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THE HEAVY OIL EMULSIFCATION PROPERTY OF A SALT-TOLERANT POLYMER FLOODING AGENT


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As a result of this research this study developed a salt-tolerant polymer for emulsifying heavy oil to overcome the limitations of traditional thermal recovery methods and explore the use of viscosity-reducing polymers as a cold flooding technique for high-salinity heavy oil reservoirs. Interfacial tension experiments were conducted to screen polymers, while emulsification experiments were used to evaluate the viscosity reduction performance of heavy oil. The results showed that polymer P-5 exhibited the best performance, significantly reducing interfacial tension and enhancing emulsion stability. As polymer concentration increased, the water separation rate of emulsion decreased, and as salinity increased, the water separation rate also decreased. The optimal formulation was determined to be polymer P-5 at a concentration of 0.25% and a salinity of 55,000 mg/L, achieving the best viscosity reduction. Microscopic images of the emulsion further confirmed its good stability. These findings provide new insights and technical support for heavy oil recovery in Kazakhstan's oilfields, guiding the application of salt-tolerant polymers in high-salinity reservoirs.
KEYWORDS: *heavy oil, high-salinity, salt-tolerant polymer.*

СВОЙСТВА ЭМУЛЬГИРОВАНИЯ ТЯЖЕЛОЙ НЕФТИ АГЕНТА ЗАВОДНЕНИЯ С СОЛЬСТОЙКИМ ПОЛИМЕРОМ

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В результате данного исследования разработан сольстойкий полимер для эмульгирования тяжелой нефти, чтобы преодолеть ограничения традиционных методов тепловой добычи и изучить использование полимеров, снижающих вязкость, в качестве метода холодного заводнения для высокосоленых месторождений тяжелой нефти.Эксперименты по межфазному натяжению проводились для отбора полимеров, а эмульсионные эксперименты использовались для оценки эффективности снижения вязкости тяжелой нефти. Результаты показали, что полимер P-5 продемонстрировал наилучшие характеристики, значительно снижая межфазное натяжение и улучшая стабильность эмульсии. С увеличением концентрации полимера скорость расслоения воды в эмульсии уменьшалась, а при увеличении солености также наблюдалось снижение скорости расслоения воды.Оптимальная формула была определена как полимер P-5 при концентрации 0,25% и солености 55 000 мг/л, что обеспечило наилучшее снижение вязкости. Микроскопические изображения эмульсии дополнительно подтвердили ее хорошую стабильность.Полученные результаты предоставляют новые знания и техническую поддержку для добычи тяжелой нефти на месторождениях Казахстана, направляя применение сольстойких полимеров в условиях высокосоленых месторождений.

КЛЮЧЕВЫЕ СЛОВА: *тяжелая нефть, высокая соленость, солестойкий полимер.*

ТҰЗҒА ТӨЗІМДІ ПОЛИМЕРЛІ СУ АЙДАУ АГЕНТІНІҢ АУЫР МҰНАЙДЫ ЭМУЛЬГАЦИЯЛАУ ҚАСИЕТІ

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Бұл зерттеу нәтижесінде ауыр мұнайды эмульгациялау үшін тұзға төзімді полимер әзірленді, бұл дәстүрлі жылулық әдістердің шектеулерін жеңуге және тұздылығы жоғары ауыр мұнай кен орындары үшін тұтқырлықты төмендететін полимерлерді су айдау әдісі ретінде пайдалануды зерттеуге бағытталған.Полимерлерді іріктеу үшін беткі керілу тәжірибелері жүргізілді, ал эмульгация тәжірибелері ауыр мұнайдың тұтқырлығын төмендету тиімділігін бағалау үшін қолданылды. Нәтижелер полимер P-5 ең жақсы өнімділікті көрсеткенін, беткі керілуді айтарлықтай төмендеткенін және эмульсия тұрақтылығын арттырғанын көрсетті. Полимер концентрациясы артқан сайын эмульсияның су бөлу жылдамдығы төмендеді, ал тұздылық артқан сайын су бөлу жылдамдығы да азайды. Ең оңтайлы құрам P-5 полимері 0,25% концентрацияда және 55 000 мг/л тұздылықта анықталды, бұл ең жақсы тұтқырлық төмендету нәтижесін көрсетті. Эмульсияның микроскопиялық суреттері оның жақсы тұрақтылығын одан әрі растады. Бұл зерттеу нәтижелері Қазақстан мұнай кен орындарында ауыр мұнай өндіру үшін жаңа түсініктер мен техникалық қолдау ұсынып, тұздылығы жоғары кен орындарында тұзға төзімді полимерлерді қолдануға бағыт береді.

