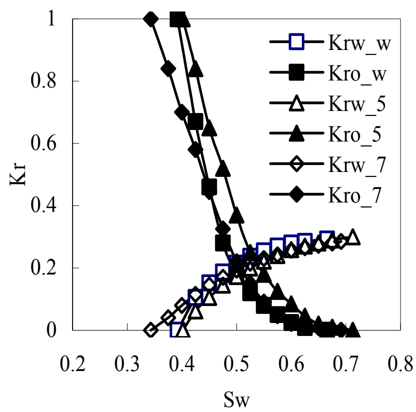

Figure 2. Relative permeability curves measured by different displacing agent

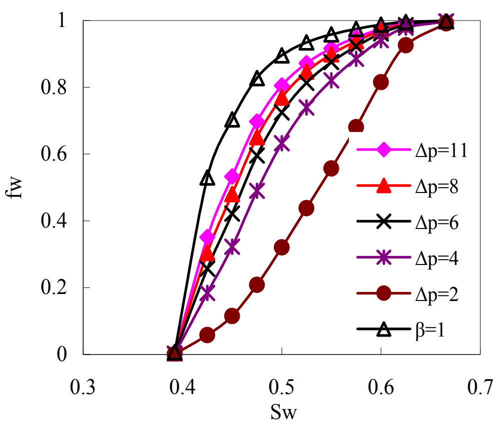

Figure 3. Water-cut curves versus production pressure difference (D112-227)

The Water-cut Variation curves under several production pressure differences are shown in Figure 3 for well D112-227. We could recognize that at the Block-faulted reservoir of buried hill with bottom water, the gravity would have great influence on the law of Water-cut Variation as:

1) If gravity unconsidered (β=1), the calculated water-cut will increase more quickly than that in the case of gravity considered along with the change of water saturation. That's if gravity considered, during early period of low water saturation, the curves are steeper with slower rate of oil production and less oil recovery; during the later period of high water saturation, more oil can be produced and the residual oil retained by water displacement should be developed by the tertiary oil recovery technologies.

2) If gravity considered, the water-cut increases along the rise of water saturation slowly. This phenomenon could be explained that the gravity of the bottom water itself that are displacing oil upwards decreases the water breakthrough or fingering, so as to slow the rising velocity of water-cut.

3) If gravity considered, the sizes of production pressure differences have obvious influence on the law of Water-cut Variation. The less production pressure difference, the slower rising velocity of water-cut along with the increase of water saturation, so is its reduced extent. This phenomenon could be explained that the action of gravity becomes less along with the increase of production pressure differences and at a certain big value of production pressure differences the action of gravity could be neglected.

For well D108-229 the Water-cut Variation curves under several production pressure differences are shown in Figure 4 which shows same law as discussed above.

For well B28-1 the Water-cut Variation curves under several production pressure differences are shown in Figure 3. From table 1 while other parameters are nearly the same, the perforation ratios for well D112-227, D108-229 and B28-1 are x=0.1193, x=0.1341 and x=0.8688, respectively. Such conclusions could be drawn as:

1) Along with the increase of perforation ratio, the effect of gravity on reducing the rising velocity of water-cut becomes less. This case will be the nearly the same as that while gravity unconsidered.

2) Along with the increase of perforation ratio, the effect of production pressure difference on the increase of water-cut becomes less, even disappears.

When the oil layers are completely perforated, that's x=1, the fluid in the whole reservoir flows in the radial direction. Then the bottom water will drive the oil at the least efficiency and its energy will make the oil well drought.

Such laws discussed above are in accordance with the actual development cases for block-faulted reservoir with bottom water.

4.2 Effect of the Clay Stabilizers

The water sensitivity index of the core samples from Budate Reservoir fall into the range of 0.60～0.67 (a bit strong water sensitivity). Besides the oil and water relative permeability curve measured, in the lab other two relative permeability curves were also measured with clay stabilizer CS-5 and CS-7 (see in Table 2). Then the effects of clay stabilizers on relative permeability curves and on the law of Water-cut Variation are analyzed to provide reference for the optimization of clay stabilizers at Budate Reservoir.

Based on the parameters from well D108-229 (see in Table 1), three curves of Water-cut Variation of water, CS-5 and CS-7 are shown in Figure 5 for gravity unconsidered and in Figure 6 for gravity considered in Figure 7.

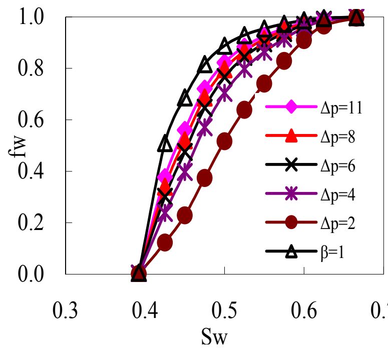

Figure 4. Water-cut curves versus production pressure differences (D108-229)

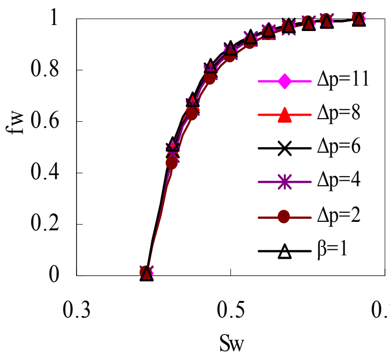

Figure 5. Water-cut curves versus production pressure differences (B28-1)

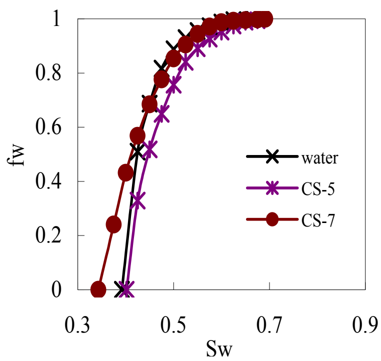

Figure 6. Water-cut curves versus different clay stabilizers (gravity unconsidered)

