

Research Article

Development and Application of Efficient Oil Displacement System for Middle-Low Permeability and High Pour-Point Heavy Oil Reservoirs

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In view of the problems of low permeability, high oil viscosity and freezing point, and low productivity of single well in Luo 321 and Luo 36 blocks of Luojia Oilfield, the chemical viscosity-reducing cold production technology was studied. By analyzing the properties of crude oil, it is concluded that the reason for high viscosity and high freezing point is the high content of asphaltene, pectin, and wax. The viscosity is mainly affected by asphaltene; the wax precipitation point and pour point are mainly affected by the wax; and the solidification point is affected by the wax and asphaltene. The treatment idea of reducing viscosity and inhibiting wax is determined. By compounding the synthetic pour point depressant POA-VA and the viscosity reducer DBD-DOPAMA, the effect of reducing the viscosity and freezing point of crude oil was evaluated. PD-7 (POA-VA 40%, DBD-DOPAMA 50%, and P-10C 10%) system was selected as the optimal formula. When the concentration of the system is 10%, the viscosity reduction rate reaches 95.2%; the freezing point can reduce by 10.2°C; it has good oil sample adaptability, salinity resistance, and temperature resistance; and the oil washing rate can reach more than 60%. The oil displacement system was injected into the formation by means of multiconcentration and multislug and was applied in the field of Luo 321-2 Well. A total of 500 t of the oil displacement system was injected, and the effect of measures lasted for 400 days, with a cumulative oil increase of 883 t. It has been applied in different blocks 30 times and achieved a good field application effect.

1. Introduction

The middle-low permeability and high pour-point heavy oil reservoirs in Shengli Oilfield are widely distributed, with reserves of about 25 million tons, mainly distributed in Chengnan, Luojia-Kenxi, Wangjiagang, Big D35-X20, Xin68, and other blocks. Taking Luo 321 and Luo 36 blocks of Luojia Oilfield in Hekou Oil Production Company as examples, the reservoir burial depth is more than 1600 m, and the reservoir permeability is less than 300 mD. The viscosity of crude oil is greater than 50 mPa·s at formation temperature (around 50°C) and more than 50,000 mPa·s at 20°C, and the freezing point of crude oil is above 30°C. At

present, there are mainly the following problems in middle-low permeability and high pour-point heavy oil reservoirs. First, due to the dual influence of low permeability and thickened oil, the limit drainage radius of underground crude oil is small, and the productivity of a single well is low. Second, the reservoir is deep-buried, low permeability, high steam injection pressure, low enthalpy, and small heating radius. Third, high wax content of crude oil, high freezing point, wellbore lifting, and crude oil gathering and transportation is difficult. Therefore, conventional development and steam stimulation cannot achieve ideal results; reserves production rate, oil recovery speed, and development benefits are in a relatively low state.

At present, by injecting viscosity reducer into the bottom of the well to reduce the viscosity of heavy oil and improve the flow of crude oil, this chemical viscosity reduction and cold production injection craft is gradually becoming an effective supplement to heavy oil steam injection production technology and has achieved certain application effect in the field [1, 2]. However, this technology also has some limitations, the indoor viscosity reduction effect is significant, the field oil increase effect is very unstable, especially for hypercoagulability and high viscosity heavy oil; a single agent component is not targeted; and it is difficult to achieve the purpose of field oil increase [3–7]. This article selects Luo 321 and Luo 36 in Luojia oilfield as a test block. Based on the understanding of the causes of high pour point and high viscosity of crude oil, specific coagulants and thickeners have been developed according to the characteristics of crude oil. Through compatibility, a high-efficiency composite flooding system for low-permeability and high-pour-point heavy oil reservoirs is formed, and typical wells are selected for on-site application on the basis of indoor evaluation. It can solve the problems of reservoir flow, wellbore lifting, and ground oil collecting in an integrated way and provide strong technical support for the efficient development of similar reservoirs.

2. Experimental Materials and Methods

2.1. Materials and Instruments. Octadecyl acrylate (POA), vinyl acetate (VA), azo-iso-butyronitrile (AIBN), dopamine (DOPA), methacrylate chloride (MA), sodium borate, triethylamine are of analytical grade (all from Shanghai Aladdin Reagent Company); hydrochloric acid, sodium borate, methanol, NaCl, KCl, Na₂SO₄ was from Sinopharm Chemical Reagent Co., Ltd; degassed heavy oil was from Luo 321 and Luo 36 blocks.

LP1002 Electronic Balance was from Changshu Weighing Device Factory; CH702 constant temperature stirred water bath was from Gongyi Yuhua Instrument Co., Ltd.; Agilent 6890 GC gas chromatograph was from Germany IKA ; Quartz crystal microbalance was from Biolin Sweden Company; DHG-9070A electric heating blast drying oven was from Shanghai Yiheng Scientific Instrument Co.,

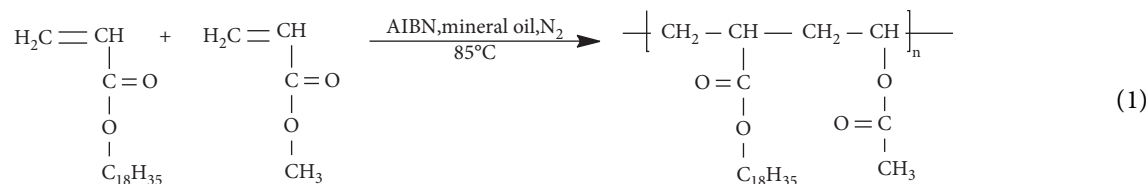
Ltd. DV-II + PRO viscometer was from USA Brookfield Company; the atomic force microscope (AFM) was used.

