Study on start-up of residual oil for different grades of water flooding zones at ultra-high water-cut stage

Mengyun Li, Ping Jiang, Guicai Zhang*
School of Petroleum Engineering, China University of Petroleum, Qingdao, Shandong, 266580, China
*Corresponding author’s e-mail: 13706368080@VIP.163.com

Abstract: At present stage, most of the oil reservoirs in China have entered the ultra-high water-cut period, and the heterogeneity is serious. The water flooding effects in different zones of the reservoirs are obviously different. The overall reservoir recovery degree is low, and there is still a large amount of remaining oil remaining in all grades of water flooding zones. This paper mainly carried out the relevant physical model experiment of the remaining oil in the ultra-high water-cut period, and simulated the recovery of the remaining oil under different subsequent flooding conditions after entering the ultra-high water-bath period of different grades of water flooding zones. The start-up law of the remaining oil in the different grades of water flooding zones was observed and analyzed. According to the experimental results, it can be seen that in the period of ultra-high water cut, the strong water flooded zone has a greater exploitation potential than the extreme water washing zone and the weak water flushed zone. Therefore, the focus of developing in the ultra-high water-cut stage should be placed on the strong water flooded zone, and the water flooding after adjusting the profile by injecting jelly can effectively improve the recovery rate of the strong water flooded zone.

1. Introduction
China has abundant reserves of petroleum resources, but after years of waterflooding development, most of the oil reservoirs quickly entered the high water cut stage, and many reservoirs’ water cuts exceeded 98%, reaching the extremely high water cut stage. Compared with the period of medium and low water cut, the period of ultra-high water cut has the characteristics of low oil recovery rate, rapid decline in production, scattered remaining oil distribution, poor effect of measures, and low economic benefits of development [1]. And in the ultra-high water-cut period, due to the long-term erosion of the injected water, the physical properties of the reservoir have changed greatly, and the degree of heterogeneity increased, resulting in the unsatisfactory water flooding effect of the remaining oil at this stage [2-4]. In the heterogeneous reservoir in the ultra-high water-cut period, the injected water flows rapidly from the dominant channel after injection. Due to the existence of the dominant channel, different parts of the reservoir have different washing degrees, so the potential tapping degree of the remaining oil is also different [5-7]. Therefore, in order to improve the recovery rate and extract the remaining oil more economically and effectively, it is necessary to study the development potential of the remaining oil in different grades of water flooding zones, and to study the start of the remaining oil in the ultra-high water-cut period [8-11].
2. Materials and Methods

2.1. Experimental Materials
The crude oil used in the experiment was reservoir crude oil in the GD area of the S oilfield. The formation water used in the experiment was configured with Nacl based on the on-site formation water salinity. The formation water salinity was 9957mg/L; the formation temperature was 68℃.

(1) Formation crude oil
The density of crude oil is measured by the specific gravity method, and the density of the sample crude oil is 0.957g/cm³; and the viscosity of the crude oil at different temperatures is measured by a viscometer, and the crude oil viscosity at the formation temperature is about 115mPa·s.

(2) Surfactant screening
According to the experimental data, 0.1% alkanolamide was selected as the surfactant flooding solution in subsequent experiments.

(3) Polymer
The selected polymer is SL-1 polymer with a molecular weight of about 180-240.

2.2. Sand Packed model
The sand packed model displacement device is mainly composed of the displacement micro-pump part, the sand-packed tube parallel model part with different permeability, the pressure monitoring part and the acquisition part.

2.3. Experimental program
(1) Water drive flow rate: Water flooding was carried out on the sand packed tubes in the ultra-high water cut period to change its water flooding velocity and observe the subsequent oil recovery of three sand filling pipes with different permeability.

(2) Surface active agent flooding: Replace the displacement fluid with a 0.1% alkanolamide solution and observe the subsequent oil recovery of three sand packed tubes with different permeability.

