Energy Proceedings
Vol 53, 2025
ISSN 2004-2965

The Study On Microscopic Mechanism of Asphalt Particle#

Zhiqiang Wang[1,2*], Hanqiao Jiang[1,2], Jie Li[1,2], Miao Zhang[1,2], Anqi He[1,2], Mengqi Ma[1,2],
1 Microscopic Reservoir Flow Simulation Laboratory, China University of Petroleum (Beijing), Beijing 102249, PR China
2 College of Petroleum Engineering, China University of Petroleum (Beijing), Beijing 102249, PR China
(Corresponding Author: 173809845@qq.com)

ABSTRACT

Asphalt particles have the characteristics of high temperature resistance, salt resistance, good stability, oil affinity, and blocking water without blocking oil. They can effectively plug large pores in high temperature and high reservoirs with salt medium and low permeability. At present, there are few studies on the micro-displacement experiment of asphalt particle system. In this paper, the micro-fluidic experiment technology is used to carry out the oil displacement experiment of asphalt particles under the condition of high temperature in the reservoir. The migration and accumulation law of asphalt particles is described, and then the mechanism of asphalt particles is analyzed, and the effect of displacement is quantitatively analyzed. The experiment shows that the asphalt particles enter the water flow channel after injection, and gather at the inlet of the model and the narrow pore throat in the form of a bridge, and self-similar aggregation occurs. The originally dispersed asphalt particles tend to gather and change the distribution of remaining oil. The accumulation effect causes the channel to block, the corresponding channel seepage resistance increases, the system flow range is reduced, the seepage velocity is accelerated, and the injection system passes through the cluster and porous remaining oil, which expands the affected area and also makes the cluster and porous remaining oil become film-like or drip-like remaining oil, increasing the overall recovery degree. Quantitative analysis of the microscopic model with pore throat radius of 40um and 75um shows that for the 40um model, when the asphalt particle injection concentration is 1.0%, the initial water flooding cluster residual oil accounts for 85%, the asphalt particle displacement cluster residual oil accounts for 80.5%, and the subsequent water flooding cluster residual oil accounts for 75%, and the overall recovery degree increases by 8.13%. For the 75um pore throat model, when the injection concentration is 2.5%, the proportion of the remaining oil in the initial water flooding cluster is 60%, the proportion of the remaining oil after the displacement of the asphalt particles is 47%, and the proportion of the remaining oil in the subsequent water flooding cluster is 43.5%, and the recovery degree is increased by 7.02%.

Keywords: high temperature and high salt medium low permeability reservoir; asphalt particles; clustered remaining oil; micro-fluidic

1. INTRODUCTION

With the continuous advancement of the exploration and development process of petroleum resources, most of the oilfields have entered the middle and late stages of exploitation [1]. In order to meet the increasing oil demand, the exploration and development of high-temperature, high-salt and low-permeability reservoirs has become a research hotspot in recent years. Asphalt particles have the characteristics of temperature and salt resistance, good stability, and blocking water without blocking oil [2]. It is a suitable profile control and water plugging agent for high-salt and low-permeability reservoirs. Its microscopic profile control and flooding law in high-temperature, high-salt and low-permeability reservoirs has rarely been studied in recent years [3].

Asphalt particle profile control is to use normal injection fluid to carry asphalt particles into the formation, and continuously migrate to the deep part of the formation. In the process of migration, the mechanical plugging effect of asphalt particles is used to plug the pores. At the same time, due to the characteristics of the particles under high temperature conditions (>40°C), they can be retained in strata at different depths to achieve high-strength plugging. By injecting different doses of asphalt particles, the purpose of deep and shallow profile control can be achieved [4][5][6][7]. The main properties of asphalt particles are as follows: 1. it is deformable and has higher plugging strength; 2. Due to its own viscosity characteristics, the

This is a paper for the 16th International Conference on Applied Energy (ICAE2024), Sep. 1-5, 2024, Niigata, Japan.

