Screening study on microsphere used in profile control under the environment of microbial oil recovery

Tiantian Zhang[1], Gang Xie[1], Shanshan Gao[1], Zhiqiang Wang[1], Junjie Wei[1], Lei Shi[1], Ya Zheng[1], Yi Gu[1], Xiaoyang Lei[1], Ai Wang[1]

[1]Petroleum Production Engineering Research Institute of Huabei Oilfield Company, Renqiu 062552, Hebei, China

cyy_ztt@petrochina.com.cn

Abstract: The performance of four microspheres samples (MS-1, MS-2, MS-3, and MS-4) were evaluated and optimized by indoor experiments. Firstly, the basic physical and chemical properties of the four kinds of microspheres were evaluated by analyzing the solid contents and the solubility in the water. Results showed that the content of the precipitated solids in MS-1 was the lowest in the four kinds of microsphere samples. The contents of the other three microspheres were similar in the value of solid content. Besides, the three microspheres of the solubility in the simulated formation water were excellent. Secondly, the expansion properties of three kinds of microspheres (MS-2, MS-3, and MS-4) were investigated. Results revealed that the expansion performance of MS-3 was greatly affected by microbial metabolism. However, the other two samples had excellent expansion performance under the condition of microbial flooding. Finally, the sealing performance of MS-2 and MS-4 was evaluated by physical simulation Block test. Results showed that compared with MS-2, MS-4 was more suitable for Block B.

1. Introduction

The microsphere tuning-drive is a new deep drive technology developed in recent years, which is of great significance to improve the water flooding and oil recovery efficiency [1-2]. However, with the development of water flooding history, the traditional method to improve water absorption profile can't meet the demand of oilfield production. From the application of profile control technology, single conventional profile control technology is not ideal and gradually restricted, due to its failure to solve the interlayer and layer contradictions. Deep compound profile technology can fundamentally solve the problems of interlayer, improve water flooding development effect, as well as improve the volume and utilization rate of injection water. The combined oil displacement technology of microbial displacement and microsphere flooding is one of deep-depth compound profile techniques. However, to the best of our knowledge, there are few studies on microspheres properties at home and abroad [3-4].

The properties of four microspheres samples were studied under the environment of microbial oil recovery through the indoor test, including the basic physical and chemical properties, compatibility with formation water, as well as the block core plugging performance targets. Finally, select the suitable microspheres sample under conditions of microbial oil displacement environment for Block B reservoir. It is of certain significant to the combination profile control technology of microbial oil displacement and microspheres profile control technology.

2. Experiment instruments and experiment agents

2.1 Experiment instruments
LA-950S static laser particle analyzer, Horiba company of Japan; JK-MSH-PRO-6B magnetic stirrer, Jingxue science instrument company of Shanghai; H-101 electric heating and constant temperature drying oven, Shanghai Yao's equipment factory; CWM-III long core physical model displacement device, Haian county petroleum research instrument company; Busher instrument, huadan instrument; and PM 4800 balance, Mettler company of Swiss.

2.2 Experiment agents
Absolute ethyl alcohol, analytical pure, Tianli chemical reagent company of Tianjin; Injection water of Block B; Microbial flooding system and nutrient solution system from Block B; and Four kinds of polyacrylamide microsphere samples, labeled as MS-1, MS-2, MS-3, and MS-4, respectively.

3. Experiment methods

3.1 Determination of the content of solid precipitated
Firstly, weigh a certain amount of the microsphere sample with full shake, labeled as m_1. Then, extract the microsphere solid by using absolute ethyl alcohol. And then, filter the microsphere solid through using Busher instrument to obtain the microsphere solid precipitated out. After that, dry the microsphere solid in the 70 ℃ oven for 2 hours. Finally, precipitate the solids quality after drying, marked as m_2. The content of microsphere solid precipitated out, marked by C, can be calculated by the following formula.

$$C = \frac{m_2}{m_1} \times 100\%$$

3.2 Compatibility testing
A certain amount of microsphere samples were added to the waste water to be prepared into a microsphere solution of 3000mg/L. Mix thoroughly, let the solution set for 3~5 minutes, and then observe whether there was a stratification of the solution.

