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Performance evaluation of micro-nano dispersion system/polymer combination system

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[Abstract] In order to carry out the research and application of the synergy effect of the micro-nano dispersion system (MDS)/polymer combination system,this paper carried out the physical and chemical properties of the MDS/polymer combination system through the interdisciplinary and innovative research methods, taking reservoir engineering, physical chemistry and biological fluid mechanics as the theoretical guidance. By the simulation macro physical simulation, the reservoir adaptability, transmission and migration ability, and the synergisticdisplacement effect are further explored. The results show thatMDS has good hydration expansion performance in polymer solution. In the optimization flooding scheme,injectMDS/polymersolutionalternately. When the injection volumeratio of0.3 PVpolymer solution (2000 mg/L) and 3000 mg/LMDSis 2:1,the synergistic effect is good.The earlier the injection time is, the higher the comprehensive recovery gets. The MDS/polymer combination system achieves the effect of enhancing oil recovery by profile control and oil displacement.The research on the synergy of the combination system and the optimization flooding schemewill help to form new technical ideas and methods for enhancing oil recovery, and can provide theoretical and technical support for greatly improving oil recovery.
[Keywords] MDS/polymer combination system; synergistic flooding; oil displacement effect; mechanism analysis

I. INTRODUCTION

As the largest offshore crude oil production base in China, Bohai oilfield is of great significance to the national oil and energy security.However, due to thereservoirheterogeneityin Bohai oilfield,it is difficult to efficiently displace remaining oilby conventional water flooding technology,and at the same time, it causes the problem of high water content in production wells. In order to improve the production degree of the remaining oil in the deep reservoir, it is necessary to propose a chemical agent that canmigrate to the deep formation to displace oil. Micro-nano dispersion system (MDS)is a typical flooding technology,which uses a new granular polymerdispersion system as the displacement phase. It presents the movement characteristics of “migration, capture, deformation, re migration, re capture and re deformation” in porous media. The permeability and water oil mobility ratio of different parts of the reservoir can be adjusted,so as to improve crude oil recovery. In order to improve its flooding effect, this paper proposes a combination system ofMDS/polymer. The research on the physical and chemical properties, reservoir adaptability, oil displacement and plugging effect of the combination system are further carried out, andthe profile control and displacement scheme is optimized. It provides guidance for the field test of MDS flooding technology.

II. EXPERIMENTAL CONDITIONS

2.1 Experimental materials

Micro-nano dispersion system (MDS), polymer (DY-2), Main crosslinking agent ①, and crosslinking agent ②was provided by CNOOC Research Institute Co., Ltd.Experimental oil and water comes from S Oilfield. The viscosity of crude oil was 45mPa·s at 60 ℃. Water quality analysis is listed in Table 1.

Table 1 Water quality analysis

Composition	Na_2CO_3	NaCl	Na_2SO_4	$NaHCO_3$	$CaCl_2$	$MgCl_2 \cdot 6H_20$	KCl	Total salinity
Content (g/L)	0.08	5.59	0.03	0.54	0.53	0.58	0.08	7153.45

Core used in the experiment

①The columnar core (see Fig.1(a)) is used in the MDS injectability evaluation experiment. The gas permeability is 1000mD, and the core specification is Ø 2.5×10 cm.

②Artificial core of uartz sand epoxy resin is used to evaluate thesynergy effect of MDS combination system. Long×wide×Height =30×4.5×4.5cm, see Fig.1(b). The gas permeability is 4000mD, 2000mD, 500mD respectively.

(a) Columnar core(b) Homogeneous square core
Fig.1 Experimental Cores

2.2 Experimental equipment

Three eye metallographic microscope is used to recordthe images of hydration and expansion of MDS. and then obtain the average diameter of MDS particles through statistical analysis. The MDS particle size experimental process is shown in Fig.2.