(3) Polymer flooding: Replace the displacement fluid with a 0.1% polymer SL-1 solution and observe the subsequent oil recovery of three sand-packed pipes with different permeability.

(4) Profile control and water shutoff: After using the gel plugging agent, water flooding is carried out at a speed of 2ml/min, and the subsequent oil recovery of three sand-packed tubes with different permeability is observed [12-15].

3. Study on the start-up law of residual oil in super high water cut period
Complete the experiment according to the experimental plan, and organize and analyze the experimental results. Calculate and record the develop situation of the three sand packed tubes after the ultra-high water cut period as shown in the following table.

| Table 1 Table of sand-packed tubes developing results after water flooding |
|---------------------------------------------------------------|
| Sand packed tubes | Total amount of oil (ml) | Production of oil (ml) | Remaining amount of oil (ml) | Recovery (%) |
|-------------------|--------------------------|------------------------|-----------------------------|-------------|
| Sand packed tubes of low-permeability | 45.1 | 17 | 28.1 | 37.69 |
| Sand packed tubes of medium-permeability | 46.3 | 20.5 | 25.8 | 44.28 |
| Sand packed tubes of high-permeability | 48.5 | 23.1 | 25.4 | 47.63 |

After normal water flooding, the low-permeability sand-packed tube has the highest remaining oil and its recovery rate is low, while the medium and high-permeability sand-packed tubes has a relatively high recovery rate.

3.1. The Influence of Water Drive Velocity on Remaining Oil Startup
Water flooding was carried out on the sand-packed tubes in the ultra-high water cut stage. The raw water
flooding speed was 2ml/min, and the water flooding speed was adjusted to 4ml/min. The water flooding continued until the oil was basically free from the outlet liquid.

The produced oil quantity was observed and counted, and the oil production curve of the three sand-packed tubes was shown in the figure. Experimental data are shown in Table 2 to analyze the impact of water displacement velocity on the start-up law of remaining oil in different water displacement zones.

| Sand packed tubes            | The total amount of oil (ml) | Production of oil (ml) | Degree of enhanced oil recovery |
|------------------------------|-------------------------------|------------------------|---------------------------------|
| Sand packed tubes of low-permeability | 45.1                         | 1.5                    | 3.33%                           |
| Sand packed tubes of medium-permeability | 46.3                         | 1.7                    | 3.67%                           |
| Sand packed tubes of high-permeability | 48.5                         | 1.6                    | 3.30%                           |

Under the condition of changing the water drive speed, higher water drive speed can improve the recovery degree of water flooding zones with different permeability to a certain extent, but the effect is not obvious. There is no significant difference in the oil output of the three sand-packed tubes, and the enhanced oil recovery range is basically maintained within the same order of magnitude.

3.2 The influence of surfactant flooding on remaining oil start-up

Use 0.1% alkanolamide solution to continue to displace the sand-packed tubes in the ultra-high water-cut period, and maintain the state of the water-flooding stage with conditions such as the displacement speed until the liquid is basically free of oil.

The produced oil quantity was observed and counted, and the oil production curve of the three sand-packed tubes was shown in the figure. Experimental data are shown in Table 3 to analyze the impact of surfactant on the start-up law of remaining oil in different water displacement zones.

| Sand packed tubes            | The total amount of oil (ml) | Production of oil (ml) | Degree of enhanced oil recovery |
|------------------------------|-------------------------------|------------------------|---------------------------------|
| Sand packed tubes of low-permeability | 45.1                         | 1.7                    | 3.77%                           |
| Sand packed tubes of medium-permeability | 46.3                         | 3                      | 6.48%                           |
| Sand packed tubes of high-permeability | 48.5                         | 2.3                    | 4.74%                           |

Under the condition of converting water flooding to surfactant flooding, the recovery of water flooding zones with different permeability has been improved to a certain extent. Among them, the
medium-permeability sand-packed tube improves the recovery rate most obviously, and the staged oil production is significantly higher than low-permeability and high-permeability sand-packed tubes; it can be seen that in the subsequent surfactant flooding after the ultra-high water cut period, the medium-permeability sand-packed tube, that is, the strong water flooded zone, have great development potential.