3.3 Testing of expansion performance

3.3.1 Preparation of microspheres aqueous solution. Firstly, the indoor preparation of water which was in accordance with the site injection water salinity, the total salinity was 6135.8 mg/L, and the water type was $NaHCO_3$. Then, add a certain concentration of nutrient solution to the water in order to simulate the field conditions. After that, filter the water sample by a membrane with aperture of 0.45μm to remove the suspended solids, etc. the suction filter. And then, sterilize water samples by putting them in high temperature and high pressure sterilization pot processing 30 min. Then, add a certain concentration of microorganism applied in Block B, mixture field simulated sewage. Finally, shake the sample fully, mixed aqueous solution, the mass fraction of 1% microspheres after partial shipments to stir well sealed stainless steel drum. Put the water sample in electric heating and constant temperature drying oven by 58 ℃. After a period of time, remove and cool to the room temperature.

3.3.2 Test of microsphere hydration particle size. The static laser particle analyzer was opened to preheat for 30min. The instrument was calibrated according to the operating rules, and the simulated site water sample used in the interior was used as an empty sample to deduct the background value. After fully shake, under test sample apply adequate amount to the beaker, prepared with the water sample adjustment under test sample concentration and light transmittance fall within the scope of the instrument was suitable (red semiconductor laser satisfy 80%~90%, blue LED light meet 70%~90%), used the static laser particle analyzer to obtain the particle size and distribution of microspheres samples at room temperature (dispersion medium refraction: 1.33, particle refractive index: 1.50).

3.4 The testing of the Blocking rate of microspheres

Firstly, the sand filling tube simulation field formation parameters, such as porosity, permeability, and so on. Then, set the temperature of the long core displacement device of physical model test to 58 ℃, which was consistent with the temperature of Block B. And then, water flooding, measurement of permeability K_1. After that, the microsphere solution of the concentration of 3000mg/L was placed for 2~3 days at the temperature of 58℃, making the microsphere expand fully. Finally, secondary water flooding, measurement of permeability K_2. The stemming ratio of the microsphere sample was obtained according to the permeability before and after the injection of microsphere sample, which was calculated by the following formula.

$$\eta = \frac{K_1 - K_2}{K_1} \times 100\%$$

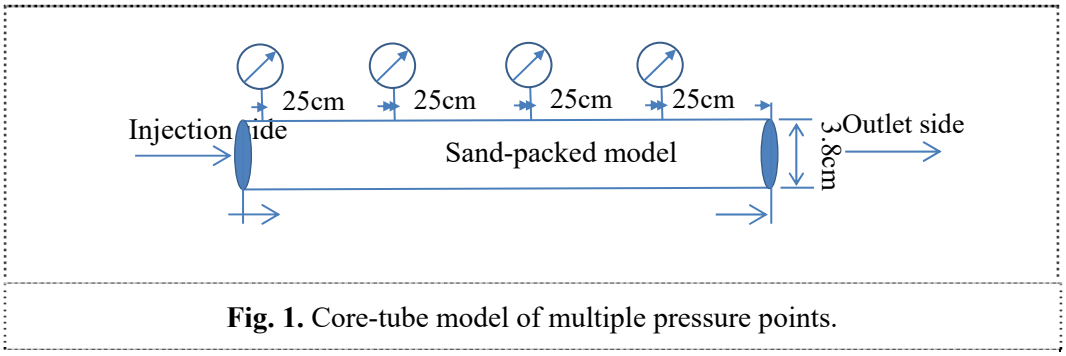

Fig. 1. Core-tube model of multiple pressure points.

4. Results and discussion

4.1 Basic physical and chemical properties of microspheres

4.1.1 Solid content of microspheres. It is the core active component of polymer microspheres that can be precipitated out. A large number of experiments showed that the content of the solid content could directly affect the blocking ability of polymer microspheres. Generally speaking, the higher the content of the solid content is, the better the sealing effect of microspheres will be. Therefore, the content of separable solid content is an important index in polymer microsphere evaluation.

