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Evaluation on Water Block in Low Permeability Formations and the Research of Water Block Control

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Abstract: Oleic permeability is severely impacted by the invasion of aqueous working fluids, especially in low porosity and low permeability reservoirs. This study mainly targeted at low permeability reservoir of Dongying Formation, Chengdao Offshore Oilfield. Water influx and its influence on oil threshold pressure were evaluated with constant-pressure injection, in which way the injuring extent of water block could be quantitatively expressed. Results indicated that, oil threshold pressure could be increased by 1.3 times merely with a water influx of 0.3 pore volumes. In addition, researches related to the system of fluid loss control had been conducted on the basis of the functional mechanism of water block. An emulsion working over fluid system had been developed by biodiesel with excellent emulsification characteristic. It can be inferred from water invasion tests that the emulsion system performed well in fluid loss control both in water phase and oil phase. The fluid loss rate could be decreased to 55.6%~86.4%. Meanwhile, mutual solvent ethylene glycol monobutyl ether (EGMBE) had been efficiently adopted in water block remediation. The threshold pressure can be reduced by 79.7% according to evaluation tests.

1. Introduction

Water block is prompted by water trapping after aqueous drilling, completion, workover or stimulation operations in low permeability reservoir [1]. The increased water saturation in the fracture or throats blocks oil and gas flow from reservoir to the well. Gas injection, hydraulic fracturing, surfactant additives and preheating the formation have proved fruitful in controlling water block [2-5]. Materials include alcohols and chemical surfactants have been used to reduce the water block fluid retention, in which way the capillary pressure will be cut down and hence a lower irreducible water saturation at a given reservoir pressure drawdown will be generated [6].

As workover fluid filtration is the leading cause responsible for water block in oil well, fluid loss control should be considered as a preferred alternative. Various additives are adopted in fluid loss control treatments, most of which fit into particulates or gels [7-9]. These materials help control fluid by bridging pore throats and providing a surface on which a filter cake can be established [10]. Even with significant effects, a throng of problems of the conventional fluid loss control additives are presented simultaneously. In normal conditions, the complete removal of wall building materials are not possible even with breakers. Anietie N. Okon [11] also reports that the over dependence on those polymers to achieve the function of drilling fluid is worrisome on the overall well drilling cost.



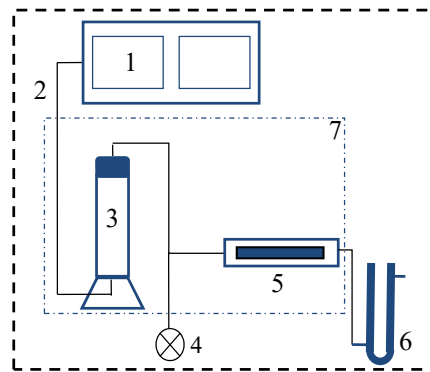
It has been shown emulsion incorporates unique advantages than conventional filtration control agents [12]. In addition to easy to be prepared, compatible with most workover fluids, and capable of withstanding fairly high differential pressures, emulsions tend to deform and invade the deeper formation, which benefits to fluid loss control to a large extent [13]. The utilization of biodiesel has made a significant progress in oil well stimulation owing to its renewability [14,15]. Given the thesis of environmental protection and the favorable emulsifiability, biodiesel recycled from abandoned vegetable oil and animal fats is optimized for emulsion preparation.

2. Materials and methods

2.1. Materials

Reagents: biodiesel (industrial grade), obtained from Mingwei Chemical Co., Ltd, China. Sodium bicarbonate (AR), magnesium chloride (AR), sodium sulfate (AR), calcium chloride (AR), potassium chloride (AR), sodium chloride (AR), ethylene glycol monobutyl ether (AR), purchased from Sinopharm Chemical Reagent Co., Ltd, China.

Apparatus: physical simulation apparatus is illustrated in **Fig.1**.



(1-plunger pump, 2-pipe line, 3-intermediate container, 4- pressure transducer, 5- core holder, 6- oil/water separator)

Fig.1 Physical radial flow apparatus

Fluids: Water samples and crude oil were obtained from Shengli Oilfield in China. The properties of the water and oil are presented in **Table 1** and **Fig.2**, respectively.

