CSCanada
Advances in Petroleum Exploration and Development
Vol. 7, No. 2, 2014, pp. 85-90
DOI:10.3968/5096

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
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Experimental Research on Placement Law of Injected Agent in General Water Shutoff for Horizontal Wells

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Supported by the Jiangsu Planned Projects for Postdoctoral Research Funds (1302180C).

Received 8 April 2014; accepted 16 June 2014
Published online 24 June 2014

Abstract

In order to research the placement law of injected agent in general water shutoff for horizontal wells, injection and water plugging experiments were carried out based on horizontal well models. Normal model was modified to research placement of gel quantitatively. Plane heterogeneity and well trajectory changes were also considered in the models. Experiments results indicated that injected agent was not uniformly placed along the horizontal direction in general injection. The agent was more likely to enter the zone near heel end because of pressure drop along horizontal well. High permeable area and lower well part were both favorable factors for blocking agent's entrance. The final placement was determined by the game between the factors and pressure drop. When the two factors existed at heel end, the non-uniform placement would be even intensified, and the differences among each part would enlarge. Conversely, when the two factors existed at toe end, it was beneficial to make the placement of injected agent more uniform. The performances of general water shutoff were influenced by the placement law of injected agent. The breakthrough water will be better plugged if more of injected agent went to objective position, which induced a better oil production after the treatment. Therefore, researching and making use of the placement law of injected agent is beneficial to improve the performance of general water shutoff in application.

Key words: Water plugging experiment; Water shutoff; Horizontal wells

Li, L. F., Zhou, F. X., & Yue, X. A. (2014). Experimental research on placement law of injected agent in general water shutoff for horizontal wells. *Advances in Petroleum Exploration and Development*, *7*(2), 85-90. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/5096
DOI: http://dx.doi.org/10.3968/5096

INTRODUCTION

Horizontal wells are widely used in reservoirs driven by bottom water in order to delay water breakthrough[1, 2]. However bottom water crest is hard to avoid because practical production exceeds the critical production in most case[3]. Along the horizontal direction, bottom water of different sections move at different speeds for well trajectory and plane heterogeneity, which causes some water break into the well at specific position[4, 5]. After water breakthrough, the oil production will decline rapidly with the rise of water cut[6, 7]. Unwanted water must be plugged to improve performances of horizontal wells.

Compared to vertical wells, it is more difficult to shut off waterflooding section accurately in horizontal wells for its long horizontal wellbore. Mechanical plugging is limited in application because many horizontal wells are completed without cementation[8]. Annular Chemical Packer technology has been presented by Schlumberger Company to resolve the problem and applied to several oilfields[9-11]. However the technology is diseconomy for horizontal wells with low production because the cost of the technology is high. Low-cost and easy-implementation water shutoff technology is desired for many horizontal wells. In water plugging of vertical wells, selective blocking agent would be applied to all formations when waterout position was not conformed sometimes[12]. Similar technology was presented for horizontal wells:

water plugging agent was injected into the wellbore without zone isolation, which was called general injection. Selective water plugging agent and injection methods were studied to improve the performance of the technology by many researchers. Three kinds of relative permeability modifiers which could reduce relative permeability of water were presented by Institut Francais du Petrole and applied in general water shutoff[13, 14]. Dai[15], He[16] researched general injection of jellied agent which was used to control water crest in horizontal well of offshore oilfield. A kind of temporary blocking agent was studied and used to plug breakthrough water in horizontal wells of Cainan oilfield, China by Wang[17]. Verre[18] studied general injection application of inorganic gel and relative permeability modifier for horizontal wells in heavy-oil reservoirs. However in application, the success rate of general water shutoff was low and the effect was considerable uncertain, which limited the popularization of the technology. Except for characteristic of agent and injection technology, the placement law of agent after injection is another noteworthy factor. Driven by injection pressure, the injected agent penetrated into formation and became plugging slug to prevent water production. The agent could not play its role if most of it failed to enter the objective position. Therefore, it is necessary to research the placement law of injected agent and its influence on treatment performance in general water shutoff.