Table.1. the content of microsphere solid precipitated out

sample number	quality of microsphere		content of microsphere solid	
	m_1(g)	m_2(g)	C (%)	mean value of C and deviation (%)
MS-1	10.211	1.989	19.48	19.01±0.50
	10.321	2.014	19.51	
	10.214	1.843	18.04	
MS-2	10.129	3.089	30.50	30.67±0.17
	10.122	3.122	30.84	
	10.217	3.135	30.68	
MS-3	10.135	3.082	30.41	30.63±0.21
	10.136	3.126	30.84	
	10.464	3.203	30.61	
MS-4	10.196	3.121	30.61	30.76±0.17
	10.289	3.182	30.93	
	10.274	3.160	30.76	

Table.1. showed the contents of the four kinds of microspheres. It showed that the solid content of MS-1 was only 19.01%, which was the lowest in the four samples. However, the solid content of the

other three microspheres samples was similar, both between 30% and 31%. Since the content of MS-1 was the lowest, considering the cost performance factor, microsphere sample of MS-1 was not recommended to use in Block B. Therefore, only the other three microspheres samples were examined in the following microsphere performance evaluation.

4.1.2 Compatibility with formation water. In order to analyze the compatibility of injected water from Block B with microspheres, microspheres solutions of 3000 mg/L was configured by using simulated field sewage. Fig.2. showed the solution samples of microspheres in sewage from Block B. From Fig. 2, it can be seen that the three samples of microspheres soluble could dissolve in reinjection sewage, after classics agitate. Both MS-2 and MS-4 solutions had a good solubility, but MS-3 microspheres solution upper suspension slightly. After placing 1h in the temperature of 58℃, the three kinds of microspheres had some stratification in different degrees, which could be dissolved after stirring.

Fig. 2. The solution sample of microspheres in sewage from Block B.
(a) MS-2 (b) MS-3 (c) MS-4.

4.2 Inflation performance

As we all know that there is a certain matching relationship between microspheres particle size and the core pore throat [5]. If the hydration size of microspheres was too small, it would be difficult to form effective and stable core pore blocking, because of its easy through. Otherwise, the injection of microspheres would be difficult, which could cause the goal of the deep displacement of the microspheres unrealizable. Therefore, the size and distribution state of the microsphere hydration particle size is an important basis for its application in the formation pore throat size, which directly affects the effect of microsphere tuning-flooding [6-7].

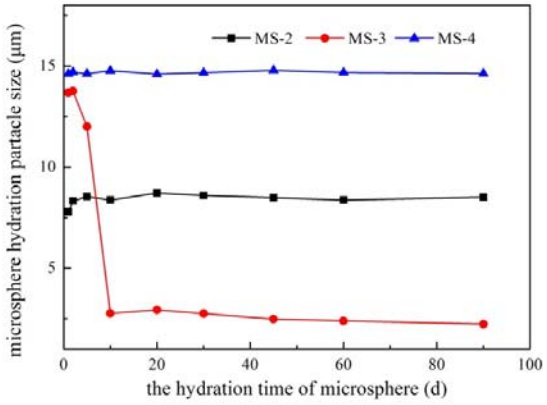

Fig. 3. The hydration particle size of microspheres at the different time.

Fig. 3 showed the expansion performance of three kinds of microsphere samples in simulated formation conditions of Block B. It can be seen that and the expansion performance of MS-2 and MS-4 are similar, which was that in a relatively short period of time (1~5 days) the hydration size had

already reached a stable value. The hydration of particle sizes were numerical difference, for example, particle size of the MS-2 after the soluble in water value stable at about 8.5μm, but MS-4 hydration size value at about 14.5μm. Unlike the expansion performance of the above microsphere samples, MS-3 was dissolved in water. In a short time of 5 days, the hydration particle size could be maintained at 12~14μm. However, after 10 days later, the hydrated particle size of MS-3 had been reduced and maintained at about 2.5μm for a long time. This indicated that MS-3 didn't apply to the site environment of Block B.

To analyze the expansion performance of microsphere samples MS-3 in simulated formation conditions of Block B, the aspects of water quality and test conditions were discussed, combining with the injected water coated tablet simulation test. Personally, there are two reasons caused the above experimental phenomena of MS-3. One is the simulated water quality, and the other is the effect of acetic acid produced by the microbial. On the basis of simulating self-matching water, the experimental water samples were added some nutrients, including carbon source, nitrogen source as well as phosphorus source, et.al, which increased the total mineralization of the water used in the experiment. In addition, coated tablet test showed that after 24 hours, the test samples of bacterium concentration reached 10^8~10^9 ml^{-1}, which make acetate microspheres solution acidic pH by producing by acetic acid. That was to say, microbial metabolism affected the expansion performance of MS-3.