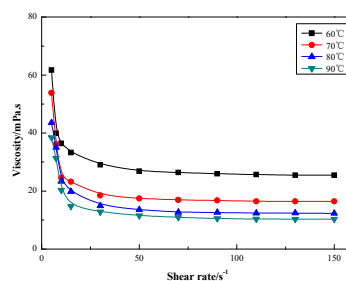


Fig.2 Viscosity-temperature curves of the crude oil

Cores: Cylindrical cores 2.51cm in diameter and 4.43cm in length were obtained from Chengdao Block, Shengli Oilfield. The permeability and pore volumes of the cores was determined at room

temperature (20°C) with formation water. The properties and mineralogical composition of the cores are listed in **Table 2**. Core samples are water-wet in their original state.

2.2. Methods

Core flooding tests were conducted in a radial flow apparatus. The mounted cores were saturated with formation water and then desaturated with dead reservoir oil to reach the restored state. Then the tested cores were flooded with injection water from the outlet end followed by reservoir oil injection from the inlet end. This was a process simulation of water block. Inlet pressures of tested cores were monitored with time. This whole procedure was conducted at a reservoir temperature of 70°C. Comparatively studies of constant-flow injection and constant-pressure injection were undertaken to evaluate the effect of water block on oil production.

Table 1 Injection water properties

Water samples	Concentration of ions /(mg.L ⁻¹)												Total salinity, mg/L ⁻¹
	Cl ⁻	OH ⁻	HCO ₃ ⁻	CO ₃ ²⁻	Ca ²⁺	Mg ²⁺	Ba ²⁺	Sr ²⁺	ΣFe	SO ₄ ²⁻	K ⁺	Na ⁺	
Formation water	242.4	0	2524.7	961.3	0.1	3.6	0	0	0	203.3	17.4	1936.8	5889.6
Injection water	4493.3	0	412.1	0	11.6	6.0	0	5.8	0.062	277.8	12.8	3029.0	7954.6

Table 2 Physical parameters of the field cores

No.	Buried depth, m ⁻¹	Permeability to water, 10 ⁻³ um ²	Pore volumes, cm ³	Mineralogical composition		
				Kaolinite	Illite	Illite/Smectite
1	3603.4	6.7	4.9	70	13	17
2	3603.4	4.7	5.2	71	15	14
3	3603.4	2.6	5.3	60	16	24

(1) The displacement was conducted at a constant flow rate of 0.1mL/min. The displacement pressure is adopted to evaluate the influence of water block.

(2) The displacement was conducted at constant pressure. The threshold pressure at which oil begins to flow is used to evaluate the water block effect.

Performance of emulsion system is investigated by constant-pressure injection as well. The restored core is treated with injection water and emulsion system, separately, and then flooded with reservoir oil. Fluid-loss control property of emulsion system was estimated by the reduction of fluid-loss velocity with unit pressure difference. The expression for fluid-loss reducing rate R of emulsion system could be given by Eq. (1), where v_1 is the fluid productivity rate of the core when flooded with injection water, v_2 is the fluid productivity rate of the core when emulsion system is injected.

$$R = \left| \frac{v_2 - v_1}{v_1} \right| \times 100\% \quad \dots\dots\dots(1)$$

3. Results and discussion

3.1. The injuring extent of water block

3.1.1. Constant-flow injection

Core No.1 is tested in this section. Displacement pressure curves during the constant-flow injection are plotted in **Fig.3**. As illustrated, the equilibrium displacement pressure barely changes before and after being invaded by a certain volume of injection water from reverse direction. However, the peak inlet pressure after water invasion is much higher than that before, which could be 1.21 times and 1.13 times of the original one respectively.

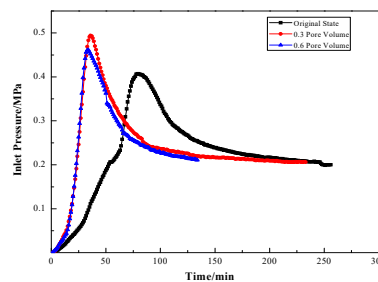


Fig.3 Inlet pressure curves

3.1.2. Constant-pressure injection

Core No.2 is tested in this section. This process is conducted with a constant pump pressure of 700kPa. As illustrated in **Fig.4**, inlet pressure is tested with different water influx. It is an obvious regularity that oil threshold pressure of the core increased greatly with different water invaded volume. A detailed description is revealed by **Fig.5**.