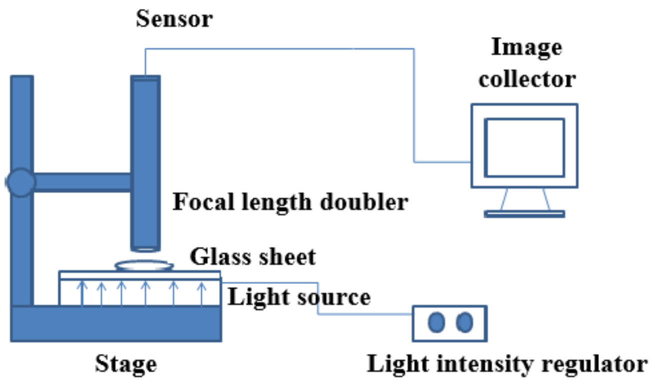


Fig.2 Particle size experimental process of MDS

Core displacement experimental equipment mainly includes advection pump, pressure sensor, hand pump and intermediate container.Except for the advection pump and hand pump, other parts are placed in a 60 ℃incubator. The physical simulation experiment is shown in Fig.3.

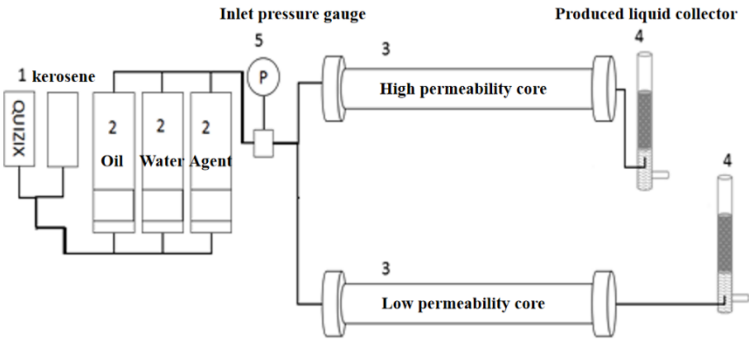


Fig.3 Physical simulation experiment equipment

2.3Experimental scheme

2.3.1 Physical and chemical properties of MDS combination system

(1) Before preparing MDS solution, stir it with a glass rod to make the MDS disperse evenly.

(2) Extract MDS solution according to the design concentration, add it to DY-2 polymer solution with a certain concentration, and then place it on a magnetic stirrer to stir for 15 minutes.

(3) Place the prepared MDS/ DY-2 solution in the sample bottle and store it in a 60 ℃ incubator for water absorption and expansion. After 1, 2, 3, 4 and 5 days respectively, shake it well and take out the sample. Observe the morphology of the microspheres with a three eye metallographic microscope, and measure the appearance size of MDS with video acquisition software.

2.3.2 Reservoir adaptability of MDS

(1) Evacuate the core and saturate with the formation water, injects simulated injection water, and records the differential pressureδP1;

(2) Inject 5PV MDS aqueous solution (3000mg/L) and record the differential pressureδP2;

(3) Hydration and expansion in the core for different days;

(4) Inject subsequent water and record the differential pressureδP3;

The injection rate of the above experimental process is 0.3mL/min, and the pressure recording interval is 30min. The retention amount of MDS in porous media can be evaluated by resistance coefficient and residual resistance coefficient (F_{R} and F_{RR}), which is defined as:

$$F_R = \frac{\delta P_2}{\delta P_1}, F_{RR} = \frac{\delta P_3}{\delta P_1} (1)$$

2.3.3 Oil displacement effect of MDS combination system

Taking the EOR (enhanced oil recovery rate) as the index,the synergistic effect was evaluated by the injection parameters of MNS combination system: injection mode, composition concentration, slug size, injection timing, and injection rate.

Experimental steps:

(1) Dry weight: use electronic scale to measure the dry weight of square core;

(2) Saturated water: inject simulated formation water into the core at a constant flow rate, measure the stable pressure at the inlet end after the flow at the outlet end and the pressure at the inlet end are stabilized, calculate the permeability of core by Darcy formula, and then weigh the wet weight of the core by electronic weight, and calculate the pore volume and porosity of the core;

(3) Saturated oil: saturate the core with different permeability at a constant flow rate. Until there is no more water at the outlet of the core and the oil production is stable, record the cumulative water production, calculate the oil saturation.

