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Experimental study on pressure field of combined well pattern by water flooding

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Abstract

Pressure field variation was investigated using 3D physical equipment. A vertical well was chosen as injector and two horizontal wells were chosen as producers. Pressure point in reservoir were measured by pressure sensors and the pressure distribution image was generated by interpolation. The pressure field was divided into four stages: the forming pressure field stage (I), the stable pressure field stage (II), the decay pressure field stage (III) and the exhaustion pressure field stage (IV). It can be concluded that the decay pressure field stage is the main stage of oil production, and the stable pressure field stage is the most efficient stage.

Keywords: Heavy oil; hot water flooding; physical simulation; pressure field; well combination.

1. Introduction

China is rich in heavy oil, but it is hard to develop because of the high viscosity and poor physical property (Jiang, 2006). It can improve productivity and reduce the cost by using horizontal well to develop heavy oil. As for the continental sedimentary reservoir with severe heterogeneity in China (Liu *et al*., 2007; Asem et al, 2016), it is more flexible to adjust the injection profile to use vertical-horizontal well (Chen & Liu, 2008). Therefore, vertical-horizontal well combination is often used in China for comprehensive development of oil field.

Hot water flooding, as a fundamental method, is widely used in China (Wang, 2011, Xu *et al*., 2007). In the process of hot water flooding, pressure field changes with water injection. It contributes practical and heuristic significance to understand the pressure field at different time. Much researches were on pressure field, by using three-dimensional physical model that used vertical well as injection or production well (Xu *et al*., 2006; Yang *et al*., 2015), but lack of consideration of vertical-horizontal well combination. In the present work, vertical and horizontal wells were chosen as injection well and production well, respectively. The flow of displacement and displaced phase under the real complex strata condition was simulated. And the pressure field of hot water flooding in heavy oil reservoir was researched. That will provide reference for the practical production of oil field and related research.

2. Experiment material and equipment

It is practical to use simulation model to study some complex phenomenon (Savsar *et al*., 2013). As shown in Figure1, The large high-pressure 3D flooding simulation device consists of injection system, reservoir model, production data collection, constant-flux pump, back pressure, etc. The maximum pressure is 5MPa, and the maximum operating temperature is 100 °C, control accuracy is ±1°C, the injection flow rate is in the range of 0.01~30mL/min.

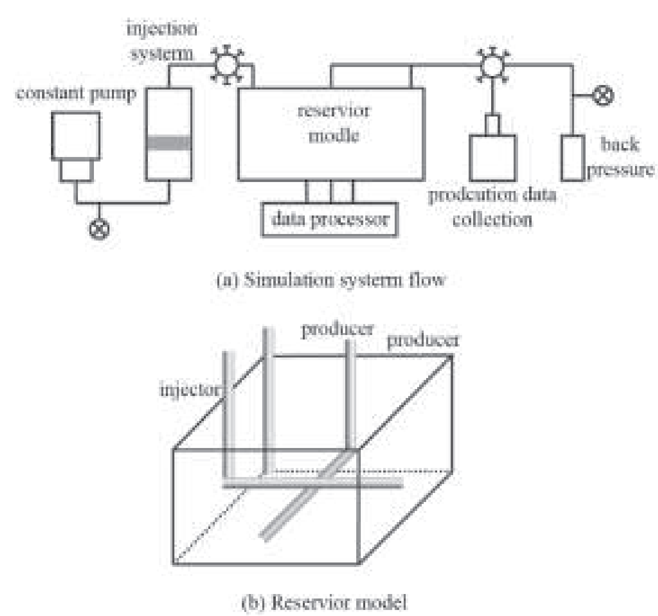

Fig. 1. System flow diagram

There were 13 measurement points on the roof of the device. The injection rate, cumulative injection volume and injection pressure were collected in real time. And the external devices were controlled by computer.

The real reservoir environment was simulated. The vertical well in the upper left corner and the two mutually perpendicular horizontal wells were set as injection well and production well respectively. Physical parameters of reservoir and crude oil are shown in Table 1. Real formation pressure was also simulated, the overlying strata pressure is 4 MPa, injection rate of hot water flow was about 1 mL/min, cumulative injection of 70 °C hot water was 3.25 PV, and back pressure was 1.5 MPa.