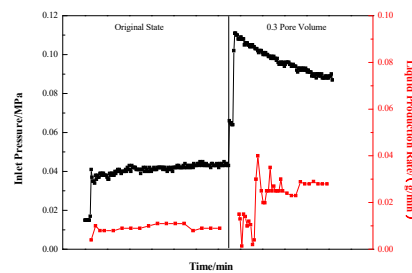


Fig.4 Inlet pressure variation and the corresponding liquid production rate.

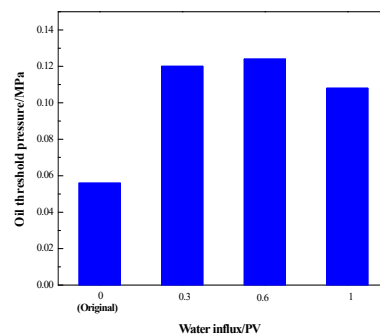


Fig.5 Oil threshold pressure variation with different water influx

3.2. Water block control

The deformability of emulsion droplets enable them to enter into deeper formation and play the role of temporary plugging during workover operation. Reservoir pore can be blocked by emulsion droplets due to the Jamin Effect, which could control the fluid leak off effectively. When production restarted, emulsion droplets will be dissolved by formation oil, accompanied with the recovery of permeability. Biodiesel recycled from abandoned vegetable oil and animal fats is optimized for emulsion preparation.

3.2.1. Composition analysis of selected biodiesel

Biodiesel is a commixture of fatty acid methyl ester, which contributes to its favorable emulsifiability. The qualitative analysis of selected biodiesel is identified through gas chromatography and mass spectrometry. The liquid solvent of 1 μ L n-hexane, containing 1% of tested biodiesel is used for GC-MS test. Composition analysis by Agilent 7890A-5975C is displayed in **Table 3**.

3.2.2. Stability of emulsion system

The adoptive emulsion is prepared by adding 1% by weight solution of selected biodiesel into the injected fluid. Setting at 70°C for a while. Size distribution of emulsion system has been observed (**Fig.6**). As can be seen, the fatty acid methyl ester emulsion system features the high stability. Further evaluation tests are carried out in the following parts.

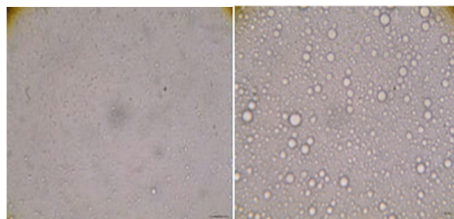


Fig.6 Drop-let size distribution of fresh emulsion and then 70°C setting for 10 day

3.2.3. Evaluation of fluid loss control property

Fluid loss control property of emulsion system could be measured by the reduction of fluid loss velocity under constant pressure difference. Experiments are conducted with a constant pump pressure of 800kPa. Core No.2 is evaluated in the following tests. According to **Fig.7**, emulsion system performs well in aqueous phase obviously. Compared with 0.28g/min in water injection, equilibrium fluid loss velocity could be dramatically reduced to 0.038g/min with emulsion system injection. Fluid loss reduction rate reaches up to 86.4%.

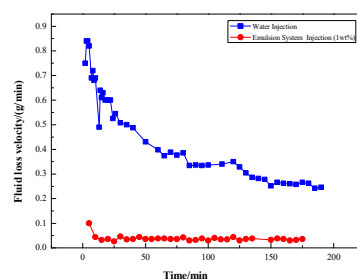


Fig. 7 Fluid loss velocity

A further study on fluid loss control property in oil phase is processed as follows. Core No.3 should be saturated with crude oil in advance. As **Fig.8** suggests, emulsion system performs well in oil phase either. Compared with 0.09g/min in water injection, equilibrium fluid loss velocity could be reduced to 0.04g/min with emulsion system injection. Fluid loss rate could be 55.6%.