In this paper, a kind of composite gel was prepared and used as water shutoff agent. Aimed at main reasons that lead to water breakthrough in oilfield application, plane heterogeneity and irregular well trajectory were considered in horizontal well models. General injection and water plugging experiments were carried out based on the models to research placement law of injected agent and its influence on performance of the general water shutoff.

1. EXPERIMENTAL SECTION

1.1 Experimental Materials

The brine water in experiments was prepared according to ion component of formation water in Jidong oilfield, China. Hundreds of horizontal wells of Jidong oilfield were troubled by breakthrough of bottom water or edge water[19]. The salinity of the water was 1,600 mg/L, and water type was sodium bicarbonate ($NaHCO_3$). A kind of simulated oil was used in experiment, with viscosity 20 mPa·s at 65 ℃.

The composite gel was prepared by sodium silicate (Na_2SiO_3) solution and acrylamide monomer (C_3H_5ON) solution. Under the laboratory condition of 20 ℃, the apparent viscosity of composite gel solution was 1.3 mPa·s, which was a little higher than that of water. Under the reservoir condition of 65 ℃, copolymerization reaction took place between acrylamide monomer and cross-linking agent, high polymer were produced during the process. Inorganic silicate gel particles of sodium silicate solution, which was inlayed in the network skeleton of high polymer, could enhance the strength of composite gel.

The strength of gel was measured in a short core with length of 10 cm and diameter of 2.5 cm. Firstly composite gel solution was injected into the core saturated with water to produce plugging slug. After gelation of the agent, water was injected from the other side and the injection pressure was recorded during the process. The yield stresses of composite gel in water and oil were tested respectively to investigate its selectivity.

As shown in Figure 1, scaled horizontal well model consisted of core and steel pipe. The two parts were bonded together and sealed by epoxy resin. The artificial pressed cores, with size of 5 cm (width) × 10 cm (height) ×80 cm (length), were used to simulate reservoir. Water could be injected from the bottom side of cores to simulate bottom water displacement. Horizontal well was simulated by steel pipe that was placed at the top of core, with length of 80 cm and diameter of 0.3 cm. The pipe was slotted to provide channel for flowing. Changes of well trajectory and plane heterogeneity, two main factors influencing waterout position, were taken into consideration in horizontal well models.

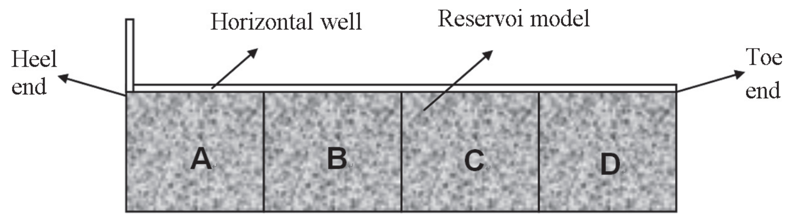


Figure 1
The Schematic Diagram of Horizontal Well Model

There were three kinds of models (shown in Table 1): standard model, plane heterogeneous model and irregular well trajectory model. Permeability of each part was different in plane heterogeneity models, and matching relation between permeability differences and flow direction was also considered. Part of horizontal well was made lower and choser to bottom water than others in irregular well trajectory model. The standard model was set as reference object.

Table 1
Characteristic Parameter of Horizontal Well Models

Model number		Size [widen×hight×length]	Permeability distribution [from A to D]	Well trajectory [location of lower well part]
Standard model	M1		1:1:1:1	None
Heterogeneous model	M2		1:3.3:5:8.3	None
	M3	5 cm × 10 cm × 80 cm	8.3:5:3.3:1	None
Irregular well trajectory model	M4		1:1:1:1	Section A
	M5		1:1:1:1	Section D

1.2 Experimental Methods

1.2.1 General Injection Experiment

In order to study placement of injected agent quantitatively, the core was marked as four parts along the horizontal direction and four exits were set at the bottom corresponding to each part. The temperature of this experiment was set at the laboratory condition of 20 ℃, and composite gel would not become blocking slug and keep flowing during the experiment. So the injected gel of different parts could flow out the model and be measured.

Composite gel solution was injected into the model saturated with water from horizontal well at a constant rate of 4 mL/min. After the outflow reached stable, flux of each exit was recorded. The ratio of each flux to the total was calculated which was named as shunt rate. The placement law of injected agent could be judged by shunt rate.