(5) Water flooding: water flood the core at a constant flow rate until no oil is produced, record the cumulative oil production of water flooding and the stable flow pressure, and calculate the water flooding recovery factor;

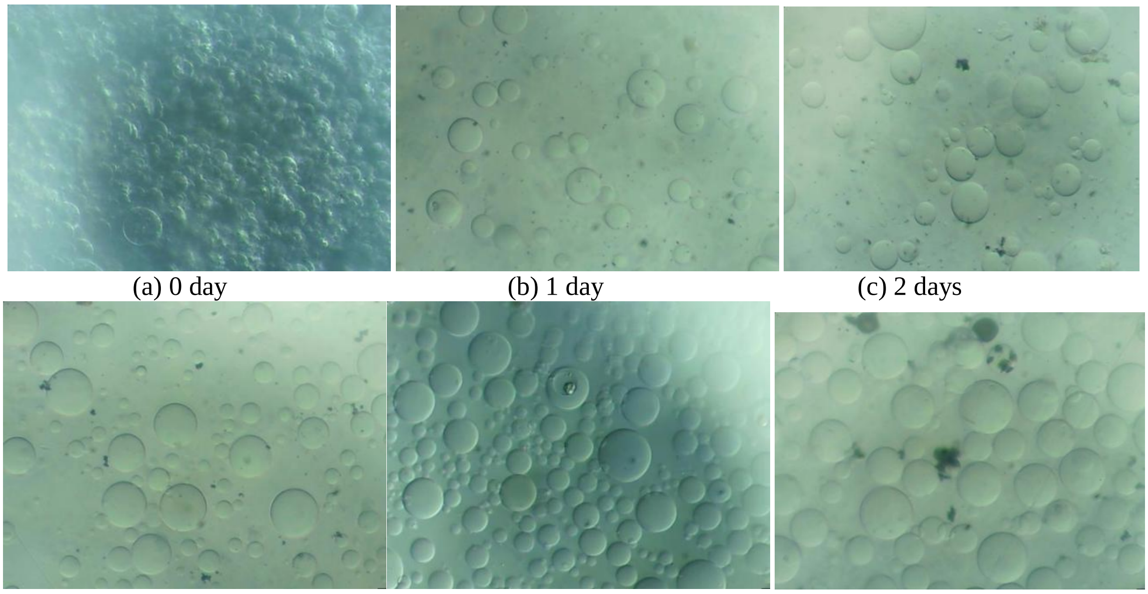
(6) Injection of MDS/polymer combination system and subsequent water flooding: inject MDS/DY-2 solution system at a constant flow rate, then aging, conduct oil displacement experiments on the system composition concentration, slug size and injection mode of MDS/dy-2 solution respectively,and then perform water flooding, calculate the oil recovery rate enhanced by MDS/dy-2 solution and subsequent water flooding.

III. EXPERIMENTAL RESULTS AND DISCUSSION

3.1Physicochemical properties of MDS combination system

3.1.1 Hydration expansion of MDS in polymer

At 60 ℃ the three eye metallographic microscope is used to observe the swelling change of MDS in the polymerunder the same focal length (MDS 1750ppm + DY-2 polymer 1250ppm), as shown in Fig.4.



(a) 0 day (b) 1 day (c) 2 days

(d) 3 days (e) 4 days (f) 5 days

Fig.4 Hydration swelling of MDS /dy-2 solution

It can be seen from Fig.4 thatMDS is sphericalin DY-2 solution, with good sphericity and compatibility.With the increase of hydration time, the size of MDS increases. In the oil phase, the initial median particle size $D_{50}$of MDS is 9.86μm. With the increase of aging hydration expansion time,the median particle sizeD_{50} of MDS reaches 54.63 after 1 day, and expansion ratio is 5.54;after 5 days the median particle sizeD_{50} of MDSreaches 79.67μm, and expansion ratio is 8.08. It shows that MDS expands rapidly in a short time, and then slows down.With the increase of aging hydration expansion time,the increase of small MDS in the observation field increases the density of MDS,and with the increase of hydration expansion time, small particle size MDS expands. The particle size distribution of MDS is uneven, which may be because the larger the specific surface area of MDS particles, the stronger the rapid swelling performance. MDS particles with rapid swelling are mostly particles with large specific surface area,while MDS particles with small specific surface area still need a certain swelling time.

