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Study on in-depth profile control system of low-permeability reservoir in block H of Daqing oil field

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ABSTRACT

According to the geologic characteristics of low-permeability reservoir in block H of Daqing oilfield, three formulations of gel systems for in-depth profile control treatment in this block was optimized by orthogonal experiment and the profile control effect of these systems was evaluated further by core experiment. The results showed that optimal profile control system can effectively block the high permeability core and have little effect on the low permeability core when the injection volume reached 0.6 PV. The changes of water flooding stable pressure was less than 8% within 45 days when its injection volume between 0.6 PV and 0.9 PV. It had a good plugging effect, and it can enhance oil recovery by more than 11%. The profile control system exhibited excellent thermal stability between 60 °C and 80 °C. With the increase of shear times, core plugging rate of the optimized profile control system decreased by less than 1.2%, it means that the plugging performance of profile control agent was less affected in the process of in-depth profile control treatment in oilfield. The application of this profile control system in Daqing Oilfield H block has achieved remarkable results. The water cut decreased by 4.66% and the well group oil productions increased by 21% after the in-depth profile control treatment.

1. Introduction

H block of Daqing Oilfield is a medium-high temperature and low permeability reservoir. The mean temperature of central pay zone is about 70 °C. With water-flooding development passed through nearly 30 years, some steps such as a fine-hierarchical setting of injection, reforming measures, adjusting injection system and boosting pressure for water injection have been performed. Unfortunately, Heterogeneity of the reservoir bed has been aggravated and high permeability zones which exist low effective circulation have been formed under flushing with a great amount of injection water (Feng et al., 1999; You et al., 2011; Jing et al., 2004). Composite water cut has achieved over 80% so far. Some in-depth profile control agents, which combine the characters such as good plugging performance, economical, initial gelling time and gel strength controllable and so on into one, are urgently needed for stabilizing production and controlling water cut in high water production oilfield. Scholars home and abroad have done much research work in the field of in-depth profile control technology (Dai et al., 2010a, 2010b; Chen et al., 2015; Sun et al., 2014; Sydansk, 1988; Zhao et al., 2013; Chou et al., 1994; Wang et al., 2016; Zhao et al., 2015), but researches on deep profile control system for a medium-high temperature and low permeability reservoir is far from enough. In this paper, with consideration of petrophysical property of the main block in this oilfield, the gel system which is suitable for deep profile control in this block was optimized by comprehensive evaluation of static and dynamic methods on effectiveness of profile control. Moreover, the shear resistance behavior and thermal stability of this deep profile control agent were studied. So that it can be suitable for field application.

2. Experimental

2.1. Materials and conditions

Major components of gel systems: the main agent is HPAM (China National Petroleum Corporation Daqing Refining &. Chemical company, Daqing). 3 different molecular weights (respectively as 2.5×10^7 g/mol, 1.6×10^7 g/mol or 8×10^6 g/mol) of HPAM should be prepared; Cross-linker is organic chromium compound cross-linking powder (Fangyuan Chemical Company Ltd, Dongying). The active ingredient content of it is above 40% and its density is 1.07 g per cubic centimeter; Gelation

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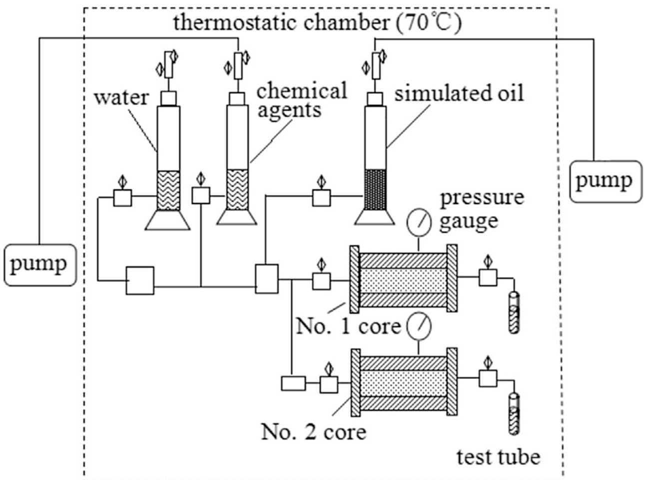

Fig. 1. Schematic diagram of Double Core Parallel Flooding Experimental Device.

additives (self-made in lab).

Experimental water: produced water from the studied oilfield (using the method of microporous filtration to remove impurities); Experimental oil: simulated oil. It blend kerosene into dehydrated crude oil of H block by a certain percentage. Its viscosity is about 2.45 mPa s under the conditions of 70 °C; Experimental Core: Artificial simulation core (Institute of Petroleum Engineering, Northeast Petroleum University). Their permeability measured with water is about 72 × 10^{-3}μm^2 or 8.2 × 10^{-3}μm^2, respectively.