2.2. Determination of Crude Oil Properties. The standard SH/T 0509-2010 “determination of four components of petroleum asphalt,” SY/T 0521-2008 “crude oil wax point determination of microscopic observation method,” SY/T 7516-2010 “modified crude oil pour point determination of melting method,” and SY/T 0541-2009 “crude oil condensation point determination method” were used to determine the four components, wax extraction point, pour point, and freezing point of crude oil in this area, respectively.

2.3. Crude Oil Viscosity-Temperature Relationship Test. After preheating the sample to 60°C, it was placed in the rotary viscometer measurement system. After the temperature stabilized, the sample was cooled at a rate of 0.2–0.9°C/min. The flat plate test system was used to record the changes of shear stress and viscosity with the change of temperature at the shear rate of 5S⁻¹, and the curve was drawn.

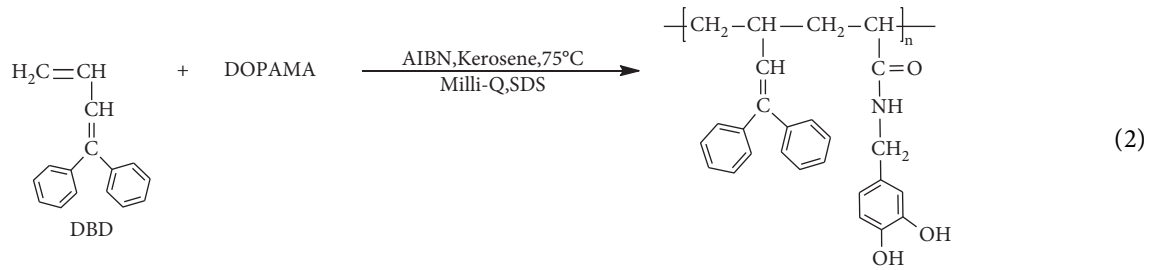
2.4. Full Component Analysis of Carbon Group of Crude Oil. Agilent 6890 GC gas chromatogram was used to test the total carbon components of crude oil and determine the peak value of carbon components. PONA quartz capillary column was used for the chromatographic column with a length of 50 mm and an inner diameter of 0.20 mm. The detector used hydrogen flame ionization detector, 220°C; the temperature of the vaporization chamber is 200°C; the temperature of the column is 80°C–320°C; and the temperature change rate is 6°C/min. The flow rate of hydrogen is 40 ml/min, and that of air is 400 ml/min.

2.5. Synthesis of POA-VA Pour Point Depressant. Totally, 32.4 g octadecyl acrylate (POA) and 8.6 g vinyl acetate (VA) were dissolved in 160 g mineral oil, and 0.3 g of initiator azo-iso-butyronitrile (AIBN) was added under stirring condition; then N₂ was passed through for 30 min for deoxygenation, and the reaction was heated at 85°C for 10 hours. The reaction equation is as follows:



2.6. Synthesis of DBD-DOPAMA Viscosity Reducer. Dopama methacrylate (DOPAMA) was firstly synthesized by adding DOPA•HCl and methacrylate chloride (MA) into 10 mL methanol at a molar ratio of 1:1, adding sodium borate

and triethylamine, and stirring at room temperature for 24 hours to get DOPAMA. The new viscosity reducer DBD-DOPAMA can be obtained by polymerization of the synthesized DOPAMA with DBD. The reaction equation is as follows:



2.7. Oil Washing Ability Test. Quartz crystal microbalance was used to determine the oil absorption capacity (QCM-D) of PD-7. The experimental procedures are as follows (Figure 1):

- (i) The heavy oil of Luo321-2 was quantitatively adsorbed on the surface of the quartz test sheet, and the mass was weighed m_1 .
- (ii) The heavy oil has continued to be cleaned on the surface of the quartz slice with a 10% concentration PD-7 solution. After the detector signal is stable, the quartz slice was taken out, and the mass was weighed m_2 , and the oil washing rate $D = 100\% \times (m_1 - m_2)/m_1$.
- (iii) The surface of the peeled quartz was then mapped using atomic force microscopy (AFM).

3. Experimental Results and Discussion

3.1. Cause Analysis of High Freezing Point and High Viscosity of Heavy Oil

3.1.1. Composition and Property Analysis of Crude Oil. Crude oils from six wells in Luojia Oilfield, including Luo 321-1, Luo 321-2, Luo 36-8, Luo 36-9, Luo 36-25, and Luo 32-1, were measured for their composition, wax extraction points, and other properties. The experimental data are shown in Table 1, and the viscose-temperature relationship was tested. The experimental results are shown in Figure 2. The experimental results show that the viscosity, wax precipitation point, pour point, and freezing point are highly related to the content, composition, and ratio of heavy components. The higher the molecular weight of asphaltenes, gums, and waxes, the stronger the interaction between the heavy components with an increase of the viscosity, wax precipitation point, pour point, and freezing point, and vice versa. When the wax molecular weight is C25 and the wax content is more than 20%, the wax crystal aggregates can be completely dispersed when the temperature is above 70°C, and the wax precipitation point is mainly affected by the wax. When the molecular weight of asphaltene is C25 and the content is more than 20%, the crude oil loses its fluidity when the temperature drops to 40°C, and the viscosity, pour point, and freezing point are mainly affected by asphaltene. When the molecular weight of the heavy component is C13 and the colloid content is more than 20%, the viscosity is mainly affected by the colloid. The freezing point is mainly affected by the wax. At the same time, the colloid can inhibit

the aggregation of wax crystals and reduce the wax extraction point and pour point.