3.1.2 Influence of polymer on MDS

The total concentration of MDS and DY-2 is 3000 mg/L, and the concentration of DY-2 polymer is 500 mg/L, 750 mg/L, 1000 mg/L and 1250 mg/L respectively. The hydration expansion of MDS in polymer is shown in Fig.5.

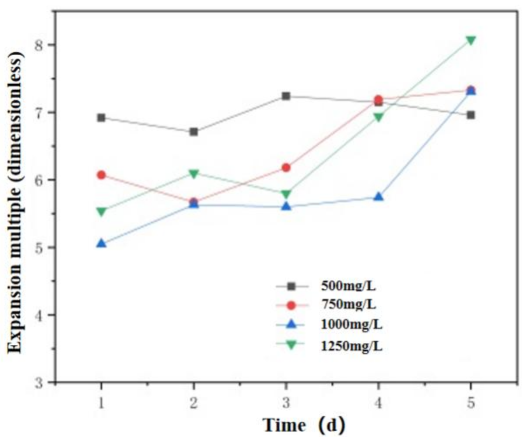


Fig.5 Hydration expansion of MDS /dy-2 solution

As can be seen from Fig.5, with the increase of hydration expansion time, the size of MDS/ DY-2 solutions with different concentrations increases.Compared with the system of 500mg/L DY-2 polymer +2500 mg/LMDS,the system of 1250mg/L DY-2 polymer +1750 mg/LMDS has small expansion times and low hydration expansion rate in the early stage. It can be analyzed that the higher the polymer concentration is, the lower the hydration expansion rate of MDS in the early stage. The reason may be that the hydration expansion of MDS needs to compete with water molecules, and the concentration gradient of polymer evenly dispersed in water proceeds from low to high, which hinders the expansion rate of MDS. MDS has strong hydration expansion, and it may be the self nature of MDS that determines its expansion size ultimately.

3.2 Reservoir adaptability of MDS

3.2.1 Injectability of MDS

Select the core with gas permeability of 1000mD, and continuously inject 3000mg/LMDS aqueous solution into the core at 60 ℃, and explore the injectability of MDS in the reservoir environment according to its injection pressure.

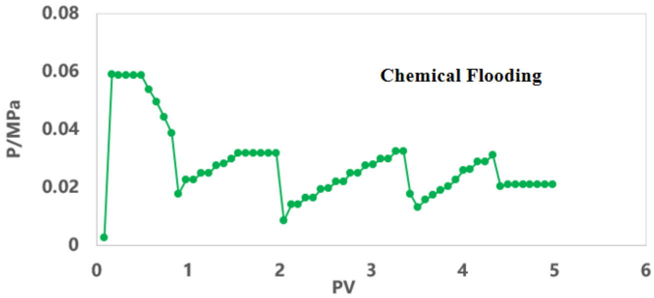


Fig.6MDSinjectabilityin the reservoir environment

As shown in Fig.6, during the injection process of MDS solution, the stable injection pressure interval first shows a downward trend, and then remains unchanged. The reason may be that MDS caused blockage and stability at the front end of injection. In the subsequent continuous injection process, MDS migrated in the core, resulting in the decrease of pressure data. The overall pressure showed a downward trend, indicating that the MDS has good injectabilityafter a short period of hydration and expansion in 1000mD core.

3.2.2 Adaptability of MDS in porous media

Using the core with gas permeability of 1000mD, inject 0.3PV, 3000ppm MDS into the core at 60 ℃, aging the core for 2 days, 7 days respectivelyfor comparative test, and evaluate the transmission and migration ability of MDS in the reservoir environment through the subsequent water flooding pressure.