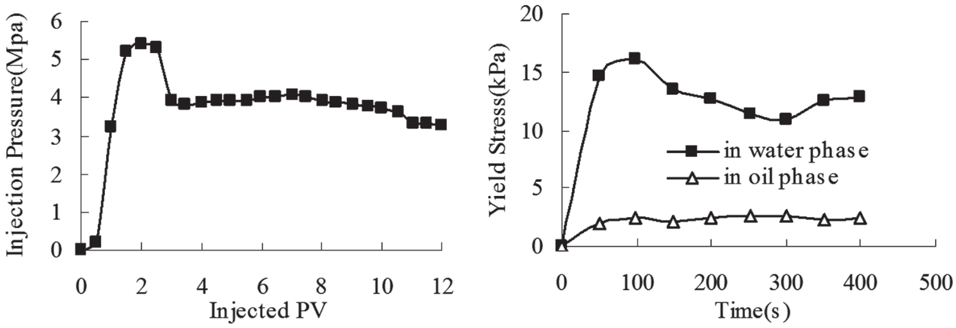
1.2.2 Water plugging at high water cut stage

This experiment was taken under the reservoir condition of 65 ℃. Firstly the model was saturated with oil to simulate initial reservoir condition. After that, water was injected into model from the bottom to displace oil in model, and oil was exploited from horizontal well till the water cut up to 90%. Then 0.15 pore volume (PV) composite gel was injected into model form horizontal well. After gelation of injected agent, subsequent water flooding was carried out until water cut up to 95%-98%.

2. RESULTS AND DISCUSSION

2.1 Blocking Capacities of Composite Gel

Water was injected into the core blocked by composite gel and the injection pressure was shown in Figure 2(a). It could be seen that the pressure rose continuously up to 5 MPa during the first 2 PV injection. During the process, there was no water flowing out of the exit, which meant the core was completely plugged by gel slug. After 2 PV injection, the gel slug was broke through and water began to outflow. Since then the pressure stabilized around 4 MPa all the time. Calculated by Darcy's Law, the permeability of core decreased from 212×10^{-3} μm^2 to 0.5×10^{-3} μm^2 because of plugging. The result showed that composite gel had strong blocking strength after its gelation in cores, even if part of it was broken through.



(a) Injection pressure (b) Yield stress in oil/water

Figure 2
Blocking Capacities of Composite Gel

Composite gel's yield stress in oil phase was about one seventh of that in water phase (Figure 2(b)). The result indicated the strength of composite gel in oil was much lower than that in water, and this kind of oil-water selectivity meet the requirement for water plugging agent: it could plug water-production formation and be less harm to oil production.

The composite gel was suitable for water plugging because of its strong strength and good oil-water selectivity.

2.2 Placement Law of Injected Agent

It can be seen in Table 2 that injected agent was not uniformly placed along horizontal direction in all models. From part A to D, shunt rate declined gradually and the difference between the highest and lowest values was 7.3% in standard model. The result showed that injected agent was more likely to enter the section near horizontal well's heel end. Analysis showed that the trend of injected agent was caused by pressure drop in horizontal well.

Pressure loss was produced in the flow of injected agent along the horizontal well. The driven pressure at the section nearing heel end is higher than others because of the pressure drop, which make more of injected agent penetrate into formation of that section.

Shunt rates of heterogeneous models and irregular well trajectory models were shown in Figure 3. It can be seen that, for model with heel end at high permeable area (M2), placement law of agent was similar to the standard one: the closer to heel end, the more blocking agent entered, and the difference between highest and lowest values enlarged to 13.2%. However, for model with heel end at lower permeable area (M3), the two parts far away heel end (C, D) had a higher shunt rate, and the difference between the highest and lowest shunt rates dropped to 6.6%.