3.1.2. Mechanism of Action of High Condensation, High Viscosity, and Heavy Oil Components. Study shows that the high viscosity of heavy oil is due to its composition contains high content of colloid and asphaltene. When there is no wax, the asphaltenes mainly form a layered accumulation structure through π - π bonds, and the colloids are adsorbed and wound around the asphaltene aggregates through van der Waals force and electrostatic action, isolating asphaltene aggregates of various sizes. When the temperature drops, the thermal motion of the molecules decreases. In such a situation, aggregate spacing shortens and interaction intensifies, leading to that the viscosity of crude oil increases greatly [8]. The asphaltene aggregates have little influence on the freezing point and pour point of crude oil due to the fact that the asphaltene aggregates can slide between layers, and there is a certain compaction space between layers [9].

But when the wax content in the crude oil is higher, the situation is different. GROMACS software is adopted to simulate the interaction between wax and asphaltene molecules, as shown in Figure 3. After the wax and asphaltene plastic wrap (Figures 3(b) and 3(c)), the high tension of the former long carbon chain caused the conjugate surface bent of the latter aromatic ring (Figure 3(e)) and weakened the π - π connection. As a result, part of the asphaltene shifted from the plane-to-surface layered structure to the internal cluster structure of the asphaltene binding wax molecules (Figure 3(d)), and the volume of the dispersed asphaltene clusters increased significantly (Figure 3(f)), that is, wax-coated asphaltene clusters. The asphaltene is no longer stacked in layers, and the volume of the clusters formed increases greatly; the distance between asphaltenes decreases; and the movement space decreases, resulting in the increase of the freezing point and pour point of crude oil.

Through the above analysis, it is found that the viscosity of high condensation and high viscous oil is mainly affected by asphaltene, the wax extraction point and pour point are mainly affected by wax, and the freezing point is affected by both of them. When the viscosity is higher, it will show the characteristics of heavy oil, and when the viscosity is lower, it will show the characteristics of high pouching oil [10]. Therefore, a single functional agent cannot solve the problems of high pouching and high viscosity at the same time, and the wax suppression must be coordinated with the viscosity reduction.

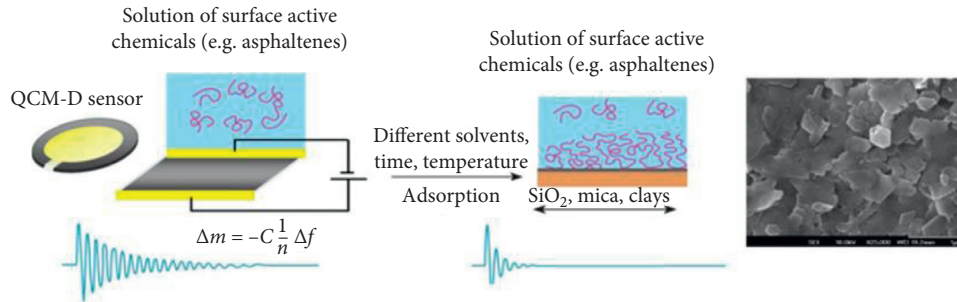


FIGURE 1: The working principle of quartz crystal microbalance.

TABLE 1: Four component analysis results of crude oil.

Sample ID	Component analysis					Characteristic analysis			
	Alkane (%)	Arene (%)	Pectin (%)	Asphaltene (%)	Waxiness (%)	Wax precipitation point (°C)	Pour point (°C)	Freezing point (°C)	Peak carbon composition of crude oil
Luo 321-1	25.19	11.83	18.22	24.43	20.33	69.1	50.3	40.3	C25
Luo 321-2	16.78	10.40	17.52	25.82	29.48	72.5	52.1	41.8	C13
Luo 36-oblique 25	19.64	16.66	12.63	22.96	18.11	62.2	50.1	39.2	C25
Luo 36-oblique 8	15.08	18.36	25.49	16.86	14.21	50.3	38.1	27.3	C13
Luo 36-oblique 9	18.08	19.27	24.23	12.61	15.81	49.8	39.1	28.8	C25
Luo 32-1	14.80	23.08	21.84	19.18	11.10	51.2	41.1	29.3	C25

3.2. Formulation Optimization and Performance Evaluation of High-Efficiency Oil Displacement System with Pour Point and Viscosity Reduction

3.2.1. Compound of the Efficient Oil Displacement System. Through literature research, POA-VA and DBD-DOPAMA were synthesized in our laboratory. The two agents were mixed to screen the system of pour-point and viscosity reduction, and a total of 9 different mixing ratios were screened. At the same time, surfactant P-10C was added to improve the miscible effect. As shown in Figure 4, the higher the mass ratio of POA-VA, the more inclined the mixed solution was to water-in-oil emulsion; on the contrary, the higher the mass ratio of DBD-DOPAMA, the more inclined the mixed solution was to a water-in-oil emulsion, and the compatibility of the two were good are shown in Table 2.

