WEP Warwick Evans Publishing

International Journal of Natural Resources and Environmental Studies

ISSN: 3006-2012 (Print), ISSN: 3006-0834 (Online) | Volume 3, Number 1, Year 2024
DOI: https://doi.org/10.62051/ijnres.v3n1.05
Journal homepage: https://wepub.org/index.php/IJNRES/index

Study on Enhanced Oil Recovery with Viscoelastic Self-regulator

Xing Zhou

School of Petroleum Engineering, Xi'an Shiyou University, Xi'an 710065, China

ABSTRACT

After long-term water flooding in low permeability reservoirs, dominant channels develop, and viscoelastic self-regulating agents can block large pores and inhibit bottom water coning. Based on the physical model experiment of sand filling pipe and the dynamic simulation system of pressure conduction online detection, this paper simulates the displacement characteristics of low permeability reservoir, and quantitatively studies the regulation and displacement performance of high permeability fracture model and low permeability matrix model of sand filling pipe with viscoelastic self-regulator under different permeability difference and different injection speed. Through pressure gradient, diversion rate and recovery factor, the formation energy conduction law under different injection and production systems is revealed. The results show that when the permeability difference is small, the blocking position of the regulating and flooding agent is in the front of the middle of the low permeability pipe and in the back of the middle of the high permeability pipe, and the opposite is true when the permeability difference is large, and the pressure gradient of the large permeability difference is greater than that of the small permeability difference. With the increase of flow rate, the pressure gradient increases gradually. The slug also increases, and the peak of the hyperosmotic tube gradually moves toward the inlet end, and the peak of the hypoosmotic tube gradually moves toward the outlet end. The formation energy conduction efficiency is positively correlated with the injection rate, that is, the higher the injection rate is, the faster the pressure rise at the production well is.

KEYWORDS

Viscoelastic self-regulator; Gradient of pressure throat; Rate of diversion; Oil recovery rate.

1. INTRODUCTION

Low-permeability reservoirs have strong reservoir heterogeneity, scattered distribution of remaining oil after long-term water flooding, edge and bottom water rising, and good viscoelasticity of viscoelastic self-regulator, which can effectively block large pores, inhibit bottom water coning and supplement the energy of upper reservoir [1,2]. However, the formation energy conduction law under different injection and production regimes of viscoelastic self-regulator displacement is not clear [3,4]. It is found that the viscoelastic self-regulator polymer can not only increase the viscosity of displacement phase, but also migrate into small pores in depth, which can increase the displacement resistance of injection medium to the bottom water layer. In addition, the greater the permeability is, the higher the polymer concentration is, and the more the dosage of crosslinking agent is, the greater the resistance coefficient and residual resistance coefficient are [5]. On the one hand, the polymer flooding parameter optimization method is widely used, and the optimization decision model of polymer injection parameters such as polymer injection mass concentration, injection velocity and slug size is established in the early stage and peak stage of effect. On the other hand, the complete permeability curve of gas flooding water phase under different pressure gradients is studied, and the development dynamics of a single well is predicted. However, the influence of displacement pressure gradient on the distribution of remaining oil cannot be directly reflected [6]. Studies have shown that the fluid physical properties of the regulating agent and the displacement mode have a significant impact on the recovery of low permeability reservoirs, but there is still a lack of research on the impact of polymer displacement pressure gradient [7]. Therefore, the pressure gradient, diversion rate and recovery efficiency of viscoelastic self-regulating agent are quantitatively studied to reveal the formation energy conduction law under different injection and production systems, so as to provide theoretical support for improving oil recovery.