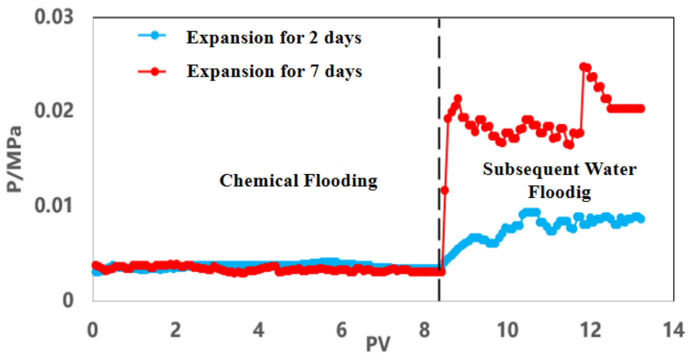


Fig.7Expansion of MDS in porous media

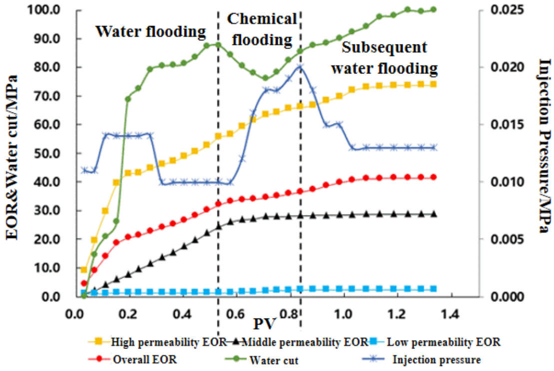
It can be seen from Fig.7 that compared with the subsequent water flooding after MDS is injected into the core after swelling for 2 days, that of MDSinjected into the coreafter swelling for 7 daysis much higher. The longer the MDS swelling time in the core, the better its effective plugging effect is.Combined with the previous experimental results, it shows that the particle size distribution of MDS is uneven. The particles with large specific surface area will rapidly expands, while the MDS with small specific surface area still needs a certain swelling time.

3.3 Oil displacement effect of MDS/polymer combination system

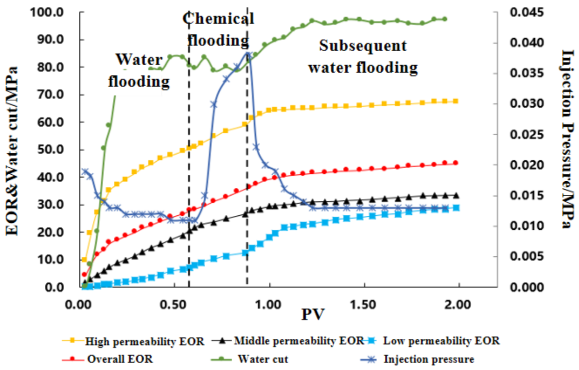
Taking the EOR as the index, the injection parameters, including injection mode, composition concentration, slug size, injection timing, injection rate, of the MDS/polymer combination system are optimized experimentally.

3.3.1 Optimization of MDS/polymer injection mode

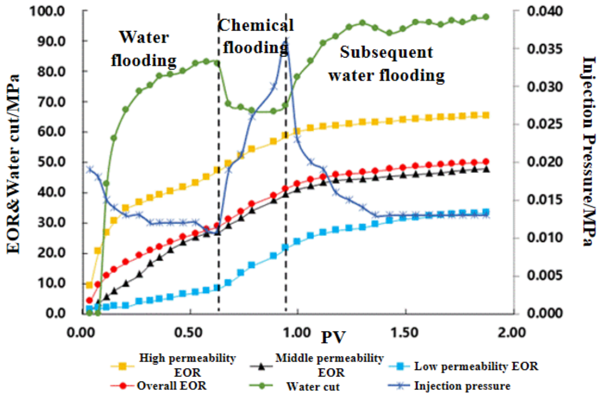
In order to study the effect of different injection methods on the oil displacement effect of the combination system, the oil displacement experiment of MDS/ DY-2 combination system was carried out by using the method of macro physical simulation. The oil displacement effect was compared and analyzed, and the best injection method was selected.