3.2.2. Pour-Point Reduction and Viscosity Reduction Tests of Efficient Oil Displacement Composite System. ① Viscosity reduction energy test of the compound system: According to the method specified in Q/SH1020 1519-2016 “General technical specification for heavy oil viscosity reducer,” taking Luo 321-2 heavy oil with the highest viscosity as the benchmark, the viscosity reduction rate of pour point and viscosity reduction compound agent was tested, and the results are shown in Table 3.

As can be seen from Table 3, pure pour point depressor depressant POA-VA (system 1) basically has no viscosity reduction effect, and the reduction effect rate of the complex system 2–4 is not up to the standard because the content of

the viscosity reduction agent DBD-DOPAMA is less than 40%, resulting in insufficient viscosity reduction efficiency. The viscosity reduction rates of the complex systems 5–10 can all reach more than 90%, and the viscosity reduction rates of systems 7, 8, and 9 are the highest. The reason is that the wax crystals released from the asphaltene after viscosity reduction are destroyed by the wax inhibitor, which reduces the interaction between asphaltene wax-gum and increases the viscosity reduction rate.

② Pour point reduction performance test of the compound system: Taking the freezing point and Luo 321-2 heavy oil with the highest wax content as the benchmark, system 5–11 with better viscosity reduction effect was selected to test the freezing point reduction effect. The experimental results are shown in Table 4.

As can be seen from Table 4, pure viscous-reducing agent DBD-DOPAMA (system 11) basically has no effect on reducing the freezing point. As the proportion of POA-VA in the recombination increases, the freezing point reduction range increases first and then decreases. The combination system 6–8 has the best effect of relatively reducing the freezing point because viscosity reduction and paraffin suppression make most of the asphaltenes arranged in layers instead of clusters, which improves the movement space and effectively reduces the freezing point. System 7 reduces the freezing point to 10.2°C.

③ PD-7 adaptability test: After comprehensive consideration of the viscosity reduction and pour-reducing effects of the complex system as well as the price factors, it is finally determined that complex system 7 is the optimal

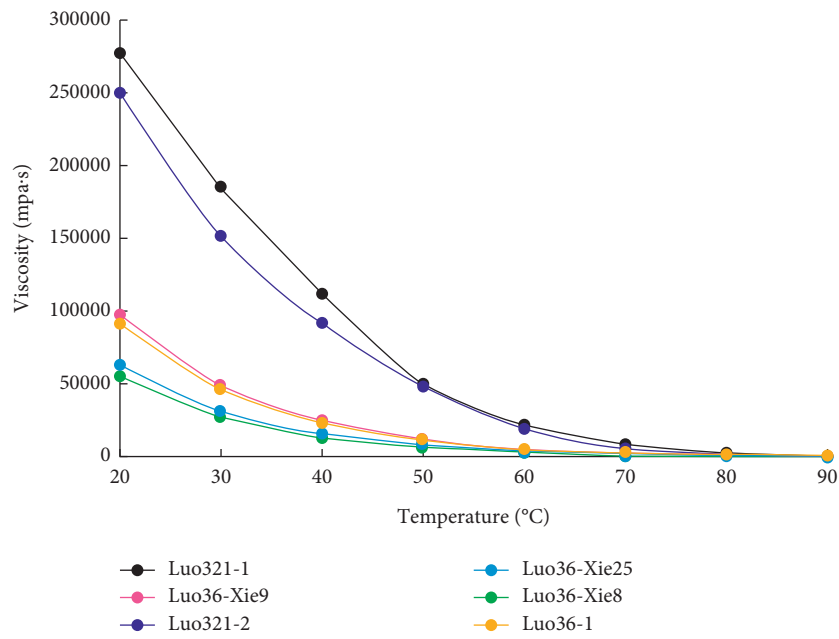


FIGURE 2: Viscosity-temperature curve of each oil sample.