2. PART OF EXPERIMENT

2.1. Experimental Material

Quartz sand with different mesh numbers (20-40, 40-70, 70-140) and clay were used to simulate the matrix low permeability reservoir and fractured high permeability reservoir. Actual formation water, CaCl2 water type, salinity 52197mg/L; Simulated injection water, Na2SO4 water type, salinity 1470mg/L; Crude oil 1.5mPa·S; Viscoelastic self-regulator 1000mg/L. Experimental equipment as shown in Fig. 1, displacement pump (ISCO-260D) type, displacement pressure is 0~ 51.7MPa, double pump continuous flow velocity range is 0.001~ 80mL /min; Two sand filling pipes (length 1000mm, inner diameter 50mm), a pressure monitoring point is set every 100mm, a total of 20 pressure monitoring points; Intelligent instrument pressure online real-time monitoring system; Intermediate container (1L, 4 sets) made by Jiangsu Huaxing Petroleum Instrument Co., LTD., withstanding pressure 50.0MPa; The experimental temperature was controlled by a thermostat at 70 ° C.

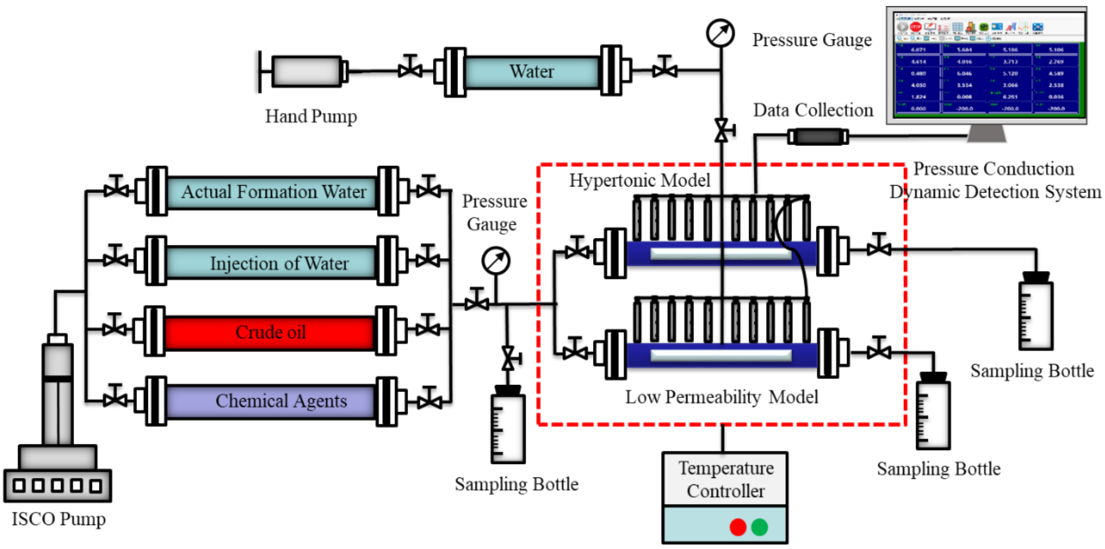


Fig. 1 Schematic diagram of experimental equipment for viscoelastic self-regulator displacement

2.2. Procedure of Experiment

(1) According to the characteristics of the reservoir, such as strong heterogeneity of the reservoir and scattered distribution of oil and water in the reservoir, the mixture of quartz sand and clay required by the sand filling pipe with different permeability is configured; Fill the sand pipe according to the requirements of the experiment, and weigh the sand pipe after loading; Install intelligent instrument pressure online monitoring system and check device connection air tightness.

(2) The two sand-filled tubes were saturated with formation water at a flow rate of 0.5 mL/min. After the tubes were fully saturated, the weight of the tubes was measured to calculate the porosity volume of the sand-filled tubes. The two sand-filled tubes were then saturated with oil at a flow rate of 0.5 mL/min. The saturation was stopped when the outlet end of the tubes contained 100% oil.

(3) Parallel sand-packing tubes were used for waterflooding oil experiments at a flow rate of 0.5 mL/min. The waterflooding was stopped when the cumulative water saturation of the two sand-packing tubes reached 90%. During the waterflooding process, the pressure changes at different positions in the sand-packing tubes were monitored in real-time, and the water saturation and oil recovery efficiency were recorded every half hour for each sand-packing tube.