ТҮЙІН СӨЗДЕР: *ауыр мұнай, жоғары тұздылық, тұзға төзімді полимер.*

Introduction. Enhanced oil recovery (EOR) plays a crucial role in maximizing hydrocarbon production from mature oilfields, especially in regions with complex geological and reservoir conditions [1]. Traditional methods for flooding high-salinity and high-viscosity reservoirs rely on thermal techniques. However, thermal drive methods consume substantial energy, incur high costs, require large amounts of water, and suffer significant heat losses in high-salinity reservoirs, which limits their oil recovery efficiency to address these limitations, chemical flooding techniques have been explored as viable alternatives [2].

Among various chemical flooding techniques, surfactant flooding has shown great potential due to its ability to regulate foam stability and reduce oil-water interfacial tension [3]. However, surfactant flooding is highly influenced by salinity and temperature, leading to high costs and excessive adsorption losses in the reservoir [4]. On the other hand, polymer flooding has gained significant attention due to its effectiveness in improving sweep efficiency and reducing water mobility. Conventional polymers used in EOR face challenges in high-salinity and high-temperature reservoirs, limiting their effectiveness in such harsh environments. Consequently, the development and application of salt-tolerant polymers have become a key focus in petroleum engineering [5].

In high-salinity reservoirs, the emulsifying capacity of polymers encounters several challenges that affect their effectiveness as EOR agents. One of the primary limitations is the impact of salinity on polymer solubility and viscosity [6]. High concentrations of divalent cations, such as Ca^{2+} and Mg^{2+}, can reduce polymer hydration, leading to molecular aggregation or precipitation, which results in polymer chains coiling and a subsequent decrease in viscosity. This problem necessitates the selection of salt-resistant polymers that maintain stability under high-salinity conditions.

Because single polymer flooding methods have two major shortcomings – lack of salt resistance and poor emulsification – developing novel polymers with both properties is crucial. Salt-resistant polymers ensure stability in harsh reservoir conditions, while emulsification enhances oil displacement efficiency [7]. To overcome these limitations, it is crucial to develop salt-tolerant polymer formulations with enhanced emulsifying properties, ensuring their effectiveness in complex reservoir conditions, such as those found in Kazakhstan's oilfields [8].

This study investigates the emulsifying capacity of salt-tolerant polymers in Kazakhstan oilfields, analyzing their performance in stabilizing oil-in-water emulsions and improving oil displacement efficiency. The research aims to provide insights into the feasibility and potential of these polymers as effective EOR agents in high-salinity heavy oil reservoirs, contributing to the sustainable development of Kazakhstan's petroleum industry.

Materials and methods. The dehydrated crude oil was from the heavy oil reservoir of Oilfield E, and their components are listed in *Table 1*. The salt tolerance polymers used in this study were provided by "Enhanced Oil & Gas Recovery International Joint Laboratory". The basic properties of salt tolerance polymer is shown in *Table 2*. All solutions were applied using distilled water, and all experiments were conducted at 30°C to simulate the actual reservoir conditions in Oilfield E.

The chemical reagents used in this study include sodium chloride (NaCl, ≥99.5%), which were employed to simulate the salinity of formation water.

This study selected five different salt-tolerant amphiphilic polymers (P-1 to P-5) to investigate their emulsification performance in high-salinity reservoirs. The brine solution used in the experiments had a salinity range of 0–80,000 mg/L to simulate the actual

Table 1 – **The properties of heavy oil from Oilfield E**

Density at 20⁰C (g/cm³)	Temperature (⁰C)	Permeability (darcy)	Salinity (g/L)	Porosity (%)	Viscosity underground (mPas, 30⁰C)	Depth (m)
0.9	28-32	0.27-1.4	55	34%-35%	460	277-285

Table 2 – **The basic properties of amphiphilic polymer**

Salt tolerant polymer	Physical property	Salt-tolerance (g/L)
P-1	White powder	60
P-2	White powder	80
P-3	White powder	60
P-4	White powder	80
P-5	White powder	100

reservoir conditions in Kazakhstan oilfields. The crude oil used in the experiments was sourced from the target reservoir and was homogenized before testing. An Overhead Stirrer (OS20-S) was used to ensure consistent mixing of experimental fluids for homogeneous solutions.