formation of plugging can also play a role in oil displacement; 3. The performance is not affected by salinity, and it is suitable for profile control and flooding of reservoirs with different salinity. The advantages are as follows: 1. The particles have good selective entry ability, which can reduce the damage to the low permeability layer; 2. Slug injection can be realized; 3. The configuration injection is simple, and the successful development of injection equipment can reduce the construction cost. High temperature and salt tolerance can meet the profile control problem of large pore reservoir, and meet the deep profile control problem under harsh reservoir conditions such as high temperature and high salt [8][9][10][11][12].

In this paper, the micro-fluidic platform experiment can visually present the micro-flow state of asphalt particles in porous media, and study the important means of chemical agent water plugging and enhanced oil recovery from a micro perspective [13][14]. In recent years, with the continuous development and improvement of micro-fluidic technology, the processing technology of glass microscopic model has been improved, and the temperature and pressure conditions in application have also been broadened accordingly, which provides experimental theoretical basis for further exploring the oil displacement mechanism of emulsified asphalt system. In this paper, a micro-fluidic model was designed and fabricated to characterize different pore sizes[15][16][17]. At the same time, different concentrations of asphalt particle systems were designed, a high-temperature micro-fluidic displacement platform was built, and microscopic visualization experiments were carried out. The migration law of asphalt particles, the mechanism of profile control and flooding, and the matching relationship of pore throats were obtained, and the oil displacement efficiency of remaining oil was quantified [18][19][20]. This paper aims to carry out preliminary exploration, research and application of asphalt profile control and flooding technology in view of the contradiction of water channeling in a Shengli oilfield. The first part of this paper introduces the design and manufacture of micro-fluidic model. The second part introduces the experimental process. The third part introduces the experimental results and analysis [21][22].

2. DESIGN AND FABRICATION OF MICROSCOPIC MODEL

2.1 Experimental materials and equipment

In this paper, a reservoir in Shengli Oilfield is taken as the research object. The oil-bearing area of the block is 1.15km^2, and its geological reserves are 290×10^{4}t. At present, the comprehensive water content in the production stage is about 97.9%, and the recovery degree is 41.0%. The effective thickness range of single layer is 2-6m, the formation temperature is 82°C, the salinity of formation water is 20921mg/L, and the viscosity of underground crude oil is 22.5mPa.s.

The image of pore structure of core section is obtained by Micro-CT scanning experiment, and the relevant data information is extracted by binarization processing and other steps. Based on the actual reservoir pore throat structure, a heterogeneous model pattern with an average pore throat radius of 40um is designed and formed:

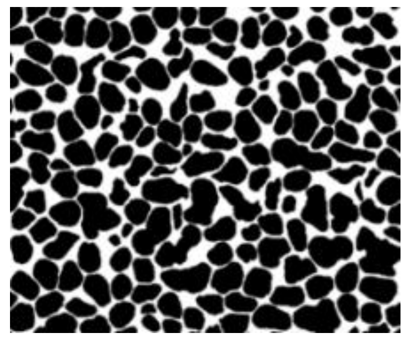

Fig. 1 Microscopic model of asphalt particles

The glass etching model needs to go through a complex process. After the model structure is determined in the early stage, the mask is used to make the glass visualization model. The accuracy can reach the nanometer level. The production steps are as follows:

(1) Cleaning glass slides: HMDS dehydrates the 4-inch glass slides at 150°C for 30 minutes;

(2) Coating resist: SVG spin coating machine;

(3) Mask exposure: mask UV exposure;

(4) Glass etching: etching speed: 1.8-4um/min;

(5) Cleaning anti-corrosion agent: 90% sulfuric acid/hydrogen peroxide chemical bath 20 min;

(6) Repeat (2) - (5) steps;

(7) Bonding.