3.3. Influence of polymer flooding on remaining oil start-up
Use 0.1% polymer SL-1 solution to continue to displace the sand-packed tubes in the ultra-high water-cut period, and maintain the state of the water-flooding stage with conditions such as the displacement speed until the liquid is basically free of oil.

The produced oil quantity was observed and counted, and the oil production curve of the three sand-packed tubes was shown in the figure. Experimental data are shown in Table 4 to analyze the impact of polymer on the start-up law of remaining oil in different water displacement zones.

![Cumulative oil production of sand-packed tubes during polymer flooding period](image)

| Sand packed tubes                  | The total amount of oil (ml) | Production of oil (ml) | Degree of enhanced oil recovery |
|-----------------------------------|-----------------------------|------------------------|--------------------------------|
| Sand packed tubes of low-permeability | 45.1                        | 3                      | 6.65%                          |
| Sand packed tubes of medium-permeability | 46.3                        | 4.7                    | 10.15%                         |
| Sand packed tubes of high-permeability   | 48.5                        | 3.6                    | 7.42%                          |

Under the condition of converting water flooding to polymer flooding, the recovery degree of water flooding zones with different permeability has been improved to a certain extent. Among them, the medium-permeability sand-packed pipe improves the recovery rate most obviously, and the staged oil production is significantly higher than the low Permeable and high-permeability sand-packed pipes; it can be seen that in the subsequent polymer flooding oil recovery after the ultra-high water cut period, the medium-permeable sand-packed pipes, that is, the strong water flooded zone, have great development potential.

4. Remaining oil start-up law of profile control and flooding in ultra-high water cut stage
Inject 0.3PV of chromium jelly into the sand-packed tubes. After 12 hours of aging time, continue water flooding on the sand-packed tubes in the ultra-high water-cut period.

The produced oil quantity was observed and counted, and the oil production curve of the three sand-packed tubes was shown in the figure. Experimental data are shown in Table 5 to analyze the impact of profile control and flooding on the start-up law of remaining oil in different water displacement zones.

![Cumulative liquid production of sand-packed tubes after during profile control and flooding](image)
After the injection of chromium gel, the water absorption profile of the sand-packed tubes changed, and the proportion of medium and low permeability sand-packed tubes increased significantly. Continue the water flooding under the conditions, the recovery of the three sand-packed tubes all have certain improvement, with the production of low permeability and high permeability sand-packed tubes have small difference with the production during the period of changing speed of water drive, but the production of medium-permeability sand-packed tubes is relatively obvious increase, the degree of enhanced oil recovery is higher the that of low and high permeability sand-packed tubes.

From this, it can be seen that after the injection of jelly to adjust the water absorption profile, in the subsequent waterflooding of the ultra-high water-cut period, the medium-permeability sand-packed tube, namely the strong water-flooded zone, has a greater development potential than other waterfloods.

### 5. Conclusions

After a long period of water injection development, the oilfield gradually enters the ultra-high water-cut period. In the ultra-high water-cut stage, the existence of the dominant water flow channel causes the degree of washing of the reservoir to be different, which has a great impact on the distribution of remaining oil. The difference in the degree of water washing of the reservoir results in different levels of recovery of the remaining oil in different parts, so the potential of different parts of the production will also be different.

The remaining oil start-up law is studied through sand-packed tubes experiments. Sand-packed tubes with different permeability are used to simulate different grades of water flooding zones. Through polymer flooding and surfactant flooding experiments, we observe the development of the remaining oil of different grades of water flooding in the ultra-high water cut stage. It is concluded that during the ultra-high water cut period, the strong water-flooded zone has a greater potential for exploitation than the extreme water-washing zone and the weak water-flushed zone. Therefore, the focus of mining in the ultra-high water-cut stage should be placed on the strong water flooded zone, and the water flooding after adjusting the profile by injecting jelly can effectively improve the recovery rate of the strong water flooded zone.