The interfacial tension (IFT) of different polymer solutions was measured using the Spinning Drop Tensiometer (SDT). Polymer solutions with varying concentrations (0.1%-0.3%) were prepared, and their IFT with crude oil was tested at 30°C to evaluate their ability to reduce interfacial tension and determine the optimal concentration.

The stability of polymer-stabilized emulsions was evaluated using a water separation test. A predetermined ratio of polymer solution and crude oil was mixed and emulsified using a high-speed shear mixer for 5 minutes. The samples were then left to stand, and the water separation rate was measured at different time intervals (0-25 h) to assess the stability of the emulsion.

An optical microscope was used to observe the microstructure of P-5 emulsions at different time points (0-25 h). The size and distribution of oil droplets were analyzed to assess the stability of the emulsion.

A rotational viscometer (Intelligent Viscometer, BGD155/2S) was used to measure the viscosity of polymer solutions under different concentrations and salinity conditions, and the viscosity reduction rate (VRR) was calculated. The viscosity changes of polymer solutions with varying concentrations (0.1%-0.3%) and salinity levels (0-80,000 mg/L) were tested to determine the optimal formulation. A Magnetic Stirrer with Heating Plate (MSH-300) was applied for uniform heating and stirring of liquid samples during preparation. An Electronic Analytical Balance (HR-250AZG) provided precise mass measurements to ensure accuracy in sample formulations. Additionally, a Water Bath (STEGLER WB-4) was used to maintain a stable temperature environment (RT+5 to 100°C) for sample incubation and controlled heating processes.

Results and discussion. *Figure 1* shows the interfacial tension (IFT) variation trend of five polymers (P-1 to P-5) at different concentrations (%). The IFT of P-1 to P-4 is relatively high, and shows an overall fluctuation or upward trend, which fails to effectively reduce the interfacial tension. In contrast, the IFT of P-5 continues to decrease and always maintains the lowest value, which reflects the excellent emulsification performance of P-5, which is consistent with the research conclusion of the effect of interfacial tension on the emulsification of emulsions, that is, the emulsification ability of emulsions increases with the decrease of interfacial tension [9].

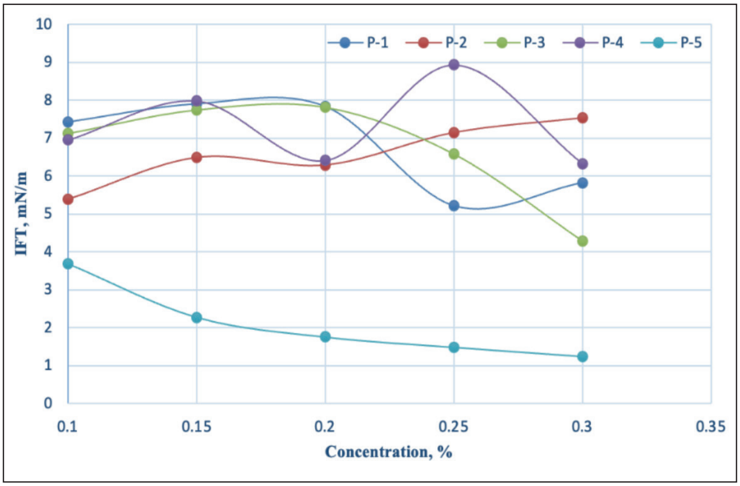

Figure 1 – **The relationship between polymer concentration with the interfacial tension**

Figure 2 shows the changes in water separation rate of different polymers (P-1 to P-5) at different times. The water separation rates of P-1 to P-4 all increased rapidly with time and stabilized at around 20-30 minutes, with the final water separation rate approaching 100%. In contrast, the water separation rate of P-5 remained at an extremely low level, with almost no water separation, indicating that P-5 has excellent emulsification stability. Yi Jianhua [10] also showed that a lower water separation rate means that the emulsion has a higher stability.