2.2 Experimental scheme and steps

In this paper, four groups of microscopic oil displacement experiments of asphalt particle system are designed. The difference of parameters is that the injection concentration of the system is different from the pore throat size of the model.The experimental steps are as follows:

(1) The simulated oil with saturated viscosity of 5mPa.s under constant pressure of 1000mbr was stained and water flooding at a constant displacement rate of 0.5uL/ min was used to observe the degree of sweep and the type and distribution of remaining oil.

(2) The asphalt particle systems with different concentrations and volumes were injected at a constant speed of 0.5uL/min, and stood for 2h in order to gather the asphalt particles, and the injection capacity and aggregation of the asphalt particle system were observed.

(3) 0.5uL/min constant displacement speed water flooding was used to compare the water flooding effect before and after the measures.

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1 Study on macroscopic migration law of asphalt particles

Each stage is displaced from the right side of the model to the left side. The red area is the distribution position of the remaining oil, the dark blue area is the water flooding swept position, and the light-yellow area is the position where the asphalt particle system enters after injection. The asphalt particles enter the water flow channel along the water flow and are retained at the pore throat, so that the liquid flow steering phenomenon occurs during the subsequent system injection and the swept area is significantly expanded.

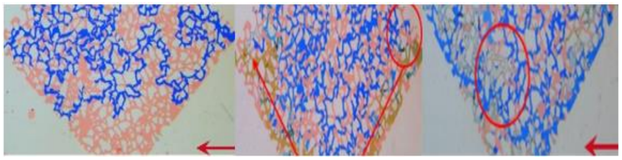

Fig.2 Macroscopic water flooding images of asphalt particle system

3.2 Study on microscopic migration law of asphalt particles

3.2.1 Pore bridging plugging

Affected by the migration ability of the asphalt particle system, it gathers at the entrance end of the model and the narrow pore throat in the form of a bridge, resulting in the subsequent system turning.

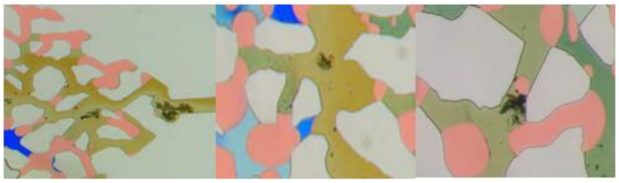

Fig.3 Microscopic aggregation images of asphalt particle system

3.2.2 Self-similarity aggregation

Due to the self-similarity of asphalt particles, they are adsorbed at the oil-water interface or adsorbed on the wall instead of bound water.

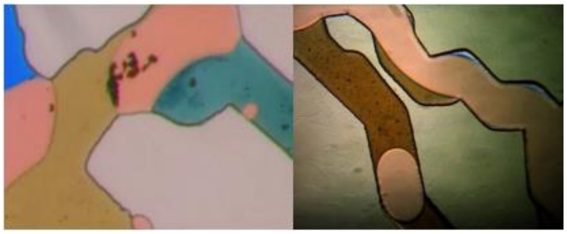

Fig.4 Self-similarity aggregation of asphalt particles

3.2.3 Self-aggregation law

The asphalt particle system has a self-aggregation law. After standing, the asphalt particles further aggregate into groups, and the originally dispersed asphalt particles tend to aggregate, which promotes the distribution of remaining oil to change, and the dispersed remaining oil gathers together.

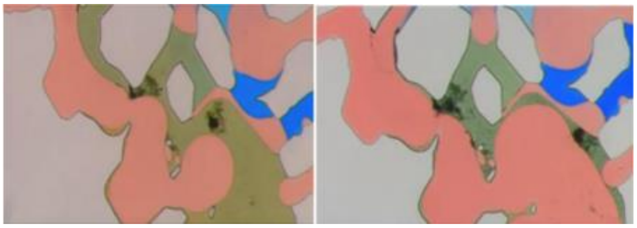

Fig.5 Self-aggregation law of asphalt particles

3.3 Study on micro flooding mechanism of asphalt particles

The increase of seepage velocity of asphalt particle system can peel off the end face of some cluster or columnar remaining oil shown in the diagram.