4.3 Blocking performance of microspheres

The mechanism of microsphere displacement was that microspheres were stranded, and then changed the configuration of main channel, forcing fluid circulation, so as to enlarge the swept volume of injected water. Therefore, the blocking rate could to character quantitatively the flooding effect of microspheres, which could be used as an important evaluation index of polymer microsphere in Block B adaptive. From Darcy formula, it can be seen that the flow rate, the viscosity, and the core pipe specifications certain cases, the permeability is determined only by the pressure difference at the ends of the tube. Therefore, if the core tube was sealed by microspheres, the water permeability measurement would be reduced, and the injection pressure would be increased after injecting microspheres.

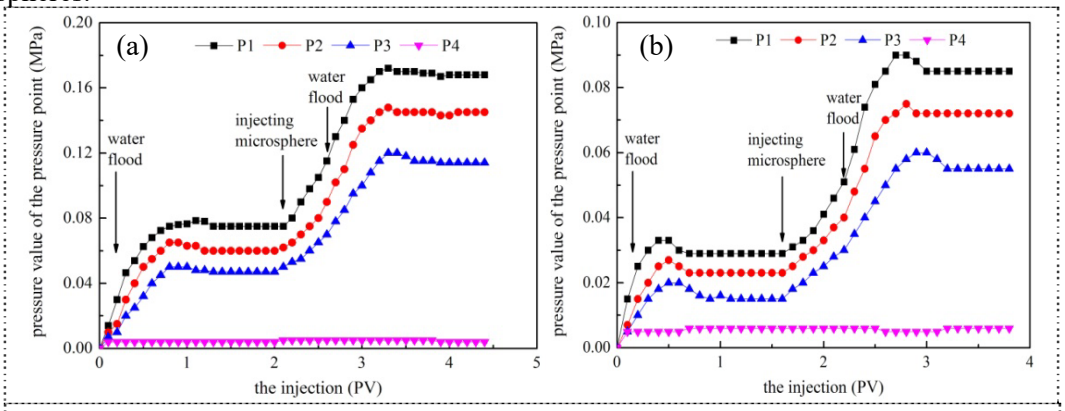

Fig. 4. The sealing situation of different microspheres in the core tube.
(a) MS-2 (b) MS-4.

Fig. 4 showed the sealing performance of MS-2 and MS-4 samples in simulated under the reservoir condition of Block B. It can be seen that the injection pressure of four pressure points changing with the increase of injection in the process of experiment. In addition, after the injection of 0.5PV microspheres with the concentration of 3000mg/L, the secondary water flooding pressure was significantly improved. According to the results of calculation, the blocking rate of MS-2 was 57.6%, while the blocking rate of MS-4 was 74.3%. This indicated that the blocking effect of MS-4 was better than MS-2 in reservoir of Block B, which may explain by that the matching relationship between microspheres particle size of MS-4 and the core pore throat was much better than that of MS-2 and the core pore throat.

5. Conclusions

In the present work, the properties of four kinds of microspheres (MS-1, MS-2, MS-3, and MS-4) under the environment of microsphere samples were studied through indoor testing, including the physical and chemical properties in microbial flooding, expansive performance, as well as Blocking performance. This paper finally comes to the following conclusions.

i. Dialyzable solids content of MS-1 was the lowest in the four microsphere samples, only 19.01%. However, the contents of the other three microspheres were similar, both in 30%~31%. MS-2, MS-3 and MS-4 all had a good solubility in the simulated injection water environment of Block B.

ii. MS-2 and MS-4 both had excellent expansion performance under microbial flooding conditions. Besides, the hydration particle size could be maintained at a stable value for a long time (90 days). MS-3 was affected by the water quality and microbial metabolism, and the hydration particle size was reduced from 13μm to 2μm in a short period of time (5 days).

iii. Blocking performance test showed that MS-4 had a higher plugging rate than MS-2. That was to say, compared with the microsphere sample of MS-2, MS-4 had a better matching with the core pore throat, which was more suitable for application in Block B.

Author information

Tiantian Zhang was born in 1988 and is an assistant engineer mainly working on the research of enhancing oil recovery now. Phone: +86-0317-2756426, E-mail: cyy_ztt@petrochina.com.cn.

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