(4) After the waterflooding experiment, the viscoelastic self-regulating agent was injected at a flow rate of (0.4, 0.8 mL/min) for the viscoelastic self-regulating agent flooding experiment. During the experiment, the pressure at different positions of the packing tube was monitored in real-time and recorded, and the water content and oil recovery efficiency were recorded every half hour for both packing tubes. The injection volume was stopped when the total pore volume of the two packing tubes was reached five times or when the water content at the outlet end of the two packing tubes stopped changing.

(5) Remove the packing material from the sand packer, clean the inner wall of the sand packer, and completely dry it before changing the permeability gradient of the sand packer or changing the injection speed of the flooding agent.

3. ANALYSIS AND DISCUSSION

3.1. Oil Displacement Efficiency in Different Experimental Stages

Before the injection of viscoelastic self-regulating agent for water flooding, the porosity and permeability of the sand pack were determined by saturating water, and then water flooding experiments were conducted. In the high permeability model and the matrix model, the cumulative water saturation at the outlet end reached 90% or more, and the water flooding was stopped. After the water flooding, the viscoelastic self-regulating agent was injected, and the oil recovery in the post-flooding stage increased by different amounts. The oil recovery efficiency in different experimental stages is shown in Table 1.

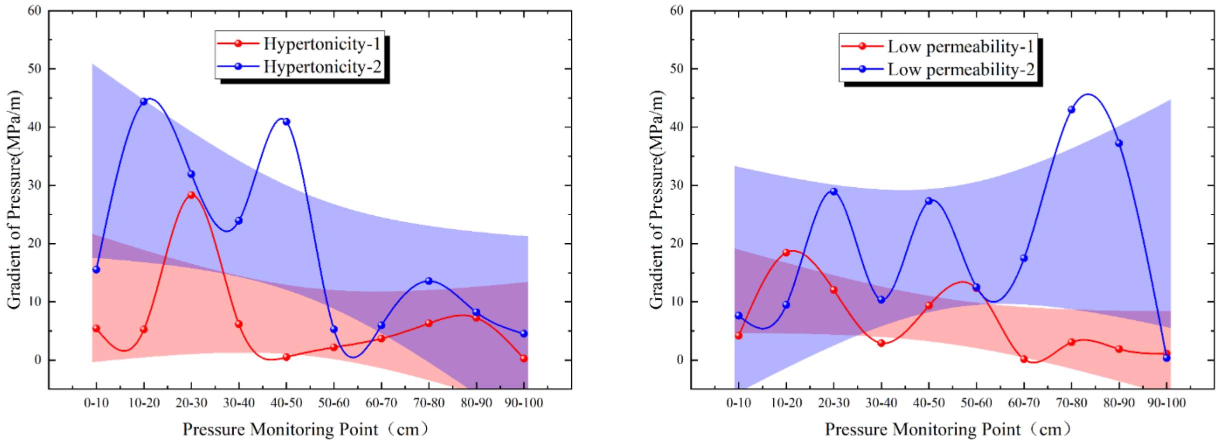
Table 1 Oil displacement efficiency in different experimental stages

Group	Number	Rate of permeability/mD	Chemical displacement rate/ mL/min	Water displacement efficiency/%	Chemical agents/%	Entirety/ %	Synthesis /%
1	H-1	107.3	0.4	77.78	7.49	85.27	84.80
	L-1	54.2	0.4	70.13	14.20	84.33	
2	H-2	101.2	0.8	73.96	13.46	87.42	78.00
	L-2	23.6	0.8	55.46	13.12	68.58	

The flow rate in the water flooding process is set at 0.5mL/min, and the cumulative water cut at the final outlet reaches 90% to stop the water flooding. After the water flooding of the four sand filling pipes, the water flooding recovery rate of the high permeability model reaches 75.87%, and the recovery rate of the low permeability sand filling pipes reaches 62.80%. The largest change in oil recovery after regulation and flooding is the low permeability No. 1 sand filling pipe. The low permeability matrix model pipe after regulation and flooding is 14.20% higher than that before regulation and flooding, reaching 84.33%. The average oil displacement efficiency of the first group of regulators is 10.85%, and the highest comprehensive recovery rate is 84.80%. The comprehensive recovery rate reached 78.00%.