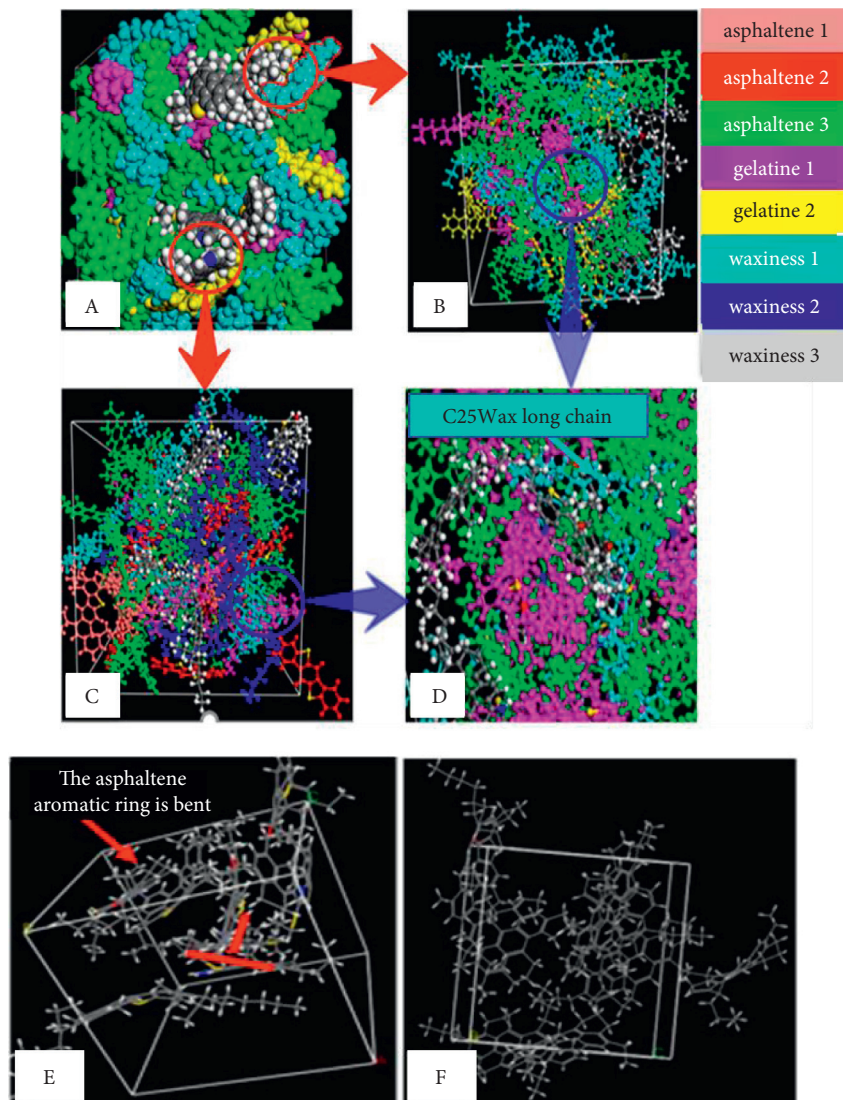


FIGURE 3: GROMACS software simulated the molecular interaction between wax and asphaltene.



FIGURE 4: Complex viscosity reducing and wax inhibiting system.

TABLE 2: Compound viscosity reducing and wax suppression system.

Compound components	Mass ratio										
	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11
POA-VA	100	80	70	60	50	45	40	30	20	10	0
DBD-DOPAMA	0	10	20	30	40	45	50	60	70	80	100
P-10C	0	10	10	10	10	10	10	10	10	10	0

TABLE 3: The effect of the compound of reducing viscosity and inhibiting wax on reducing viscosity.

Drug concentration, % (mOil:mPotion = 1:1)	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11
0	0	0	0	0	0	0	0	0	0	0	0
2	2.1	42.4	48.4	65.1	80.3	82.2	88.1	89.8	88.3	86.4	82.4
5	5.2	58.1	68.1	75.1	85.5	88.5	92.5	93.3	91.8	89.8	88.1
10	8.1	61.3	72.1	80.3	90.2	92.2	95.2	96.7	94.3	92.5	91.3

TABLE 4: Effect of viscosity reducing and wax inhibiting compound on freezing point.

Drug concentration, % (mOil:mPotion = 1:1)	System 5	System 6	System 7	System 8	System 9	System 10	System 11
0	41.8	41.8	41.8	41.8	41.8	41.8	41.8
2	40.1	39.3	38.3	38.7	39.5	40.3	41.3
5	38.1	37.8	35.8	36.8	38.8	39.1	40.8
10	34.7	32.8	31.6	33.1	36.6	38.4	40.1

formula combination (PD-7). The concentration of 2–10% has the effect of viscosity reduction and pour-reducing, and the viscosity reduction rate reaches 95.2% at the concentration of 10%. The measured wax extraction point, pour point, and freezing point can be reduced to 13.7°C, 17.4°C, and 10.2°C, respectively. As a slug reservoir agent, it can effectively reduce viscosity, improve oil flow capacity, avoid the risk of wax extraction and wax formation and enable oil to be pumped smoothly and in normal production. The adaptability test of this system in other oil samples was carried out, and the results are shown in Table 5. The reason for choosing 50°C chosen to test of viscosity reduction rate is that 50°C is the most representative and closer to the actual formation temperature. The viscosity reduction rate of PD-7 with 10% concentration on the oil samples was all over 95%, and the wax extraction point, pour point, and freezing point were all reduced by more than 10°C. That is to say, PD-7 has a universal viscosity reduction and paraffin suppression

effect on the low permeability and high condensing heavy oil in Luo321 and Luo36 blocks.

3.2.3. Performance Test of Efficient Oil Displacement System PD-7.

① Resistance to salinity performance: NaCl, KCl, and Na₂SO₄ were used to simulate formation water, and PD-7 solutions of 5% and 10% were prepared with water of different salinity degrees, respectively, to evaluate the influence of salinity on the viscosity reduction rate and freezing point of PD-7. The test temperature is set to 50°C, and the experimental results are shown in Figure 5.

As can be seen from Figure 5, the viscosity reduction rate increased slightly with the increase of salinity, while the freezing point decreased slightly. When the salinity increased by 100,000 ppm, the viscosity reduction rate of Luo 321-2 heavy oil with 10% PD-7 concentration was 96.3%, and the freezing point decreased by 10.6°C. This is because

TABLE 5: Adaptability test for viscosity reduction and wax suppression of the compound system 7.