### Acknowledgments

This paper is one of the phased achievements of (1)National Key R&D Program of China "Basic Research and Industrial Demonstration on chemical composite cold recovery of heavy oil" (2018YFA0702400); (2)National Science and Technology Major special project "Enhanced Oil recovery Technology during Super High Water Cut Period of Shengli Oilfield"(2016ZX05011-004) and sinopec "Ten Dragon" Project "Shengli Integrated Oilfield During Super High Water Cut Period Of Deep Plugging Adjustment Technology" (217007).
References
[1] Li Dongbo, (2013) The main technical measures and enlightenment of foreign high-water-cut oilfields during the ultra-high water-cut period. Contemporary Petroleum & Petrochemical, 21(10): 13-15, 21.
[2] He Fen, Li Tao, (2001) Research on periodic water injection to improve water drive efficiency. Petroleum Drilling & Production Technology, 11(1): 53-54, 61.
[3] Gao Jutong, (2015) Research on Ng_5 subdivision variable flow line well pattern adjustment technology in Gudong Second District. Journal of Southwest Petroleum University (Natural Science Edition), 37(3): 122-128.
[4] Yao Bo, Zhao Qingdong, (2003) Subdivision adjustment measures have yielded initial results in Gaotaizi oil layer. Petroleum Exploration and Development, 203(2): 220-224.
[5] Yuan Xiangchun, Yang Fengbo, (2003) Reorganization and adjustment of injection-production well pattern during high water cut period. Petroleum Exploration and Development, Vol. 5 (5): 94-96.
[6] Jin Yanxin, Shi Shubin, Fu Wei, Wang Tao, Xu Peng, (2015) Research on the technical boundary of deep profile control in ultra-high water-cut reservoirs. Special Oil & Gas Reservoirs, 22(3): 77-80, 154-155.
[7] Huang Weigang, Guo Ping, Xu Yanmei, (2005) Remaining oil distribution geological research method. Journal of Southwest Petroleum Institute, 3: 5-7.
[8] Li Xingguo, (1994) Using microstructures and reservoir sedimentary microfacies to study remaining oil distribution in reservoirs. Li Xingguo. Oil and Gas Recovery Technology, 1: 68-80, 86.
[9] Zhu Guangpu, Yao Jun, Zhang Lei, et al, (2017) Remaining oil distribution and formation mechanism in ultra-high water cut period_Zhu Guangpu. Chinese Science Bulletin, 62(22): 2553-2564.
[10] Liu Jiyu, Ma Zhixin, Lu Jing, (2007) Current research status of remaining oil distribution in high water cut period_Liu Jiyu. Petroleum Geology and Engineering, 115(3): 11, 61-63.
[11] Lai Fengpeng, Li Zhiping, (2007) Research on the prediction method of remaining oil distribution in high water cut period. Xinjiang Oil & Gas, 3: 37-41, 103.
[12] Sun Ming, Li Zhiping, (2009) Identification and description technology of dominant seepage channels in water injection development sandstone reservoirs_Sun Ming. Xinjiang Oil & Gas, 5(1): 51-56, 105-106.
[13] Liu Hongqi, Li Baoying, Wang Wanfu, et al, (2014) Characteristics analysis of reservoirs and dominant channels in Jin 16 block_Liu Hongqi. Journal of Southwest Petroleum University (Natural Science Edition), 36(6): 60-68.
[14] Ekrem Kasap, Lumay Viloria, Fangjian J. Xue, (2002) Seismic-Based-Gas-Water-Contact, Porosity, and Permeabilities for Condensate Reservoirs: Tested and Corrected by History Matching. SPE 75222, 1-12.
[15] Brigham W E, et al, (1983) Analysis of Unit Mobility Ratio Well to Well Tracer Flow to Determine Reservoir Heterogeneity. SUPRITR-36.