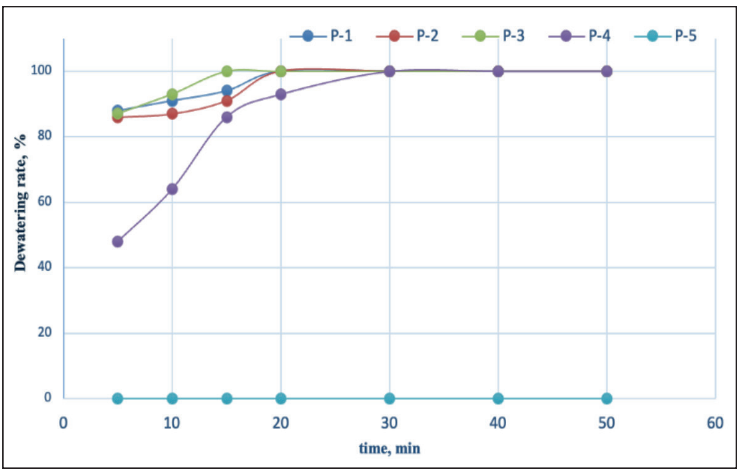

Figure 2 – **The relationship between time with dewatering rate**

Figure 3 shows the change trend of the water separation rate of P-5 over time. In the initial stage (0-5 hours), the water separation rate quickly rose to about 60%, then the growth slowed down and stabilized at about 75% after 25 hours. This trend shows that P-5 can maintain a high stability for a long time, reflecting good emulsification stability.

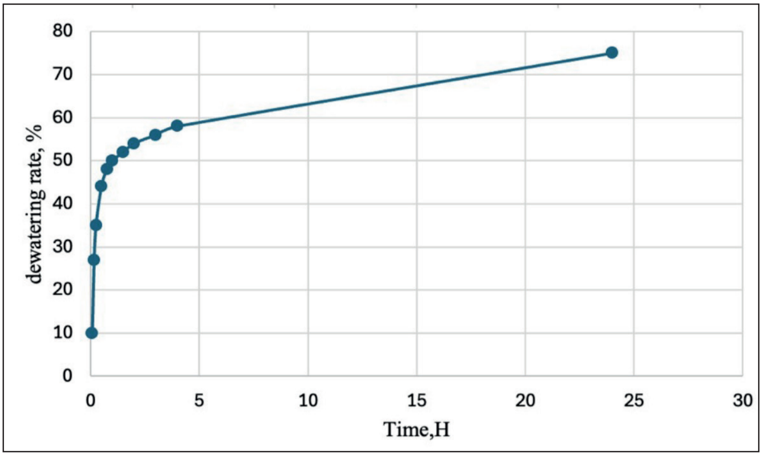

Figure 3 – **Changes of water extraction rate over time**

Figure 4 shows the microstructural changes of P-5 emulsion at different times. a) and b) are the microscopic observation results of the emulsion under the action of P-5 after 30 minutes and 25 hours, respectively. By comparison, it can be seen that even after 25 hours, the oil droplets still remain at the micron sizes, indicating that P-5 can effectively stabilize the emulsion and show excellent emulsification performance. This result further verifies the conclusion that the stability of the emulsion is closely related to the particle size of the dispersed phase and the performance of the emulsifier [11], indicating that P-5 has good emulsification stabilization ability and can effectively prevent oil droplet aggregation and demulsification.

Figure 5 shows the effect of different concentrations on viscosity and viscosity reduction rate. Overall, the viscosity (blue curve) fluctuates with concentration, with a significant decrease at 0.25%, and then rises to a higher level at 0.3%. At the same time, the VRR (orange curve) remains between 70%-80% at low concentrations (0.1-0.2%), reaches a maximum at 0.25%, and then decreases. This shows that 0.25% is the optimal concentration, with the lowest system viscosity and the largest viscosity reduction rate,

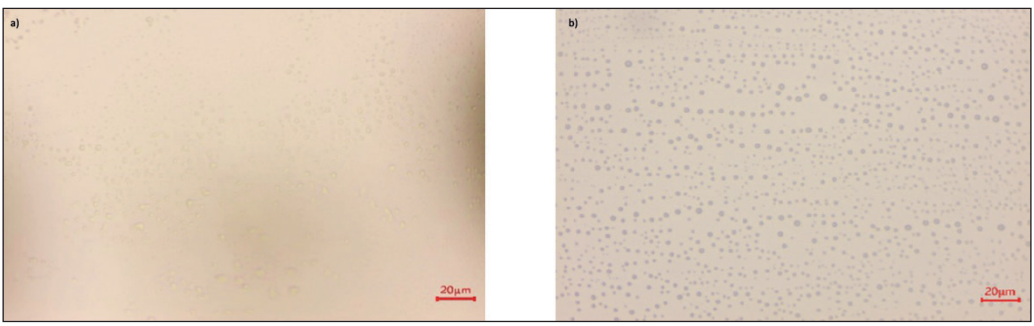

Figure 4 – **Microstructure changes of P-5 emulsion at different times a) 30min b) 25h**

which is conducive to improving emulsification ability. This result is consistent with the conclusion reported in the literature that viscosity can be effectively regulated and oil recovery (EOR) can be enhanced by optimizing polymer concentration and salinity [12].