Table 2
Shunt Rates of All Models

Model number	Shunt rate [%]			
	Section A	Section B	Section C	Section D
M1	28.7	27.6	22.4	21.4
M2	31.6	25.7	24.3	18.4
M3	23.6	22.1	28.8	25.5
M4	29.8	27.6	24.8	17.8
M5	22.2	26.6	24.7	26.5

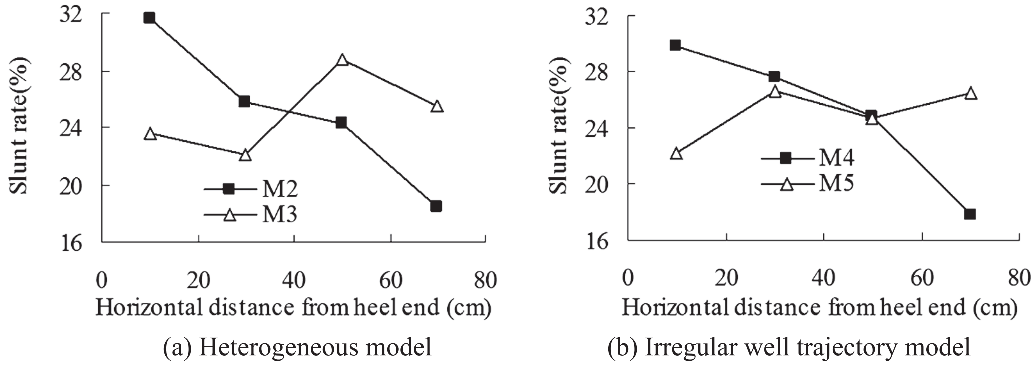


Figure 3
Placement of Injected Agent Along Horizontal Well

Experimental results indicated that higher permeable area was a favorable factor for composite gel's entrance, and the placement of injected agent was influenced by combined action of pressure drop and heterogeneity in heterogeneous models. When the heel end located at high permeable area, the trend that more composite gel penetrated into zone near heel end would be strengthened compared to standard model; because the two factors were both beneficial for the trend. Conversely, when the heel end located at low permeable area, the flow trends of injected agent influenced by two factors were conflict and the final placement was determined by the game of the two factors. In the experiment of M3, part C was the section that most agent went to.

For model with lower well part at heel end area (M4), the placement was the same as that of standard model: injected agent that entered the section near heel end was more than others, while the difference between the highest and lowest values increased to 12.0%. The injected agent of M5 was placed more uniformly and the maximum difference among each part dropped to 4.4%. It can be seen that the lower well part was also a beneficial factor for agent's entrance and placement law was influenced by combined action between pressure drop and lower well part in irregular well models.

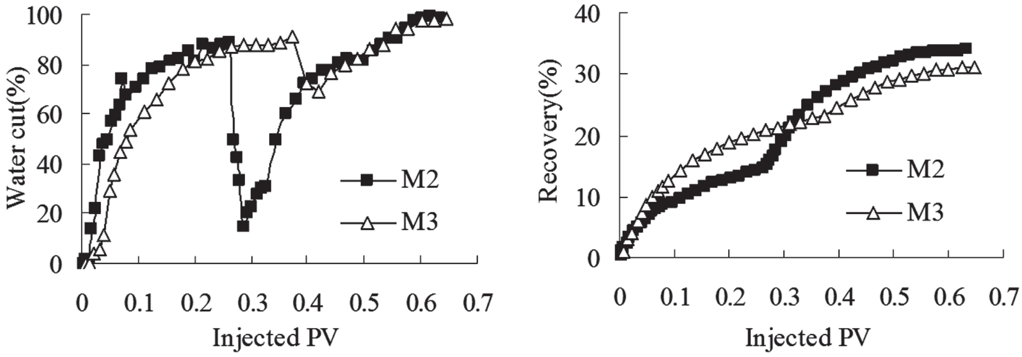
2.3 Production Performances After Blocking Treatment

It is shown in Table 3 that general injections were effective for all models: water cut decreased and the recovery increased after treatment. 32.3% of oil in standard model was exploited by first water flooding. After the general water plugging, water cut dropped by 25.2% and the recovery increased by 9.7% up to 42%. In standard model bottom water profile was more uniform than other models, so the first water flooding performance of the model was best.