3.2. Characteristics of Pressure Gradient Distribution

When the real-time online pressure monitoring system is used to intuitively reflect different injected PV numbers, the pressure value of each point after the sand filling pipe model is stabilized is counted, the pressure difference between two adjacent positions is calculated, and the pressure gradient value in different position segments is plotted, as shown in Fig. 2.



(a) Hypertonic group (b) Low permeability group

Fig. 2 Pressure gradient change curve

Through the comparison of pressure gradients, it was found that the average pressure gradient of hyperosmium-1 was 6.53MPa/m, that of hypoosmium-1 was 6.54MPa/m, and that of hyperosmium-2 and hypoosmium-2 was 19.42MPa/m. Compared with the high permeability 2 sand filling pipe, the pressure gradient wave peak of the high permeability 2 sand filling pipe moves forward, the wave peak increases, and the value is larger, the maximum is 44.40MPa/m. The wave peaks of low-permeability sand filling pipe with -1 and low-permeability sand filling pipe with -2 are similar, reflecting the characteristics of three peaks, but the wave peaks of low-permeability sand filling pipe with -2 are more obvious than those of low-permeability sand filling pipe with -1, and the value is larger, the maximum is 45.82MPa/m.

The experimental results show that the high pressure gradient of the first group of high permeability tube is mainly concentrated in the middle of the outlet end, and the high pressure section of low permeability tube is mainly concentrated in the middle of the inlet end. The second group of high permeability and high pressure segments is mainly concentrated in the middle of the inlet end, while the low permeability and high pressure segments are mainly concentrated in the middle of the outlet end. The permeability difference of the first group and the second group is 1.98 and 4.29, respectively. It is concluded that when the permeability difference is small, a large number of viscoelastic auto regulators are concentrated in the middle of the low permeability tube and the middle of the high permeability tube, but the opposite is true when the permeability difference is large, and the pressure gradient of the large permeability difference is greater than the pressure gradient of the small permeability difference. Hyperosmolar -1 has one slug, hypoosmolar -1 has two slug, and hyperosmolar -2 and hypoosmolar -2 have three slug. The reason is that with the increase of regulating flow rate, the pressure gradient gradually increases (the peak value is larger and the number of peaks is more); The slug also increases, and the peak of the hyperosmotic tube gradually moves toward the inlet end, and the peak of the hypoosmotic tube gradually moves toward the outlet end.

3.3. Pressure Conduction Characteristic

By comparing the PV number of the hyperosmotic model and the matrix model at the time of starting pressure, especially the PV number at 90cm, the speed of pressure conduction in the sand filling pipe can be intuitively reflected. The distribution of starting pressure injection at 90cm is shown in Fig. 3.