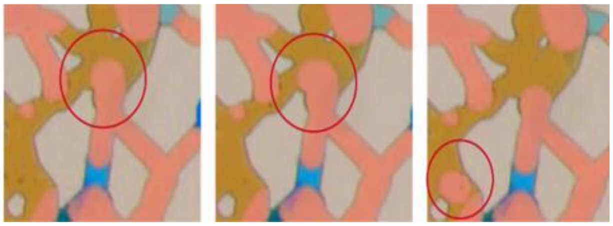

Fig.6 Microscopic process of asphalt particles stripping columnar remaining oil

The seepage velocity of the asphalt particle system is accelerated, and the residual oil in the larger pores can be effectively utilized by scouring.

3.4 Quantitative analysis of the effect of asphalt particles

Under the condition of 40um model with permeability of 3000mD, when the injection concentration of asphalt particle system is 2.5%, the recovery degree in the initial water flooding stage is about 60.21%, the recovery degree in the asphalt particle displacement stage increases to 64.34%, and the recovery degree in the subsequent water flooding stage is about 69.81%, and the recovery degree before and after the action of asphalt particle system is 9.60%.

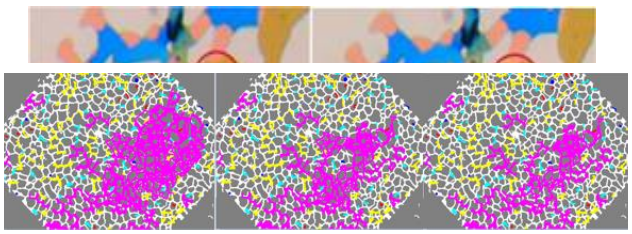

Fig.8 Variation diagram of recovery degree of microscopic model

The numerical value of the change of the proportion of different types of remaining oil in each displacement stage is drawn into the following figure, and the change of the proportion of cluster remaining oil is the main way to improve the recovery rate. Among the different types of remaining oil, the cluster remaining oil accounts for the most, and the membrane remaining oil accounts for the least. Before standing, the action mode is mainly to block the pore throat channel, disperse or peel the cluster residual oil/porous residual oil and produce the drip residual oil. After standing, it is mainly to block the large pore channel to make the liquid flow turn to the cluster residual oil.

3.5 Adaptability of asphalt particle concentration and reservoir permeability (pore throat size)

For the model with permeability of 3000mD (i.e., pore throat radius of 40um), the experimental results of the injection concentration of 1.0% of the asphalt particle system are shown in the following figure. The sealing effect of the system is poor, and it is easy to flow along the original water channel. When the injection concentration is increased to 2.5%, the effect of expanding the spread of the system is significantly improved.

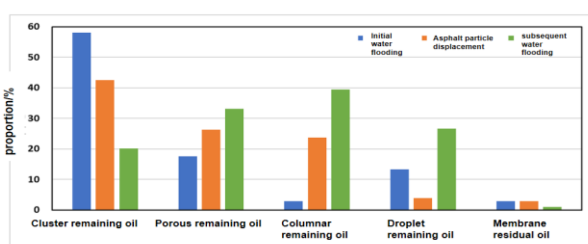

Fig.9 Variation diagram of recovery degree of microscopic model

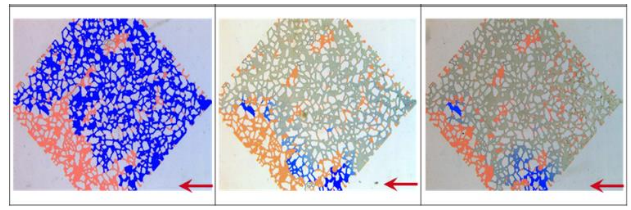

Fig.10 Comparison of water flooding effect when the injection concentration of asphalt particles is 1.0 % under the reservoir condition of 3000mD.