To make the experimental process similar with practice production, similar principle was used to convert the model to real reservoir. Since it is impossible to meet all similar principles, and this research is conducted just to understand the pressure field qualitatively, four main geometry similar and physics similar were selected. The eight similar principles are following (Bai *et al*., 2006):

$$\pi_1 = \frac{k_o}{k_{cwo}} \tag{1}$$

$$\pi_2 = \frac{s_{wi}-s_{cw}}{\Delta s} \tag{2}$$

$$\pi_3 = \frac{s_{ro}}{\Delta s} \tag{3}$$

$$\pi_4 = \frac{\rho_w}{\rho_o} \tag{4}$$

$$\pi_5 = \frac{\mu_o}{\mu_w} \tag{5}$$

$$\pi_6 = \frac{l}{w} \tag{6}$$

$$\pi_7 = \frac{\Delta P_{wfo}}{\rho_o g h} \tag{7}$$

$$\pi_8 = \frac{\Delta P_{wfw}}{\rho_o g h} \tag{8}$$

Where, k_o -oil effective permeability, $10^{-3}\mu m^2$;k_{cwo} oil relative permeability at connate water saturation, $10^{-3}\mu m^2$; s_{wi} initial water saturation, %S_{cw} critical water saturation, %Δ s -oil/water zone saturation, %;ρ_w - water density ;ρ_o - oil density μ_o -oil viscosity, mPa · s; μ_w -water viscosity, mPa · s l-reservoir length, m; w-reservoir width, m;ΔP_{wfo} -production pressure differential, MPa; ΔP_{wfw} -injection pressure differential, MPa; -gravity, 9.8m/s^2-reservoir thick, m;

Table 1. Parameters of oil and formation

Parameter	Model	Prototype
l/m	0.5	500
w/m	0.5	500
ΔP_{wfo}/MPa	0.02	2
ΔP_{wfw}/MPa	0.02	2
$K_{cow}/10^{-3\mu}$m2	241	241
$K_o/10^{-3}\mu m^2$	147	147
μ_w/(mPa·s)	0.6	0.6
μ_o/(mPa·s)	127	127
S_{wi}	0.32	0.32
S_{cw}	0.32	0.32
ϕ	0.23	0.23

3. Result

As the injection volume increased, the oil production rate, water cut and field variation changed.

3.1. Production

Relationship of oil production and time are shown in Figure 2. The cumulative oil production was 1.53 L, hot water flooding ultimate recovery was 20.93%. Considering oil production and water cut volume, pressure field distribution can be divided into four stages (Yang *et al*., 2007). That was: the forming pressure field stage (I), the stable pressure field stage (II), the decay pressure field stage (III) and the exhaustion pressure field stage (IV).

According to the change of pressure field, the each stage of oil production and injection time ratio of total oil production and injection time were calculated (shown in Table 2).

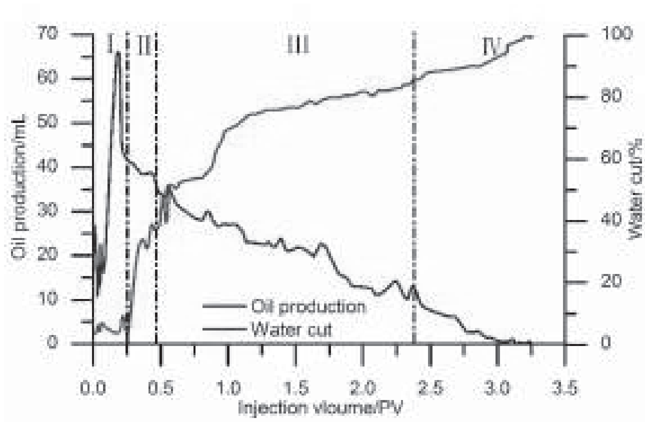

Fig. 2. The relation between oil production, water cut and time

Table 2. Oil production and time of different stages

Stage	Oil production, %	Time, %
I	17.94	7.91
II	13.02	5.06
III	67.09	62.96
IV	1.95	24.07

Table 2 shows that the oil production efficiency of pressure field stability stage was the highest stage of oil production, but it lasted for a short time only. The oil production of decay pressure field stage was the main oil producing stage, accounting for 67.09% of the total oil production. However, its production efficiency was low because of the long duration of time. Results suggest that duration of the plateau stress field should increase to improve the oil recovery and oil production efficiency.

3.2. Pressure field change

The upper-left corner vertical well was used as the injector, and two horizontal wells were used as producers that are perpendicular. The wells are shown as dotted line in Figures 36-. The data collected in real time was transferred into pressure field by the modified Shepard's interpolation method. The pressure field of every stages is shown in Figures 36-.