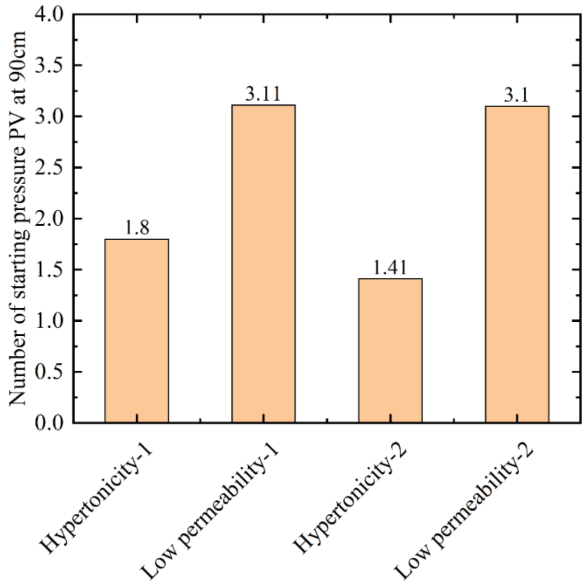
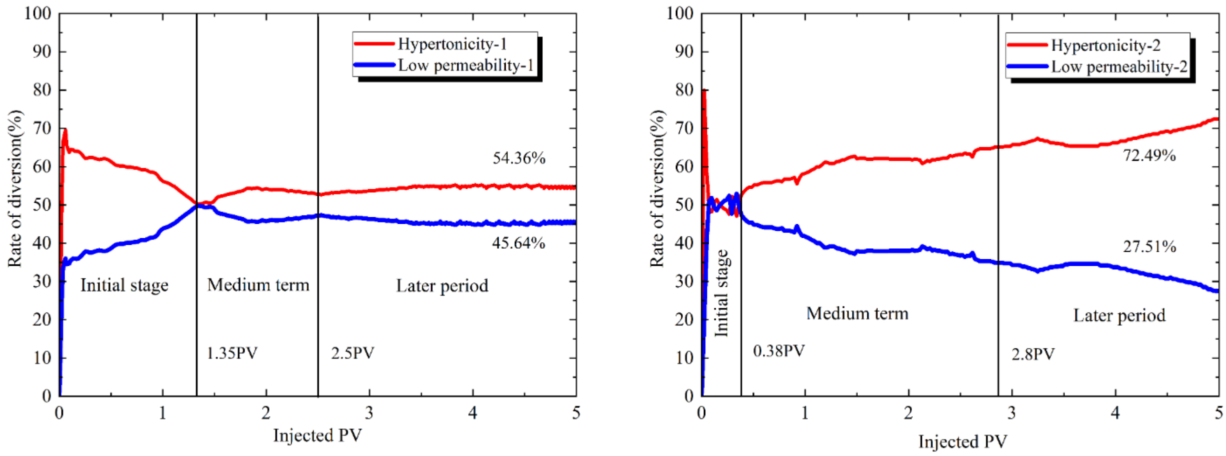


Fig. 3 Distribution of starting pressure injection at 90cm

3.4. Characteristics of Shunt Rate Curve

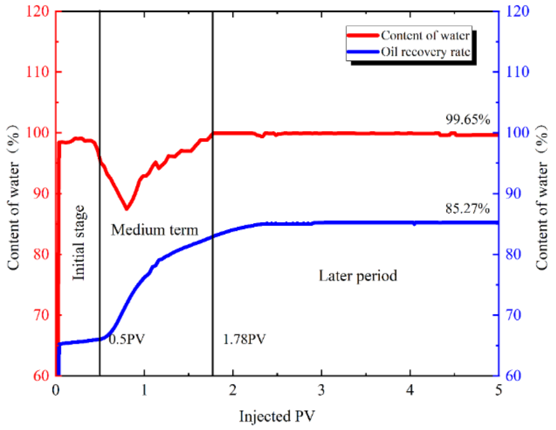


(a) Group 1 (b) Group 2

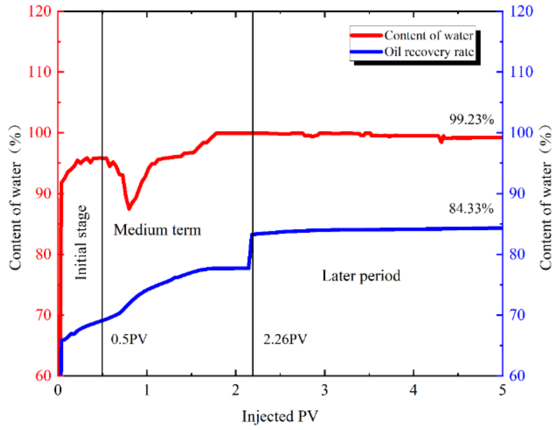
Fig. 4 Distribution curve of diversion rate