The following figure shows the displacement effect of each displacement stage when the injection concentration of asphalt particles is 2.5% under the condition of 5000mD reservoir (the radius of model pore throat is 75um).

The recovery degree values of each stage in the statistical experiment are calculated, and the variation range is calculated. Based on the numerical difference of water flooding recovery degree before and after asphalt particle injection, the adaptability of particle concentration and reservoir permeability is evaluated, and the effect is divided into two kinds: 'need to be optimized 'and' more suitable'. It can be seen that 2.5 % is a suitable injection concentration for 3000mD reservoirs, while the suitable injection concentration in 5000mD reservoirs needs to be further optimized.

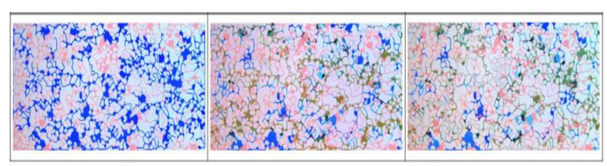

Fig.11 75um pore throat radius of each system concentration result diagram

4. CONCLUSIONS

In this paper, a reservoir in Shengli Oilfield is taken as the research object, and a glass microscopic model that can reasonably characterize the pore throat structure size characteristics of the reservoir is designed and manufactured. The overall image and local phenomenon of the displacement process of the asphalt particle system are obtained by means of micro-fluidic experiment. The image is processed by quantitative analysis software to clarify the degree of remaining oil production and the proportion of various remaining oil under the action of the system, and the mechanism of the formation of the asphalt particle system is summarized. The specific conclusions are as follows:

(1) The asphalt particles enter the water channel along the water flow and are retained at the pore throat, so that the liquid flow diversion phenomenon occurs during the subsequent system injection and the affected area is significantly expanded.

(2) Asphalt particles will aggregate in a bridging manner or adsorb at the oil-water interface due to self-similarity aggregation, or change the distribution of remaining oil due to self-aggregation, or increase the seepage resistance due to accumulation to peel off the columnar remaining oil, and use drip or film-like remaining oil.

(3) For example, under the condition of 40 um model, the injection concentration of asphalt particle system is 2.5%. The asphalt particle system can effectively use the cluster remaining oil, and the overall recovery degree increases by 9.60%.

(4) The 2.5% asphalt particle system matches the 3000mD reservoir, while the appropriate injection concentration in the 5000mD reservoir needs to be further optimized.

ACKNOWLEDGEMENT

The authors grateful acknowleadge the financial support provided by reservoir engineering research group, the assistance provided by Dr. Ma Mengqi and the chart data provided by Mr. Li Jie.

REFERENCE:

[1] Mo Han. Field experimental study on asphalt particle profile control. Master of Engineering Graduation Thesis of Northeast Petroleum University 2008. (Reference to a dissertation)

[2] Liu Yuzhang, Bai Baojun, Liu Gehui. Study on water plugging and profile control technology of asphalt-type particles. Petroleum drilling and production process 1999;21: 65-68. (Reference to a journal publication)

[3] Bai Yujie, Cao Guangsheng, Zhang Yu, Huang Jianzhao, Sun Jian. Indoor experimental study on concentration and slug combination optimization of asphalt particle profile control agent in P reservoir of Lamadian Oilfield. Contemporary Chemical Industry 2017;04: 603-606. (Reference to a journal publication)

[4] Gaobo. Study on Asphalt Particle Profile Control Technology in Lamadian Oilfield. Daqing Petroleum Geology and Development 2006;4: 96-97+125. (Reference to a journal publication)

[5] Gong Xin, Gong Qingfa, Lu Jun. Asphalt particle deep profile control technology and its application in Daqing Oilfield. Oilfield Chemistry 2004;21: 150-153. (Reference to a journal publication)