(a) oil displacement effect of singleMDS



(b) mixed injection of MDS/ DY-2



(c) alternating injection of MDS/ DY-2

Fig.8 Dynamic characteristic curve of injection mode optimization

On the basis of the same total dosage of the agent, the experiments of mixed injection and alternate injection of MDS/ DY-2 combination system were compared. Compared with the experimental results in Fig. 8(b) and Fig. 8(c), mixed injection can improve oil recovery rate by 16.4%.The enhanced oil recovery of alternate injection is 21.1%. Obviously, the effect of alternate injection is better. From Fig.8, it can be seen that the oil recovery experiment of single MDS flooding is 7.4%. Compared with MDS/ DY-2alternate injection,the alternate injection method improves the oil recovery by 13.7%. Therefore, MDS alone cannot play a good role in plugging or oil displacement.

3.3.2 Optimization of composition and concentration of MDS/polymer system

The appropriate composition concentration is optimized through the double pipe parallel displacement experiment of high and low permeability cores by using the method of alternating injection.

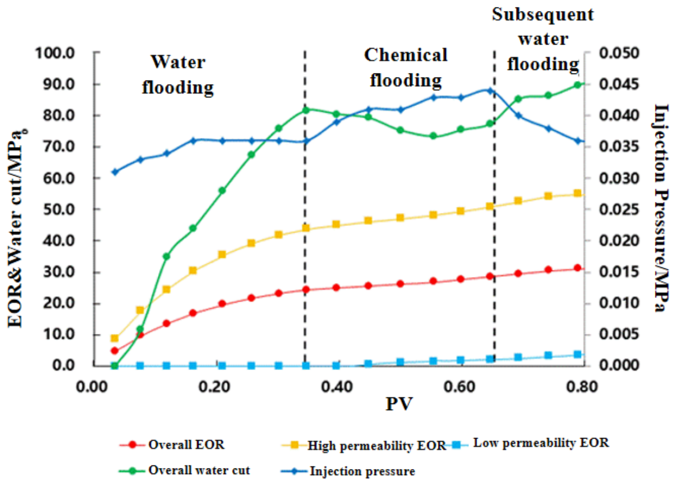
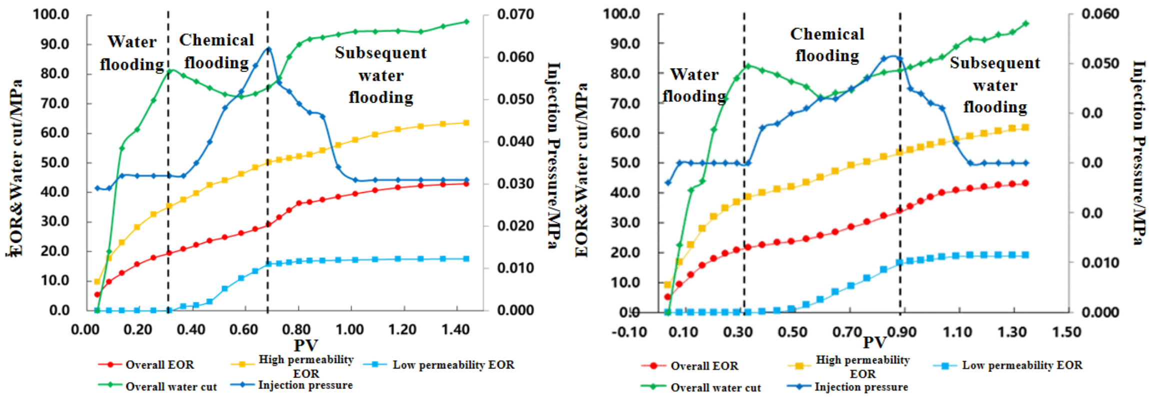


Fig.9SingleMDS oil displacement effect

From Fig.9, it can be seen that the oil recovery is improved by 7.4% by injecting MDS process and subsequent water flooding into the parallelcore. The oil recovery is low. It shows that the oil displacement ability of single MDS flooding is poor, and it can not effectively migrate to the low permeability areas.