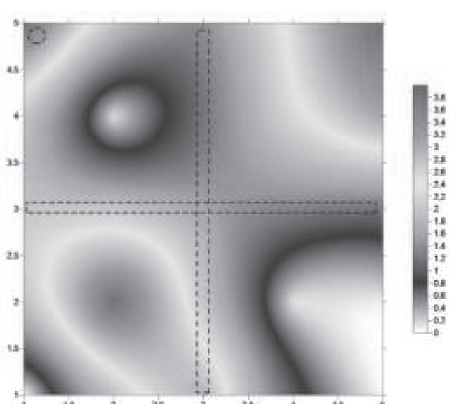

Fig. 3. The forming pressure field stage

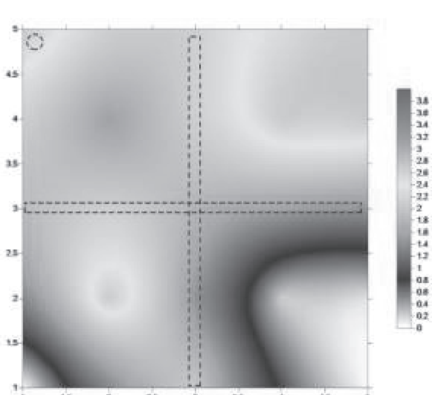

Fig. 4. The stable pressure field stage

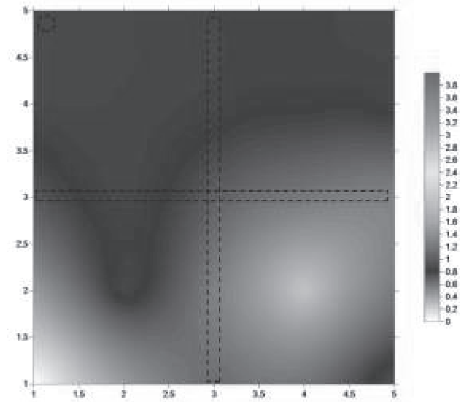

Fig. 5. The decay pressure field stage

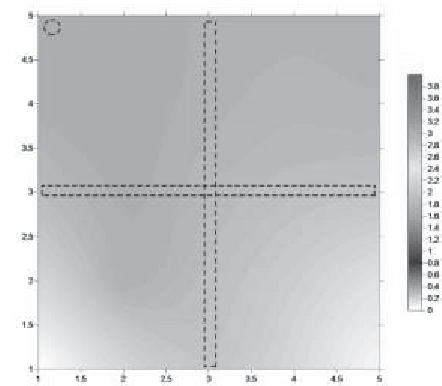

Fig. 6. The exhaustion pressure field stage

3.2.1 The forming pressure field stage

As shown in Figure 3, the hot water was injected to simulate reservoir from upper-left vertical well. The reservoir pressure increased with the water injected, until it reached the highest, this may be due to the poor mobility of oil at initial temperature and a little of pore could form stable flush-flow channel. Thus, this stage could be divided into the forming pressure field stage that lasted 0.24PV. The pressure of simulated reservoir decreased near the production wells. High oil production efficiency and low water cut were also observed in this stage. This may be because in the process of non-piston water flooding, the oil flow was primarily to production wells. The pressure field of lower-right part of the reservoir was still at initial state, which may be due to super imposed flush-flow effect of two horizontal wells, and the hot water cannot sweep through the lower-right part of the reservoir.

3.2.2. The stable pressure field stage

Figure 4 shows that reservoir pressure field distribution was relatively uniform at this stage. The reservoir pressure field was close to 0 at the lower-right part of the reservoir due to the high production and pressure release of two horizon wells. Meanwhile, the production tended to be stable. This stage can be divided into the stable pressure field stage that only lasts 0.18 PV.

With increase of the injection volume of hot water, reservoir temperature was enhanced, the viscosity of crude oil was decreased and mobility was enhanced. The internal pressure field of reservoir was dynamic balance because that may be because the speed of new formed seepage channel has coincided with the speed of injection rate and the production rate. The water cut started to increase instability, but overall production tended to be stable. This may be because the mixed section of non-piston flooding process gradually got into the production well and the number of effective seepage pore increased. We believe that the duration of the stable pressure field stage is related to the injection rate and reservoir internal seepage characteristics. Improving the duration can enhance the oil recovery.

3.2.3. The decay pressure field stage

As shown in Figure 5, internal pressure of reservoir began to fade slowly after a short time being stable, until the pressure equals the setting back pressure. At this time, water cut and liquid production increased and the production was stable.. This stage can be divided into the decay pressure field stage. It is the main producing stage and lasts 2.04 PV.

Because of the long time hot water injection, the temperature of reservoir increased significantly. Most of the effective porosity had formed the stable seepage channel, and the reservoir began to release pressures entirely through production wells. Hence, internal pressure of reservoir field was under control and constantly decreased. The oil production ratio decreased, which may be because the oil-water mixed zone has become the main part of the water flood front.