The experimental temperature was 70 °C.

2.2. *Experimental apparatus*

Brookfield viscometer; Balance; Electrothermal constant-temperature dry box (Its maximum temperature is 300 °C with ±2 °C of system control accuracy); Magnetic stirrers; Double Core Parallel Flooding Experimental Device (It can be seen in Fig. 1).

2.3. *Experimentation scheme*

The molecular weight and concentration of HPAM as well as the concentration of organic chromium compound cross-linking solution and gelation additives were selected as influencing factors of the gelling experiment. Four-factor and three-level orthogonal experiments were designed (as listed in Table 1). Gel systems were prepared under the conditions of reservoir temperature and water salinity. Then taking initial viscosity, initial gelling time, gelation time, gelation viscosity and the stability of each gel system as evaluation criteria of gelling condition, three groups of deep profile control formulations (as shown in Table 2) were optimized according to the experiments designed in Table 1. Then to inject these three sets of gel systems, which were preliminarily selected before, into the core with different pore volumes respectively. After the gels were formed under the conditions of constant 70 °C, water flooding was conducted until the pressure reached a stable condition. Then to record the indicators like the breakthrough pressure, stable injection pressure and permeability and so on, and to calculate core plugging rate respectively. The value of enhance oil recovery under profile control treatments were estimated through the double core parallel flooding experiments. In addition, the shear resistance and thermal stability performance of the optimized profile control system which can meet the field requirement of H block in Daqing oilfield was evaluated.

Table 1
Experimental factors and levels design table.

Levels number	Molecular weight of HPAM (×10^4 g/mol)	HPAM concentration (mg/L)	Cross-linker concentration (mg/L)	Gelation additives concentration (mg/L)
1	2500	3000	400	16.25
2	1600	2000	600	12.5
3	800	1000	800	7.5

Table 2
The optimized Formulations Information of the Profile Control Systems in Experiment.

	No. 1 scheme	No. 2 scheme	No. 3 scheme
Molecular weight of HPAM (×10^4 g/mol)	2500	1600	800
HPAM concentration (mg/L)	3000	3000	3000
Cross-linker concentration (mg/L)	400	600	800
Gelation additives concentration (mg/L)	7.5	16.25	7.5
Initial viscosity (mPa·s)	303.8	152.2	10.8
Initial gelling viscosity (mPa·s)	4482	2926	685
Initial gelling time (h)	4	11	8
Gelation time (mPa·s)	30,987	19,519	6978
Gelation viscosity (h)	30	74	68

3. Results and discussion

3.1. *Breakthrough pressure analysis*

According to real situation of H block, artificial columnar cores with different two kinds of permeability were chosen. The next step was to take them into the core holder of the double core parallel flooding experimental device. Then to experiment under the condition of simulating the geologies of the studied block. The breakthrough pressures with different injection volume were measured, as shown in Fig. 2.

As shown in Fig. 2, with the injection rates increasing, breakthrough pressure initially increased and then became relatively flatter. To be specific, the breakthrough pressure inflexion of the profile control systems we optimized expected at 0.6 PV of injection rate under the simulated geologies of H block conditions. It increased rapidly at first, and then slowed down. The highest breakthrough pressure reached 12.19 MPa during the whole process. When the injection rate was 0.6 PV, the breakthrough pressure of No. 1 scheme and No. 2 scheme both reached 9 MPa. The breakthrough pressure of No. 3 scheme was small, but it also up to 7 MPa as the injection rate reached 0.6 PV. Accordingly, the gel systems we prepared have a certain plugging strength, which can meet the requirements of the field profile control treatment.

3.2. *Plugging rate analysis*

The plugging rate is the ratio of the changing value of water

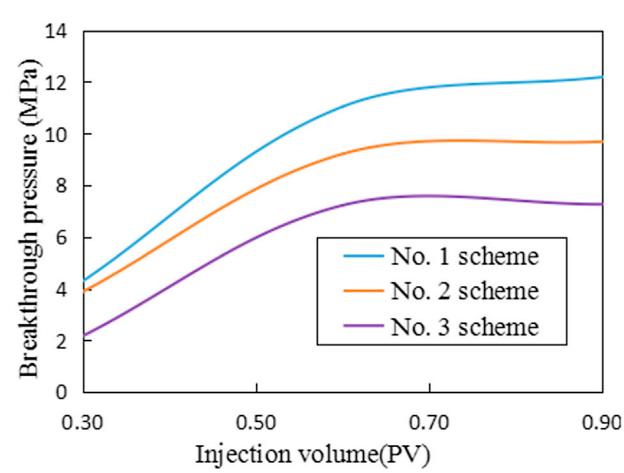

Fig. 2. Curves of relationship between breakthrough pressure and injection volume.