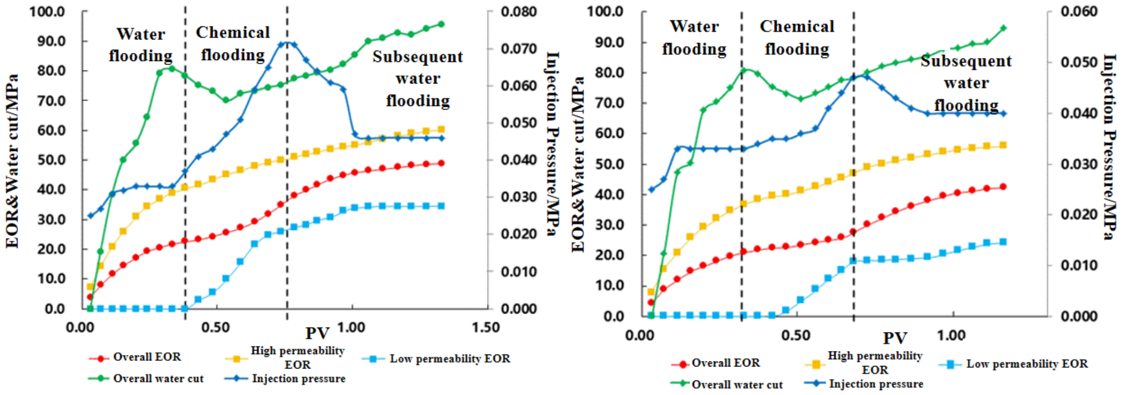


(a) 2000 mg/L DY-2 polymer and 3000 mg/LMDS (b) 1000 mg/L DY-2 polymer and 4000 mg/LMDS
Fig.10Dynamic characteristic curve of composition and concentration optimization

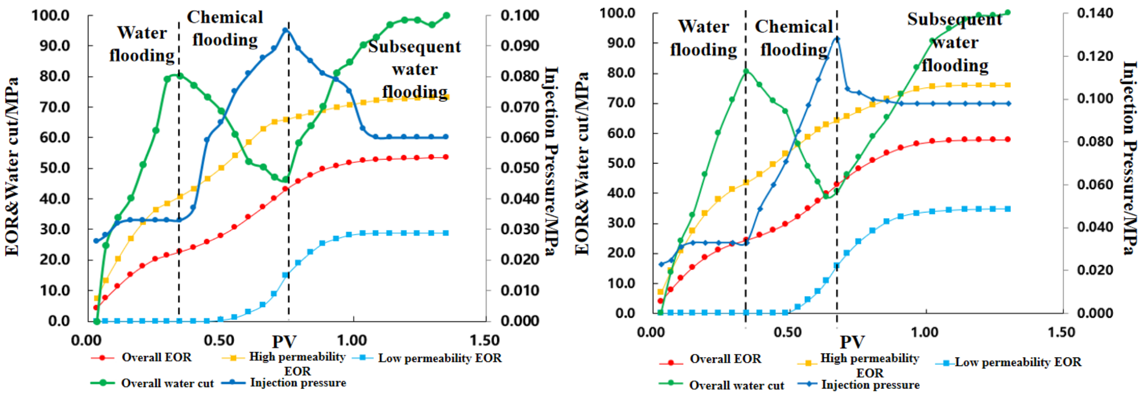
Combined with Fig.10, after injecting0.225 PVDY-2 polymer (2000 mg/L) and 0.15 PVMDS (3000 mg/L) into the core, the recovery rate of high permeability crude oil is increased by 26.0%, that of low permeability crude oil is increased by 17.3%, and that of the overall crude oil is increased by 22.1%. After injecting 0.45 PVDY-2 polymer (1000 mg/L) and0.1125 PVMDS (4000 mg/L) into the core, the recovery of high permeability is increased by 23.0%, and that of low permeability is increased by 19.2%, and that of the overall is increased by 21.4%. Therefore, the injection of 0.225 PVDY-2 polymer (2000 mg/L) and 0.15 PVMDS (3000 mg/L) is slightly better in oil displacement effect, but there is little difference.