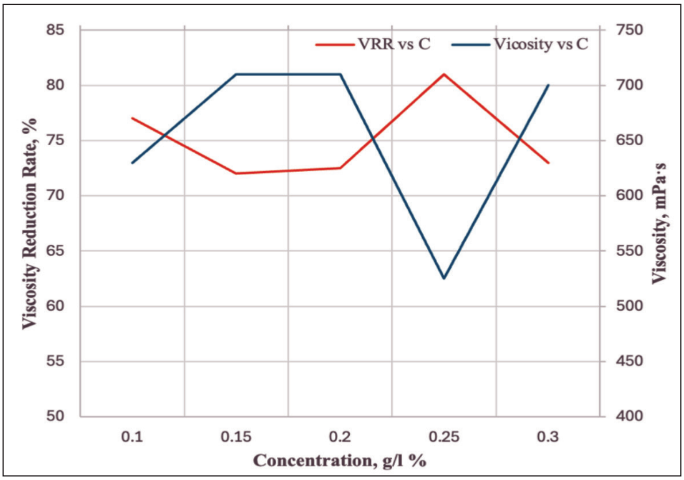

Figure 5 – **Effect of concentration on viscosity and viscosity reduction rate**

The *Figure 6* shows the effect of different salinities (mg/L) on viscosity (mPa·s) and viscosity reduction rate (VRR, %). Overall, the viscosity (blue curve) fluctuates with salinity, reaching the lowest value at 55,000 mg/L, and rebounding at higher salinities (80,000 mg/L and above). At the same time, the VRR (orange curve) reaches its maximum value at 55,000 mg/L, indicating that the system has the best viscosity reduction effect and the strongest emulsification ability under this salinity condition, which is conducive to enhanced oil recovery (EOR). This result is consistent with the conclusion proposed by Luan Pengfei et al. [13] that the viscosity of the polymer solution can be effectively regulated, the emulsification performance can be enhanced, and the recovery rate can be improved by optimizing the salinity conditions.

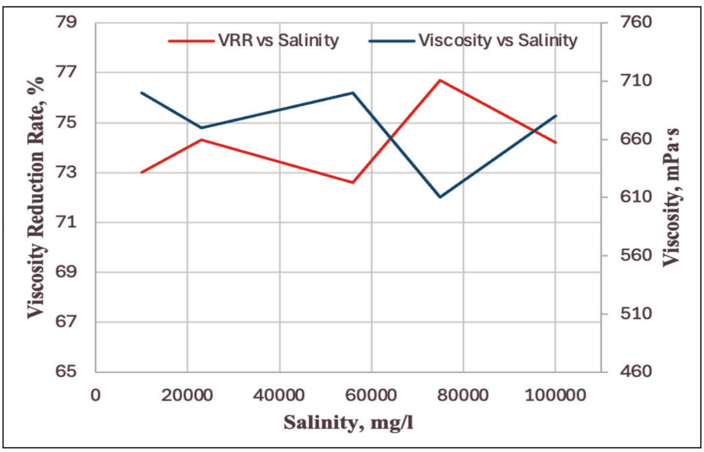

Figure 6 – **Effect of salinity on viscosity and viscosity reduction rate**

Conclusion. This study demonstrates that salt-tolerant amphiphilic polymers have strong emulsification heavy oil capacity and stability in high-salinity reservoirs, making them effective EOR agents in Kazakhstan oilfields. Among the tested polymers, P-5 exhibited the best performance, achieving the lowest interfacial tension and highest emulsion stability. The optimal formulation was determined to be P-5 at a concentration of 0.25% and a salinity of 55,000 mg/L, which resulted in the greatest viscosity reduction and enhanced oil displacement efficiency. These findings highlight the potential of amphiphilic polymers as a promising alternative to traditional thermal methods for heavy oil recovery.

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