In group 1 (Fig. 4, a), the shunt rate of the hypertonic model decreased significantly at the beginning of the injection of viscoelastic self-regulator, while that of the matrix model increased significantly. When the injection volume was greater than 1.35PV, the shunt rate of the hyperosmotic model gradually increased, and the shunt rate of the hypoosmotic model gradually decreased, and the shunt volume gradually increased. When the injection rate is greater than 2.5 PV tends to be stable, high permeability model rate of diversion is 54.36%, low permeability model rate of diversion was 45.68%, high permeability and low permeability rate of diversion differential value of 8.72%. In group 2 (Fig. 4, b), when the injection volume was 0.38PV, the shunt rate of the hypertonic model was the lowest 52.8%, and the shunt rate of the hypotonic model was the highest 47.2%, and the difference between hypertonic and hypotonic model was 5.6%. As the injection volume was greater than 2.8PV, the difference of shunt rate increased, and the final shunt rate of the hypertonic model was 72.49%. The low permeability model was 27.51%, and the effect of regulating and flooding was significantly worse. That injection rate of 0.8 mL/min, the crack/high permeability channel and reservoir matrix rate of diversion minimum value difference; As the injection rate continues to increase, the diverting rate difference also increases greatly, and the effect of regulating and driving becomes worse.

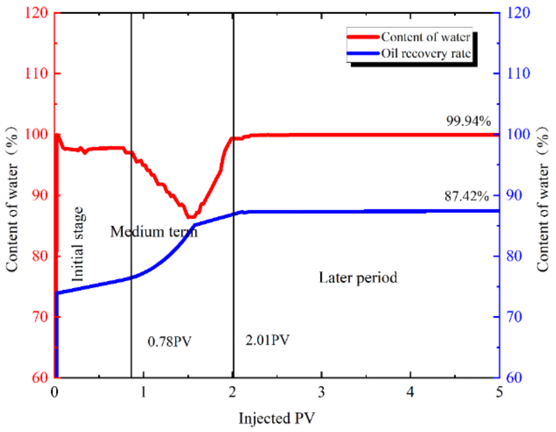
3.5. Recovery Features



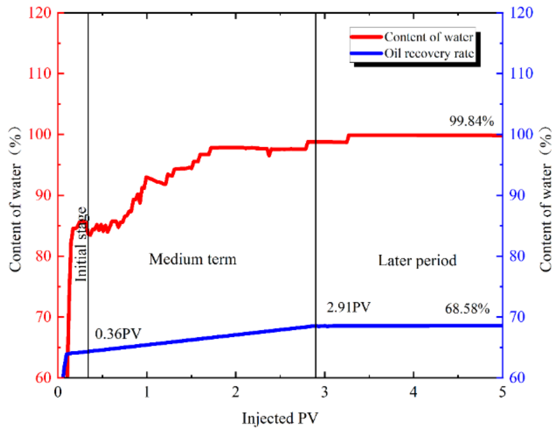
(a) Hypertonicity-1



(b) Low permeability-1



(c) Hypertonicity-2



(d) Low permeability-2

Fig. 5 Curves of water cut and recovery as a function of injected PV

As shown in Fig. 5, a and b, the initial recovery rate of hypertonicity -1 is slow, the initial recovery rate of low permeability 1 is slow, and the recovery rate of hypertonicity -1 and low permeability 1 is greatly increased in the middle stage. At this time, a large amount of crude oil in the pores of the sand filling pipe is driven out, and the recovery rate increases rapidly. When the injection volume of the regulation and flooding agent in the hypertonicity -1 sand filling pipe reaches 1.78PV, the late recovery rate enters. When the injection volume of the regulating and flooding agent reaches 2.26PV, the recovery rate and water cut of the high-permeability and low-permeability sand filling pipes tend to be stable. The water content of high permeability 1 sand filling pipe is stable at 99.65%, and the recovery rate increases by 7.49% compared with water flooding, and finally stabilizes at 85.27%. The water content of low-permeability sand-filling pipe is stable at 99.23%, and the recovery rate increases by 14.2% compared with water flooding, and finally stabilizes at 84.33%, indicating that the recovery rate of low-permeability sand-filling pipe is significantly improved after the injection of viscoelastic self-regulator.