Table 3
Improvement of Oil Production Performance After Treatment

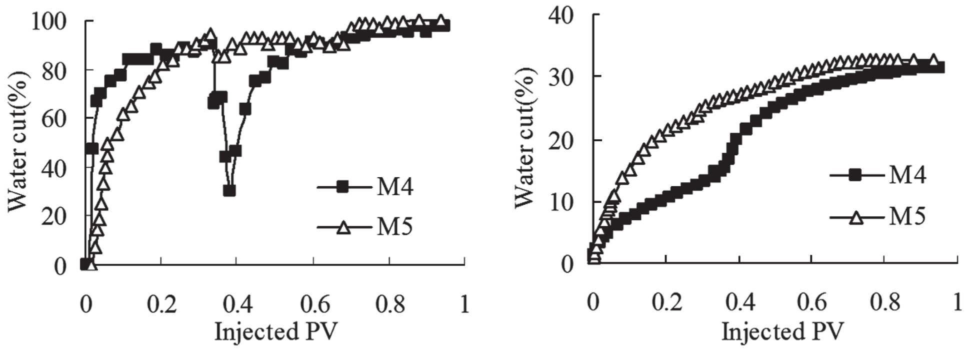
Model number	Initial oil saturation [%]	Decrease of water cut [%]	Recovery[%]		
			First water flooding	Increase of recovery	Total
M1	49.6	25.2	32.3	9.7	42.0
M2	53.1	74.2	14.4	19.6	34.0
M3	51.4	22.2	23.2	8.0	31.2
M4	50.2	59.9	13.7	17.8	31.5
M5	50.0	9.0	25.8	7.0	32.8

Production performances of heterogeneous models were shown in figure 4. Because of heterogeneity, water breakthrough position of M2 was section A and that of M3 was section D. After general injection of blocking agent, water cut of M2 decreased by 74.2%, and final recovery increased by 19.6%. While for model M3, the decline of water cut was 22.2% and the increase of recovery was only 8.0% by the treatment.



(a) Water cut (b) Oil recovery

Figure 4
Production Performances of Heterogeneous Models



(a) Water cut (b) Oil recovery

Figure 5
Production Performances of Irregular Well Trajectory Models

Production performances of irregular models were shown in Figure 5. Water broke through at lower well part in irregular well trajectory models, and M4's water entry position located at section A, M5's located at section D. M4 had a better water plugging effectiveness: the decrease of water cut was 59.9% and the rise of recovery was 17.8%. While for M5, the decrease of water cut was 9.0% and the rise of recovery was 7.0%.

It can be seen that for different models, improvement of production performance by general water shutoff differed greatly. For models (M2, M4) that more of agent went to objective position, the water cut declined at larger scale after treatment, which indicated the breakthrough water was better plugged compared to others. The bigger increase of final recovery showed that the treatment for the models had a better performance. However, for models (M3, M5) that less blocking agent penetrated into the wanted section, the production performances after water plugging were not improved as good as two models above. Comprehensively, the performances of the general water shutoff: were markedly influenced by the placement law of injected agent.

Although injected agent is not uniformly placed along horizontal direction, general injection were effective for different water breakthrough condition in experiment. While in application, plugging slug in reservoir is easier to be damaged than that in experiment. Therefore, at the condition of the same injection rate, if more of agent entered to the water-production formation, it could plug water even part of it was broken. If less of injected agent went to objective position, it is hard to form plugging slug. That is one of the reasons that one kind of water plugging agent is effective for a well, while is useless for another.

CONCLUSION

Due to reservoir heterogeneity and well trajectory, injected agent is not uniformly placed along the horizontal well in general water shutoff, which has important influence on the effect of the technology. Therefore, it is necessary to make clear the placement law of injected agent before application of general water shutoff. If little agent could penetrate into water breakthrough, general water shutoff should not applied to the well and alternative technology should be taken into consideration. If most of agent could enter the objective formation, injection policy can be optimized to reduce the cost of the technology.

REFERENCES

[1] Wan, R. P. (1997). *Recovery technologies of horizontal wells in different reservoirs of China*. Beijing: Petroleum Industry Press.

[2] Hadia, N. J., Chaudhari, L, S., Mitra, S, K., Vinjamur, M., & Singh, R. (2008). Effect of scaling parameters on waterflood performance with horizontal and vertical well. *Energy Fuels*, *22*, 402-409.