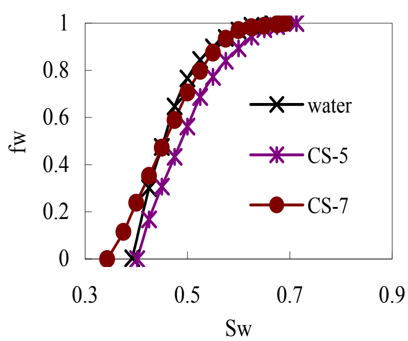

Figure 7. Water-cut curves versus different clay stabilizers (gravity considered)

Table 2. Feature values of relative permeability curves measured at lab

Core No.	K_g ($10^{-3}\mu m^2$)	ϕ (%)	S_{wi} (%)	S_{or} (%)	Krw at Sor (%)	Anhydrous Recovery (%)	Ultimate Recovery (%)	Range of oil-water phases (%)	S_w at point of two curves's intersection (%)	Clay stabilizer
C166-1	119.21	23.19	39.21	33.43	29.30	18.31	45.01	27.36	49.20	水
C166-2	114.01	22.92	40.17	28.72	30.00	25.71	52.00	31.11	53.80	5
C166-4	186.56	23.05	34.30	30.88	28.50	32.47	53.00	34.82	50.75	7

Conclusions could be drawn as:

1) Using clay stabilizers can reduce the rising velocity of water-cut at the stage of low water saturation, that's oilfield can recovery more oil at the stage of low water saturation than that in the case of water flooding.

2) Using clay stabilizer CS-5 makes the point of water breakthrough later than that the case of water flooding.

3) Using clay stabilizer CS-7 makes the rising velocity of water-cut smooth and makes the oil recovery at the low water saturation the biggest number but with earlier point of water breakthrough.

4) Using clay stabilizers makes the flowing range of two phases wider. The anhydrous oil recovery efficiency and the ultimate number both obviously larger than that of the case of water flooding.

5 Conclusions

1) Gravity has great influence on the law of Water-cut Variation for the Block-faulted reservoir of buried hill with bottom water: if gravity considered, the water-cut increases along with the rise of water saturation slowly at the stage of low water saturation. The less production pressure difference, the slower rising velocity of water-cut along with the increase of water saturation, so is its reduced extent. At a certain big value of production pressure differences the action of gravity could be neglected.

2) Both the perforation ratio and the production pressure difference have great influence on the law of Water-cut Variation for the Block-faulted reservoir of buried hill with bottom water. Along with the increase of perforation ratio, the effect of gravity on reducing the rising velocity of water-cut becomes less. This water-cut curve will be the nearly the same as that while gravity unconsidered. Along with the increase of perforation ratio, the effect of production pressure difference on the increase of water-cut becomes less, even disappears.

3) Clay stabilizers can reduce the rising velocity of water-cut at the stage of low water saturation and make the anhydrous oil recovery efficiency and the ultimate number both obviously larger than that of the case of water flooding.

6 Nomenclature

K_{rw} — relative permeability water, dimensionless;
K_{ro} — relative permeability oil, dimensionless;
μ_w — water viscosity, mPa•s;
μ_o — oil viscosity, mPa•s, mPa•s;
γ_w — relative density of water, dimensionless;
γ_o — relative density of oil, dimensionless;
H — thickness to avoid water in a oil well, m;
α' — Reservoir pressure coefficient, dimensionless;
R_e — well spacing, m;
R_w — wellbore radius, m;
S_w — water saturation;
K_g — gas permeability, $10^{-3}\mu m^2$;
φ — porosity, dimensionless;
S_{wi} — irreducible water saturation, dimensionless;
S_{or} — residual oil saturation, dimensionless.

REFERENCES

[1] BO Song-zhang, “Development of carbonate buried hill reservoir,” Petroleum Industry Press, Beijing, Vol. 5, pp.2-8, 1996.

[2] S. Ullah, Tse Yone Shen, S. A. Mobarak, et al., “Development feasibility study: Dongshengpu buried hill reservoir,” SPE 17577, Vol. 11, pp. 273-284, 1988.

[3] M. G. Starcher, J. R. Murphy, P. D. Alexander, et al., “Video camera log used for water isolation in the main body ‘B’ pool, Elk hills field, Kern Co., California-water and oil identification,” SPE29654, Vol. 3, pp. 384-394, 1995.

[4] K. A. Edwards, B. Anderson, and B. Reavie, “Horizontal injectors rejuvenate mature miscible flood-south swan hills field,” SPE77302, Vol. 2, pp.174-182, 2002.

[5] CHEN Shao-sheng, XU Kun, Han Yun, et al., “Study on characteristics and development law of fractured basement reservoirs: A case study of fractured basement reservoirs in Damintun depression of Liaohe basin,” SPE80541, Vol. 4, pp. 1-9, 2003.

[6] ZHANG Ji-guang, WANG Jin-kui, QIN Long-pu, et al., “Characteristics of metamorphic buried hill reservoir in Sude’erte of Beir fault depression in Hailar basin,” ACTA PETROLEI SINIC, Vol. 28, No. 4, pp. 21-30, 2007.

[7] LU Ai-min andYAO Jun, “Change of water cut and oil production in fractured reservoir with bottom water,” Special Oil and Gas Reservoir, Vol. 13, No. 5, pp. 56-61, 2006.

[8] LU Ai-min and YAO Jun, “Rational perforating level and well spacing for fractured carbonate reservoirs with bottom water,” Vol. 35, No. 1, pp. 97-100, 2008.