[6] Ren Chengfeng. Low-cost asphalt particle profile control technology in Lamadian Oilfield. Journal of Northeast Petroleum University 2014;38: 81-86+10. (Reference to a journal publication)

[7] Dai Caili, Fu Yang, You Qing et al. Development and Performance Evaluation of Plugging Agent for High Temperature and High Salinity Reservoirs. Xinjiang Petroleum Geology 2014;35: 96-100. (Reference to a journal publication)

[8] K. Xiao, H. Jiang, Q. Wang et al. Adaptability Study on Plugging Thief Zones with Asphalt Particle in Polymer Flooding Offshore Field. SPE Energy Resources Conference 2014;9: 9-11. (Reference to a journal publication)

[9] Gao, B. Bitumen Particles Profile Control Technique in Lamadian Oilfield. Petroleum Geology & OilField Development in Daqing 2006;25: 96–97. (Reference to a journal publication)

[10] Guangwei liu, Hanqiao Jiang, Junjian Li et al. Evaluation of the performance of polymer gels mixed with asphalt particle as a novel composite profile control system. Journal of Industrial and Engineering Chemistry 2015;26: 309-314. (Reference to a journal publication)

[11] Adnan Al-Ibadi, Faruk Civan. Experimental Investigation and Correlation of Treatment in Weak and High-Permeability Formations by Use of Gel Particles. *SPE Prod & Oper* 2013;28: 387-401. (Reference to a journal publication)

[12] Baojun Bai, Liangxiong Li, Yuzhang Liu et al. Preformed Particle Gel for Conformance Control: Factors Affecting its Properties and Applications. SPE Res Eval & Eng 2007;10: 415–422. (Reference to a journal publication)

[13] Baojun Bai, Yuzhang Liu, Liangxiong Li. Preformed Particle Gel for Conformance Control: Transport Mechanism Through Porous Media. *SPE Res Eval & Eng* 2007;10: 176–184. (Reference to a journal publication)

[14] Hao Zhang, Baojun Bai. Preformed Particle Gel Transport through Open Fractures and its Effect on Water Flow. SPE J 2011;16: 388-400. (Reference to a journal publication)

[15] Abdulmohsin Imqam, Baojun Bai, Mustafa Al Ramadan et al. Preformed-Particle-Gel Extrusion Through Open Conduits During Conformance-Control Treatments. SPE J. 2015;20: 1083–1093. (Reference to a journal publication)

[16] Chen Tianke. Emulsified asphalt of heavy oil thermal recovery horizontal well. Chemical industry management. 2020;12: 115-116. (Reference to a journal publication)
[17] Tan Sen. Study on Emulsified Asphalt as Water Plugging System for Thermal Horizontal Wells of Chunguang Oilfield. China University of Petroleum Mater Degree Thesis 2018. (Reference to a dissertation)
[18] Chen Zehua. Research on the Matching Relation between the Diameter of Elastical Particle and Permeability of the Formation. China University of Petroleum Mater Degree Thesis 2016. (Reference to a dissertation)
[19] Wang Wei. Laboratory Evaluation on Modified Asphalt Water Shutoff/Profile Modification Agent. ADVANCES IN FINE PETROCHEMICALS 2012;13: 24-26. (Reference to a journal publication)
[20] Li Kehua, Wang Chunyu, Zhao Fulin. Study on the Matching Relationship of Solid Grains to Formation Aperture. Fault-Block Oil & amp 2000;7: 24-25+4-3. (Reference to a journal publication)
[21] Su Zhan. Prepration and Performance Evaluation of Organic Particle Heat Resistant Plugging System. Oilfield Chemistry 2021;38: 74-79. (Reference to a journal publication)
[22] Huang Bo, Chen Weiyu, Shi bin et al. Experimental study on a cationic emulsified asphalt plugging agent. Contemporary chemical industry 2014;43: 2219-2221. (Reference to a journal publication)