[3] Zhou, D. Y., Jiang, T. W., Zhao, J. Z., & Feng, J. L. (2004). The uncertainty and production of critical output of horizontal wells in bottom water reservoirs. *Oil Drilling & Production Technology*, *28*, 33-36.

[4] Zhang, H. L., Wang, Z. L., & Wang, J. (2011). Watering crest along a horizontal well in heterogeneous reservoir with bottom water. *Petroleum Science and Technology*, *23*, 2471-2479.

[5] He, F. G., Li, L. C., Yue, X. A., Zheng, J. P., & Jiang, J. L. (2011). The influence of horizontal well trajectory on recovery effectiveness of bottom water oil reservoir. *Journal of Southwest Petroleum University* (*Science & Technology*), *31*, 105-109.

[6] Permadi, P., & Lee, R. L. (1995). Behavior of Water Cresting Under Horizontal Wells. *SPE Annual Technical Conference & Exhibition*, SPE Paper 30743.

[7] Sanosh, V., Mitra, S, K., Vinjamur, M., & Singh, R. (2007). Experimental and numerical investigations of waterflood profiles wiht different well configurations. *Energy Fuels*, *21*, 3353-3359.

[8] Wei, F. L., Liu, Y. Z., Li, Y. K., Tang, X. F., & Xiong, C. M. (2007). Developing trend and current situation of water plugging technology for slotted pipe horizontal wells. *Oil Drilling & Production Technology*, *29*, 40-43.

[9] Zhu, H. J., Xu, Z. D., Luo, J, H., Dai, G. H., & Wang, D. C. (2004). Technologies of water and gas shuttoff in horizontal wells: an overview. *Oilfield Chemistry*, *21*, 85-90.

[10] Arangath, R., & Mkpasi, E. E. (2002). Water shut-off treatments in open hole horizontal wells completed with slotted liners. *SPE/ICoTA Coiled Tubing Conference and Exhibition*.

[11] Bond, J., Blount, C. G., Davies, S. N., Keese, R. F., Lai, Q. J., & Loveland, K. R. (1997). Novel approaches to profile modification in horizontal slotted liners at Prudhoe Bay, Alaska. *SPE Annual Technical Conference and Exhibition*.

[12] Zhu, H. J., Long, Q. L., Luo, J, H., Xiong, C. M., Jiang, H. J., & Bai, F. L. (2009). Experimental study on water shutoff of sulfonated larch tannin extract to aqueous layer in the fracture-cavity karst reservoir. *Acta Petrolei Sinica*, *30*, 565-568.

[13] Coste, J. P., Zaitoun, A., & Bai, B. J. (2000). IFP self selective agents for water shutoff. *Petroleum Exploration and Development*, *27*, 93-97.

[14] Zaitoun, A., Bertin, H., & Lasseux, D. (1998). Two-phase property modifications by polymer adsorption. *SPE/DOE Improved Oil Recovery Symposium*, SPE Paper 39631.

[15] Dai, C. L., Zhao, F. L., Li, Y. L., Feng, D. C., & Ren, S. H. (2005). Control technology for bottom water coning in horizontal well of offshore oilfield. *Acta Petrolei Sinica*, *26*, 69-72.

[16] He, L., Dai, C. L., Hou, Y., Liu, C. H., & Zhao, F. L. (2009). Research on water shutoff technology in the western zone of South China Sea oilfield. *Oilfield Chemistry*, *26*, 145-147.

[17] Wang, X. H., Zhao, L. L., Kong, M. W., & Ma, L. H. (2010). Application of temporary-blocking agent for water plugging in horizontal wells. *Journal of Oil and Gas Technology*, *32*, 352-354.

[18] Francesco, V., Martin, B., Alan, M., & Tony, M. G. (2005). Applicability of water shutoff treatment for horizontal wells in heavy-oil reservoirs. *SPE Europec/EAGE Annual Conference and Exhibition*.

[19] Bi, Y. G., Zhang, M., Ma, G. Z., Liu, Z. J., & He, E. (2011). Research on water breakthrough characteristics and influence factors of horizontal well in complex faultblock reservoirs. *Fault-Block Oil & Gas Field*, *18*, 79-82.