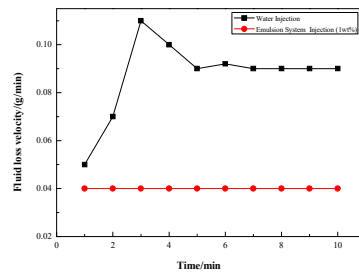


Fig. 8 Fluid loss velocity

Table 3 Potential composition of selected biodiesel

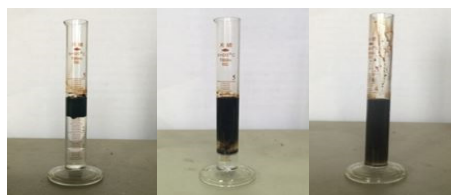
No	molecular weight	Potential Compounds
1	242.225	Methyl 12-methyl-tridecanoate
2	282.256	Ethyl 9-hexadecenoate
3	268.24	9-Hexadecenoic acid, methyl ester
4	270.256	Hexadecanoic acid, methyl ester
5	284.272	Methyl 14-methylhexadecanoate
6	294.256	9,12-Octadecadienoic acid, methyl ester
7	296.272	11-Octadecenoic acid, methyl ester
8	298.287	Methyl 16-methyl-heptadecanoate
9	294.256	7,10-Octadecadienoic acid, methyl ester
10	282.256	Cyclopropaneoctanoic acid, 2-hexyl-, methyl ester
11	326.318	Nonadecanoic acid, 10-methyl-, methyl ester

3.3. Water block remediation

In view of that the capillary force induce the elevation of oil threshold pressure, the elimination of two-phase interface should be a preference selection. Further tests reveal that oil and water phase turns to be miscible with the presence of mutual solvent ethylene glycol monobutyl ether (EGMBE), which will bring a sharp reduction on flowback resistance.

3.3.1. Mutual solubility of EGMBE

The mutual solubility is measured optically. 2mL of EGMBE, 1ml of water and 1mL of reservoir oil is smoothly added into measuring cylinder in sequence. Then set it in 70 °C water bath for a certain time. As can be seen in **Fig.9**, phase boundary vanished 6h later, which indicates the feasibility of the EGMBE in eliminating the oil and water interface.



(a) Original state; (b) 2h later; (c) 6h later

Fig. 9 Observation of mutual solubility

Ternary phase diagram is constructed to obtain the experimental conditions that contribute to the complete miscible of three mixed components. Phase behavior is illuminated by **Fig.10**. Notice that with the absence of mutual solvent, water and oil would be totally immiscible. Addition of EGMBE lead to a gradually increase in the system stability. Plait point represents the critical composition necessary to maintain miscibility. As displayed in **Fig.10**, the mixtures are inclined to be miscible when the volume ratio of EGMBE to water higher than 1:1.

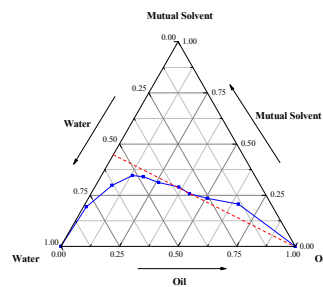


Fig. 10 Ternary phase diagram

3.3.2. Evaluation of water block remediation

The threshold pressures under three conditions are compared in **Fig.11**. It is apparently that oil threshold pressure could be raised significantly from 0.027MPa to 0.38MPa with a reverse water invasion. And then it markedly reduces to 0.077MPa after treated with EGMBE, which relieves water block damage remarkably. The threshold pressure reducing rate could be 79.7%.

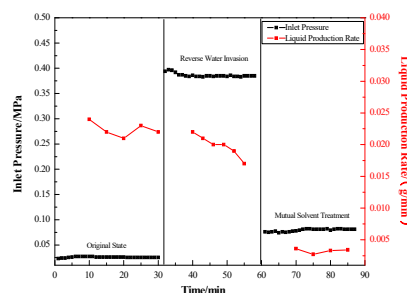


Fig. 11 Oil threshold pressure variation before and after EGMBE treatment

4. Conclusion

(1) Water influx and its influence on oil threshold pressure are evaluated with constant-pressure injection, in which way the injuring extent of water block could be quantitatively characterized. The invasion tests showed that oil threshold pressure could be increased by 1.3 times merely with a water influx of 0.3 pore volumes.

(2) Fluid loss control ability of biodiesel emulsion system turned out to be excellent. It performs well in fluid loss control in both aqueous and oil phase. The fluid loss rate could reach to 55.6%~86.4%.

(3) Mutual solvent EGMBE relieves water block damage remarkably. The threshold pressure reducing rate could be 79.7% according to evaluation tests.

Acknowledgements

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