Drug concentration, 10% (mOil: mPotion = 1:1)	Viscosity ratio (% 50°C)	Wax precipitation point (°C)			Pour point (°C)			Freezing point (°C)		
		Beginning	Dosage	Δ	Beginning	Dosage	Δ	Beginning	Dosage	Δ
Luo 321-1	96.8	69.1	55	-14.1	50.3	33.7	-16.6	40.3	29.2	-11.1
Luo 36- oblique 8	97.5	50.3	39.1	-11.2	38.1	22.8	-15.3	27.3	17.1	-10.2
Luo 36- oblique 9	96.2	49.8	37	-12.8	39.1	24.5	-14.6	28.8	18.1	-10.7
Luo 36- oblique 25	98.1	62.2	48.4	-13.8	48.7	30.6	-18.1	39.2	26.9	-12.3
Luo 32-1	96.3	51.2	39.1	-12.1	41.1	27	-14.1	29.3	18.5	-10.8

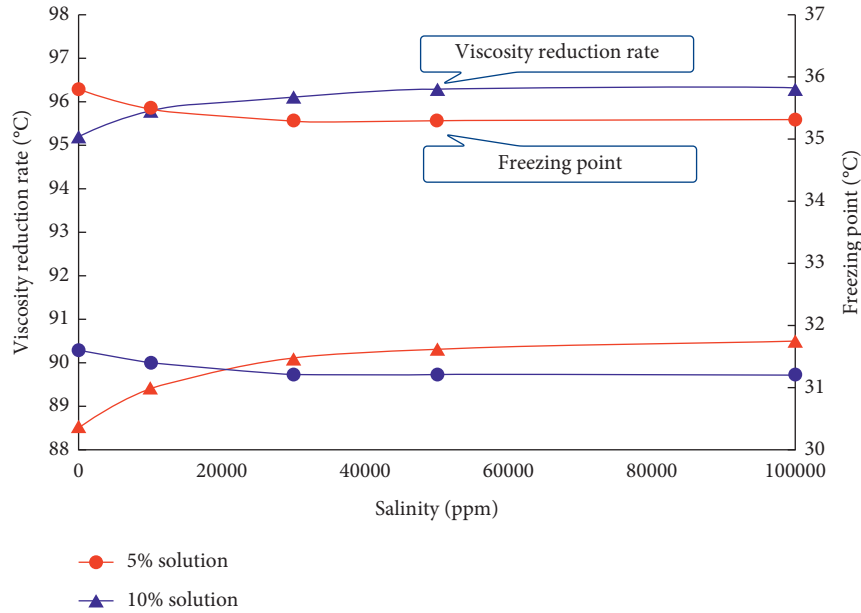


FIGURE 5: Influence of salinity on viscosity reduction rate and freezing point of PD-7.

the cation concentration increases at high salinity, and the ionized cation significantly increases the polarity of ortho dihydroxyl groups, further improves the polarity of catechol groups, increases the interfacial activity of DBD-DOPAMA, and enhances the emulsification effect, which is conducive to improving the viscosity reduction rate.

② Temperature resistance: The influence of 5% and 10% PD-7 solution on the viscosity reduction rate and freezing point of crude oil was measured at different temperatures, and the influence of temperature on the viscosity reduction rate and freezing point of PD-7 was evaluated. The experimental results are shown in Table 6.

It can be seen from Table 6 that when the temperature is higher than 100°C, the viscosity of Luo321-2 heavy oil is less than 200 MPa·s, the viscosity after viscosity reduction is less than 30 MPa·s, and the viscosity of light oil with API > 31.1 is basically 10–35 MPa·s. That is to say, there is no problem in the fluidity after viscosity reduction above 100°C. In fact, the effect at this time is to improve the fluidity rather than viscosity reduction, and the corresponding viscosity reduction rate is no longer of practical significance. Therefore, PD-7 can maintain its activity at 130°C washing oil ability.

The oil washing ability of 0.5%, 2%, 5%, and 10% PD-7 solution was evaluated, and the experimental results were

shown in Figure 6. The red line represents that the QCM-D detection signal is stable, that is, the oil washing is over, and the remaining crude oil adsorbed on the quartz surface cannot be further stripped.

According to the results of QCM-D, a curve was plotted (see Figure 7). As can be seen from the curve, with the increase of PD-7 concentration, the oil washing rate also increases. When the concentration reaches 10%, the oil washing rate is >60%; at this point, the washing rate tends to be stable.

AFM is used to map the remaining oil distribution of quartz slices, and the experimental results are shown in Figure 8. With the increase of PD-7 concentration, the area of a bright spot on quartz surface increases, and the stripping effect of crude oil increases. When $C = 0.5\%$, PD-7 still has a certain stripping ability to the crude oil on the surface of the sandstone. When $C = 10\%$, the crude oil is stripped and cleaned in a large area, but compared with 5%, the oil washing ability tends to be stable, and the stripping effect of the remaining oil decreases with the increase of concentration. So if the oil near the well is thick and causes a blockage, it can be cleaned quickly with a high concentration of agents. When the injection pressure of heavy oil is too high in water injection and displacement, the concentration

TABLE 6: Influence of different temperatures on viscosity reduction rate and freezing point of PD-7.