As shown in Fig. 5, c and d, the initial recovery rate of the hypertonicity -2 sand filling pipe is faster, and the initial recovery rate of the low-permeability -2 sand filling pipe is faster. The initial viscoelastic self-regulator flows along the high-permeability water channel, and the recovery rate changes significantly. After injection of 0.78PV in the high permeability model and 0.36PV in the low permeability model, the recovery rate of the sand filling pipe in the high permeability model and the low permeability model increased, and the increase of the high permeability model was more significant. After injecting 2.01PV in the high permeability model and 2.91PV in the low permeability model, the recovery and water cut gradually become smooth. The water content of hypertonicity -2 sand filling pipe is stable at 99.94%, and the recovery rate increases by 13.46% compared with water flooding, and finally stabilizes at 87.42%. The water cut of low-permeability -2 sand filling pipe is stable at 99.84%, and the recovery rate increases by 13.12% compared with water flooding, and finally stabilizes at 68.58%. This is because the viscoelastic self-regulator reduces the recovery rate with the increase of permeability range, and the effect of regulating and flooding becomes worse. The comprehensive recovery rate decreases to 78.00% from 14.35%.

4. SUMMARY

(1) The distribution characteristics of pressure gradients under different injection rates were determined. The sealing position of the regulating and flooding agent in the fracture/high permeability zone and reservoir matrix was first in the middle of the low permeability pipe and second in the middle of the high permeability pipe, and the pressure gradient with large permeability difference was greater than the pressure gradient with small permeability difference.

(2) With the increase of regulating flow rate, the pressure gradient gradually increases (the peak value is larger and the number of peaks is more). The slug also increases, and the peak of the hyperosmotic tube gradually moves toward the inlet end, and the peak of the hypoosmotic tube gradually moves toward the outlet end.

(3) The higher the injection speed at the injection end is, the faster the pressure rise at the outlet end is, the higher the permeability is, the lower the formation energy conduction efficiency is, the higher the difference of diversion rate is, and the lower the integrated recovery rate is.

REFERENCES

[1] Zhe Wang, Guangsheng Cao, Yujie Bai, et al. Development Status and Prospect of EOR Technology in Low-Permeability Reservoirs. Special Oil & Gas Reservoirs. Vol.30 (2023) No. 01, p. 1- 13.

[2] Lei Bai, Pengchao Sun, Xiaodie Hu, et al. Characteristics of Preferential Migration Pathway of Polymer Flooding in Conglomerate Reservoirs and Its Effects on Remaining Oil. Special Oil & Gas Reservoirs. Vol.28 (2021) No. 04, p. 108- 115.

[3] Ping Yi, Rong Zhang, Bo Ma, et al. Preparation and properties of viscoelastic self- regulating water profile control and flooding agent. Journal of Shaanxi University of Science & Technology. Vol.39 (2021) No. 06, p. 97- 102.

[4] Jiecheng Cheng, Quan Zhou, Wanfu Zhou, et al. Plugging method of polymer gel with controllable low initial viscosity for dominant flow paths in deep reservoirs and its application. ACTA PETROLEI SINICA. Vol.41 (2020) No. 08, p. 969- 978.

[5] Jianchong Gao, Nan Zhang, Lin Wang, et al. Influence of Injection Pressure of Profile Control and Displacement Agent on Diversion Rate and Its Mechanism. Oilfield Chemistry. Vol.38 (2021) No. 03, p. 427- 433.

[6] Shiyi Yuan, Qiang Wang, Junshi Li, et al. EOR Technological Innovation Keeps China's Crude Oil Production Stable on Long-term Basis. Oil Forum. Vol.40 (2021) No. 03, p. 24- 32.

[7] FENG Q,ZHAO Y,WANG, et al. Pore-scale oil-water two-phase flow simulation based on phase field method. Journal of Computational Physics. Vol.37 (2020) No. 04, p. 439- 447.