3.3.3 Slug size optimization of MDS/polymer system

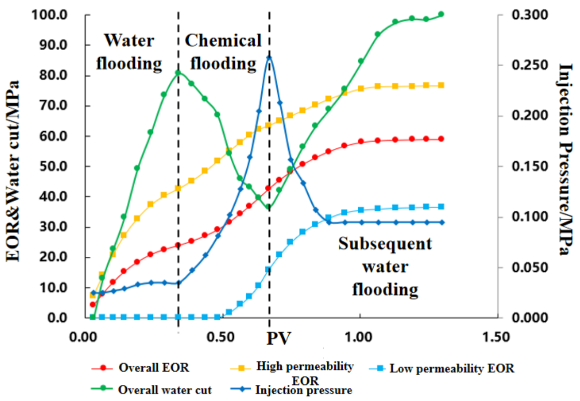
When the total agent dosage is certain,the increase effect of oil recovery with different ratios of MDS/ DY-2 is optimized.



(a) the ratio of polymer to MDS is 2:1(b) the ratio of polymer to MDS is 1:2



(c) the ratio of polymer to MDS is 3:1(d) the ratio of polymer to MDS is 4:1



(e) the ratio of polymer to MDS is 5:1

Fig.11Dynamic characteristic curve of slug size optimization

According to Fig.11(a), when the dosage ratio of DY-2 to MDS is 2:1, the recovery rate in high permeability is increased by 21.2%, chemical flooding recovery rate is increased by 34.6%, and the final recovery rate is increased by 27.2%.Fig.11(b) shows that when the ratio of polymer to MDS is 1:2, the recovery in high permeabilityis increased by 19.2% andchemical flooding recovery rate is increased by 24.3% with thecombination systemof 0.15 PVDY-2 (2000 mg/L) and 0.2 PVMDS(3000 mg/L). The final recovery is increased by 21.3%. As the ratio of polymer to MDS increases,the EOR can reach 36.0%. It shows that the greater the injection amount of MDS, the better the plugging ability of high permeability area. Compared with MDS, the addition of polymer has a more significant increase in crude oil recovery. The reason is that as the relative concentration of polymer continues to rise, the corresponding injection pressure will be greater, and the oil recovery rate will be higher. Considering the injection pressure and oil recovery rate,the final optimized slug size is the ratio of polymer to adaptive micro gel 2:1.

IV. CONCLUSION

(1) For the 1750ppm MDS +1250ppm DY-2 solution system, the expansion multiple of MDS can reach 8.08, and the compatibility between MDS and DY-2 solution is good.MDS of different concentrations showed the ability of rapid hydration and expansion in the early stage, and the expansion rate was slow in the late stage. And the expansion rate of MDS with relatively small specific surface area was slow.

(2) Compared with the water flooding pressure, the pressure of MDSis high in 500mD permeability. For 1000mD permeability of square core, MDS has good injectability, and can migrate to the depth of core with the increase of MDS injection volume. The longer the hydration expansion time of MDS in the core, the higher the subsequent water flooding pressure and the stronger the plugging property.

(3) Taking EOR as an index, the synergy effect of MDS/dy-2 combination system was explored. The experimental results show that on the basis of the same total dosage of reagents, alternate injection is conducive to enhance oil recovery, the overall effect of changing the composition concentration of the system is not significant,and a slightly higher concentration of polymer is conducive. As the slug ratio of MDSand DY-2combination system increases. When the slug ratio is 2:1, the experimental injection pressure is moderate, and the crude oil recovery is high.

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