Temperature (°C)	Viscosity reduction rate (%)		Freezing point (°C)	
	C = 5%	C = 10%	C = 5%	C = 10%
80	94.1	98.1	35.1	31.6
90	95.1	98.8	34.5	30.4
100	86.5	89.1	34.3	29.2
120	77.4	80.1	34.3	29.2
130	50.1	60.5	34.3	29.2

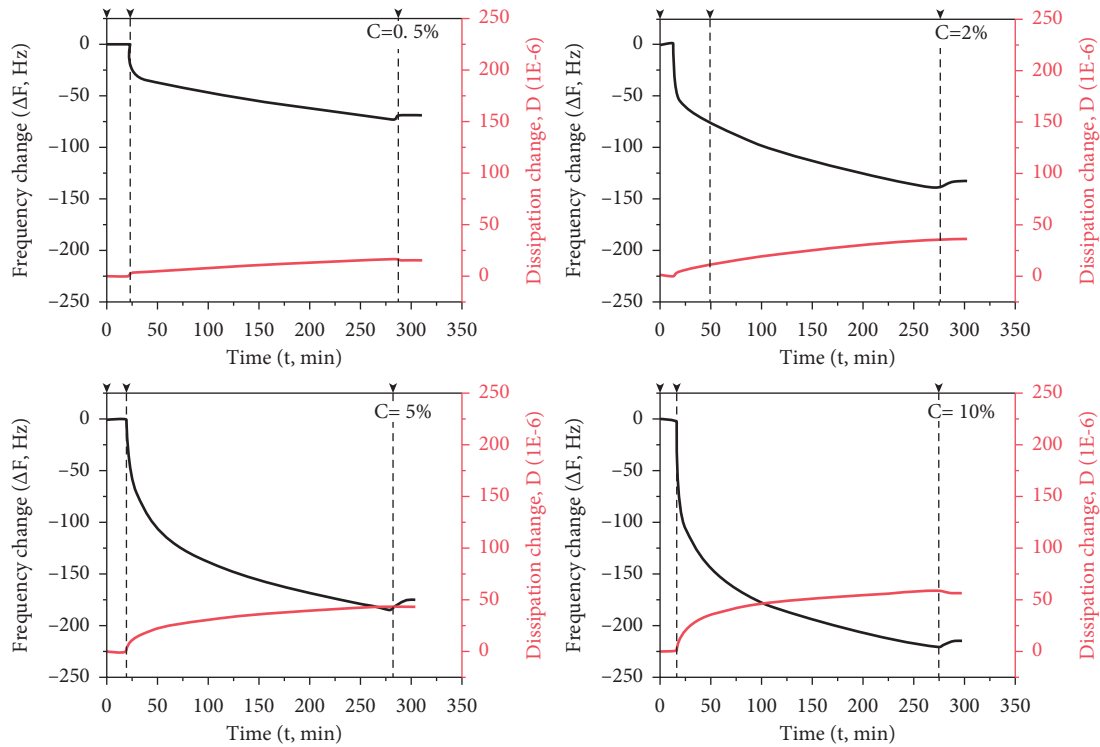


FIGURE 6: QCM-D results of different concentrations of PD-7.

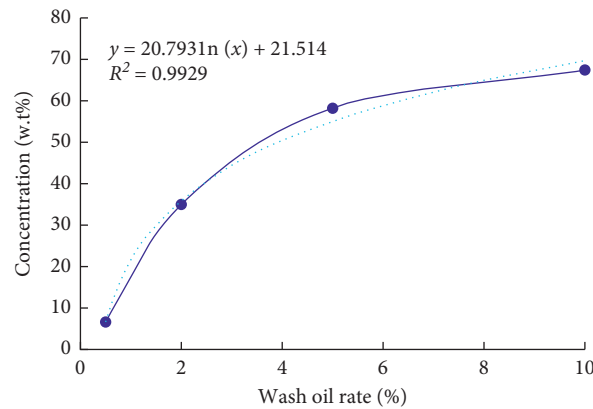


FIGURE 7: Relationship between different concentrations of PD-7 and oil washing rate.

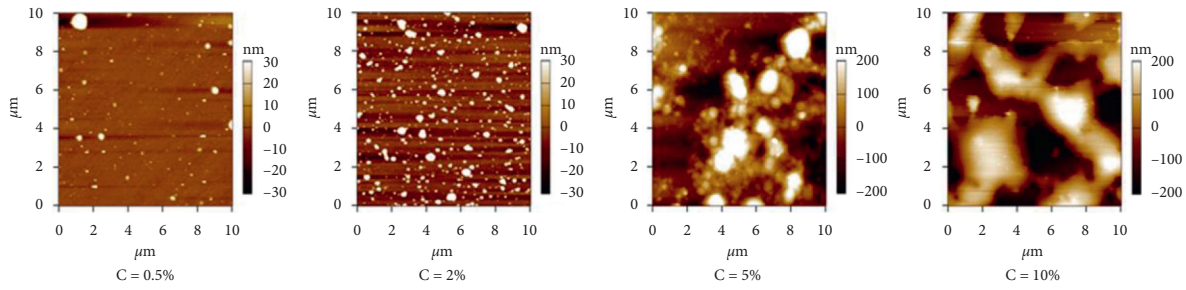


FIGURE 8: Stripping effect of heavy oil with different concentrations of PD-7.