3.2.4.The exhaustion pressure field stage

As shown in Figure 6, the reservoir pressure decreased consistently with the back pressure. At this stage, the reservoir pressure field remained stable again with low oil production ratio and high water content. The secondary development of oil reservoir potential was close to exhaustion. This stage can be divided into the exhaustion pressure field stage that lasted 0.78 PV.

After long time displacement, the simulated reservoir formed a completely stable seepage channel, with high water content in water flood front. Water cut was very high at this stage. Meanwhile, hot water washing the formation of the seepage channel repeatedly was the development potential. The crude oil in the seepage channel was the irreducible oil, which was difficult to recover in the same conditions. The water cut was more than 98%. It has reached the limit of water cut for practical oilfield development. There is no economic value for development to continue.

4. Conclusion

Based on the characteristics of the pressure field of the reservoir development process, the reservoir development can be divided into four stages. That is the forming pressure field stage (I), the stable pressure field stage (II), the decay pressure field stage (III) and the exhaustion pressure field stage (IV). The decay pressure field stage is the main oil production stage that lasts for the longest time. The forming pressure field stage is the highest effective stage. Duration of the decay pressure field stage should be improved to enhance the recovery of crude oil and oil production efficiency. The crude oil in lower right part of the reservoir cannot be displaced well. More study should be conducted to improve the recovery of lower right part. Thepressure cone of pressure release was weakened by potential superimposition effect of horizontal wells.

5. Acknowledgement

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References

Asem S.O. R., Misak F., Alenezi A., Roy W. Y., Shahid S. A. & Al-Awadi M. (2016). Effects of crude oil on some soil types of Kuwait. Kuwait Journal of Science, **43**(4):150-161.

Bai Y., Li J. & Zhou J. (2006). Effect of physical parameter range on dimensionless variable sensitivity in water flooding reservoir. Ac-ta MechSinica, **22**(5):385-391.

Chen T. & Liu J. (2008). Experimental Research of tar oil EOR By hot water flooding. Journal of Daqing Petroleum Institute, **32**(4):45-48+135.

Jiang W. (2006). The viscous oil development technology in Canada and considerations of new technology for developing viscous oil in Bohai Sea, China. China Offshore Oiland Gas, **18**(2):123-125.

Liu L., Wang X., Gao Y., Yang L. & You S. (2007). SAGD process with the combination of vertical and horizontal wells in super-heavy oil reservoir. Prtroleum Exploration and development, **34**(2):234-238.

Savsar M. (2013). Modeling and simulation of maintenance operations at Kuwait public transport company. Kuwait Journal of Science, **40**(2):115-129.

Wang Z. (2011). Physical Simulation on Thermal Water Flooding After Steam Flooding in Different Rhythm Heavy Oil Reservoir. Journal of Petrochemical Univresities, **24**(1):52-58.

Xu H., Qin J., Jiang H. & Wang J. (2006). On seepage flow mechanism of Alkali-surfactant-polymer flooding for enhanced oilrecovery with 3D physical reservoir model. Journal of Oil and Gas Technology, **28**(6):94-97+3.

Xu H., Qin J., Wang J. & Jiang H. (2007). 3-D physical modeling on macroscopic fluid flow mechanism of enhanced oil recovery by polymer flooding. Petroleum Explortion and Development, **34**(3):369-373.

Yang L., Chen Y., Wang H. & Li T. (2007). Physical and numerical simulation of steam assisted gravity drainage with vertical and horizontal well combination in extra heavy oil reservoir. Journal of China University of Petroleum, **31**(4):64-69.

Yang H., Zhang H., Sun Z. & Xu J. (2015). 3D physical simulation experiment on the fault-block oil reservoir with edge water. Petroleum Geology and Oilfeld Development in Daqing, **32**(2):77-80.

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دراسة تجريبية عن مجال الضغط لنمو بئر مُدمج عن طريق دفع الماء

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خـلاصـة

تم البحث عن الاختلاف في مجال الضغط باستخدام المعدات الفيزيائية ثلاثية الأبعاد. تم اختيار بئر عمودي كحاقن وتم اختيار اثنين من الآبار الأفقية كمنتجين. تم قياس نقاط الضغط في الخزان بواسطة أجهزة استشعار الضغط وتم انتاج صورة توزيع الضغط عن طريق الاستنباط. تم تقسيم مجال الضغط إلى أربع مراحل: مرحلة تشكيل الضغط (I)، مرحلة استقرار مجال الضغط (II)، مرحلة انحدار مجال الضغط (III) ومرحلة إنهاك مجال الضغط (IV).). ويمكن استنتاج أن مرحلة انحدار مجال الضغط هي المرحلة الرئيسية لإنتاج النفط، وأن مرحلة استقرار مجال الضغط هي المرحلة الأكثر كفاءة.