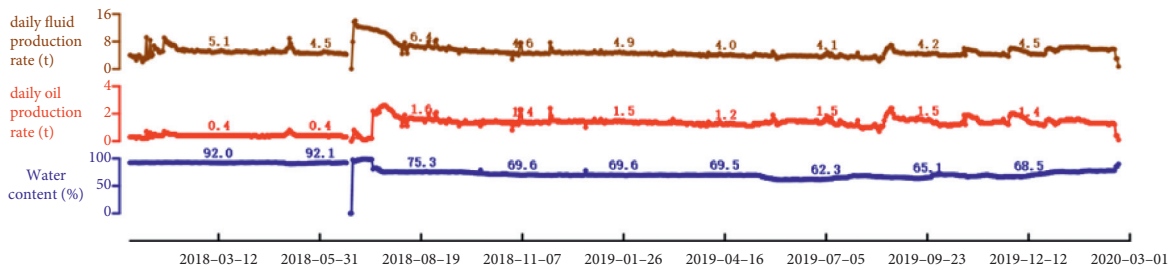


FIGURE 9: Oil production curve of well Luo 321-2.

can be increased in time to clean the oil wall area formed through the reservoir, so as to avoid the invalid injection caused by the change of injection direction.

3.3. Reservoir Test Application

3.3.1. Injection Process. Three slug concentration injection method was used: the first slug is injected with high displacement (20–40 t/h) and high concentration (8–10%) oil displacement system to reduce viscosity and pour point; remove the wax crystal, gum, and asphaltene retained on the rock surface; solve the problem of organic matter blockage near the well zone; and avoid excessive dilution of subsequent injection agent to reduce the effect. In the second slug, high displacement (20–40 t/h) is injected into the medium concentration (5–8%) displacement system to clean the reservoir, improve the oil production channel, and improve the reservoir permeability. In the third slug fluid, low displacement (10–20 t/h) is injected into low concentration (2–5%) displacement system to improve the sweep range of injection agent, enhance the mobility of heavy oil in the early high-speed injection space, and improve the liquidity of crude oil and the connectivity of reservoir energy.

3.3.2. Field Application. Luo 321-2 well is preferred for field implementation. The well is put into operation in the S4 section, with a buried depth of 1,800 meters, a reservoir depth of 50 meters, degassing viscosity of 15,853 mpa·s, and freezing point of 41.8°C. It was put into production in February 2004 with the conventional thickening method. In the initial stage, the daily liquid production was 16.8 tons; the daily oil production was 15 tons; and the water cut was 19%. However, the production decline was fast. Before the

test, the daily liquid production was 5 tons; the daily oil production was 0.3 tons; and the water cut was 92.2%. The total accumulated oil was 9,600 tons, and the accumulated water was 15,411 tons.

Implemented in June 2018, a total of 500 t oil displacement system was injected into three slugs: the first slug was filled with 100 t liquid, concentration was 8%, injection displacement was 30 t/h, plug removal and near well space release. In the second slug, 200 tons of liquid is prepared; the concentration is 5%; and the injection displacement is 30 t/h. The reservoir is cleaned, and the liquid outlet channel is improved. The third slug is 200 tons; the concentration is 3%; and the injection displacement is 30 t/h. The oil production curve of well Luo 321-2 is shown in Figure 9. After the implementation, the peak production of daily liquid is 10.7 tons; daily oil is 2.6 tons; water cut is 75.2%; stable production of daily liquid is 4.5 tons; daily oil is 1.4 tons; the effect of the measures lasts for 400 days; the cumulative oil increase is 883 tons; the purpose of dredging seepage channel, reducing pour point, and viscosity is achieved; and the continuous and stable production is realized.

From 2018 to 2020, the technology has carried out 30 field tests in Luo 321, Luo 36, Chen 371, and other blocks of Hekou Oil Production Plant of Shengli Oilfield, with a cumulative oil increase of 1,027,400 tons and an average single well oil increase of 342.5 tons. Compared with steam huff puff, the measure cost is reduced by more than 60%, and the economic benefit is remarkable.

4. Conclusion

- (1) The viscosity and freezing point of crude oil in the Luojia oilfield are closely related to the content, composition, and proportion of heavy components.

The larger the molecular weight of asphaltene, gum, and wax, the stronger the intermolecular interaction of heavy components, and the higher the viscosity and wax precipitation point, pour point, and freezing point of crude oil. The viscosity of high pour point and high viscosity oil is mainly affected by asphaltene; the wax precipitation point and pour point are mainly affected by wax; and the freezing point is affected by both of them.

- (2) The efficient oil displacement system formed by POA-VA and DBD-DOPAMA was screened. The results show that PD-7 (POA-VA 40%, DBD-DOPAMA 50%, and P-10C 10%) is the best flooding system. When the concentration is 10%, the viscosity reduction rate reaches 95.2%, and the freezing point can be reduced by 10.2°C. The indoor evaluation shows that the oil sample has excellent adaptability, salinity resistance, and temperature resistance, and the oil washing rate can reach more than 60%.
- (3) Field application was carried out in well Luo 321-2. A total of 500 tons of the oil displacement system with different concentrations were injected into three slugs. The effect of the measures lasted for 400 days, and the cumulative oil increase was 883 tons. Thirty field tests were conducted in different blocks, and the cumulative oil production increased by 10,274 tons, and the cost of measures was reduced by more than 60% compared with steam huff puff.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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