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Experimental investigation of factors affecting gravel pack efficiency for thermal recovery wells in Bohai Bay, China

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ABSTRACT

Sand production from unconsolidated formations is a common problem of thermal recovery wells in Bohai Bay, China. In order to select and optimize the method of sand control, statistics of the formation properties of the major sand production zones is first reported in this paper. Next, laboratory experiments are carried out to investigate the effects of several controllable production parameters on the performance of the gravel packing sand control method, which is the most widely used sand control technique in Bohai Bay. Both oil and sand production rates for different gravel packing parameters are investigated. Based on the experimental results, an empirical formula of Oil Productivity Index Per Meter (OPIPM), a parameter used to quantify the oil production rate with sand control treatments, is obtained for this area. Finally, implications of this study on sand control design and optimization of oil production rate are discussed.

1. Introduction

The existing studies on the selection and design of mechanical sand control methods mainly focus on the analyses of the sand control screens (Dees, 1992, 1993; Talaghat et al., 2009; Hugh and Ramos, 1995). Based on experimental studies, Coberly (1937), Schwartz (1969), Saucier, (1974), Tiffin et al. (1998), Gillespie et al. (2000), Abass et al. (2002), and McCarthy and Mickelburgh (2010), proposed a series of methods for the selection of mechanical sand control techniques, including slotted liner, wire wrapped liner, metal mesh screen, metal cotton screen, pre-pack screen, and gravel packing. Johnson's (Gillespie et al. 2000) methods consider both the grain size distribution and the heterogeneity of formation. Johnson's study is useful for selecting sand control methods and optimizing the precision of the screens of the corresponding methods. However, for gravel packing specifically, which is the major sand control method for heavy oil wells in Bohai Bay, the effects of several factors on the performance of this technique are still not fully understood. These factors include in-situ viscosity of the production fluid, thickness of the gravel pack, differential pressure of production, and the size of screen and gravel.

Four thermal recovery wells were tested in the Nanbu oilfield in Bohai Bay. The results show that thermal recovery treatment can remarkably improve the production of heavy oil. However, three of the four wells experienced serious sanding problems which finally caused the cease of the productions. Two of the three sanding wells did not have sanding problems during the cold production period, but significant sanding occurred after thermal stimulation. This phenomenon implies that shear failure occurs in the formation. To mitigate sand production, sand control measures must be taken during well completions. Gravel packing is the most popular sand control method in the Bohai Bay area. The influence of various factors on the performance of gravel packing method needs to be investigated for guiding sand control design for the thermal stimulation wells in this area.

This paper presents laboratory tests of gravel packing treatments with sand samples similar to the formation sands and test conditions similar to the in-situ down hole conditions. Based on the test results, several parameters' effects on gravel packing are investigated, including production parameters (e.g. differential production pressure) and sand control parameters (e.g. screen type, gravel size, sand retention precision, packing thickness gravel). Furthermore, a guideline is proposed for the design of gravel packing treatments in the unconsolidated formations in Bohai Bay. The ultimate goal of this work is to use an optimized gravel packing method to effectively mitigate sand production without compromising the productivity of the wells.

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Table 1
Characteristics of Minghuazhen heavy oil formation in the oilfields in Bohai Bay.

Oilfield	Median grain size (d50), μm	Uniformity coefficient (UC)	Total clay content, %	Clay minerals	Relative content of montmorillonite, %
Penglai 19-3	160–230	1–3	19.1–45	Illite, kaolinite	5
Nanbao 35-2	140–200	3–20	10–45	Montmorillonite, illite smectite mixed layer	60
Kenli 3-2	50–210	5–10	13.1	Montmorillonite, illite smectite mixed layer, kaolinite	58
Bozhong 29-4S	70–180	4–11	12.6	Montmorillonite, kaolinite	68.7
Bozhong 29-4	40–80	5–14	16.4	Montmorillonite, Kaolinite	55
Bozhong 34-1	85–253	3–15	10.2–20.3	Kaolinite, illite smectite mixed layer	10
Bozhong 28-2S	73–213	3–5	13.2	illite smectite mixed layer	65

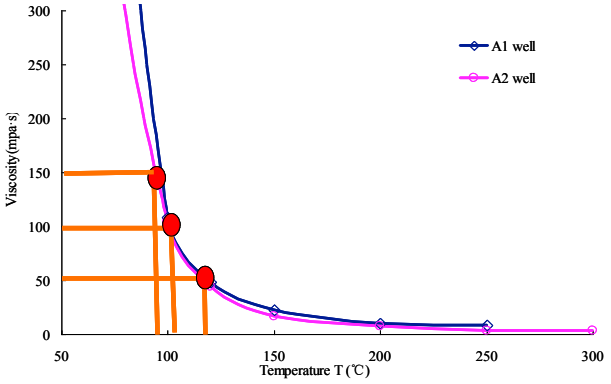

Fig. 1. Viscosity of heavy oil from Minghuazhen formation at different temperature.

Table 2
Designs of the orthogonal tests.

Test No.	Influential factors			
	Production pressure, MPa	Sizes of screen and gravel (SSG), μm	Oil viscosity, mPa s	Gravel thickness, mm
1	1	120 (20/40)	50	19
2	1	150 (16/30)	100	38
3	1	200 (10/30)	200	52
4	2	120 (20/40)	100	52
5	2	150 (16/30)	200	19
6	2	200 (10/30)	50	38
7	4	120 (20/40)	200	38
8	4	150 (16/30)	50	52
9	4	200 (10/30)	100	19

2. Characteristics of minghuazhen heavy oil formation in Bohai Bay

In this work, information from several hundreds of thermal recovery wells in Bohai Bay is investigated to characterize the sanding formations. These wells spread over several oilfields, including Qinhuangdao 33-1S oilfield, Penglai 9-1 oilfield, Nvda 16-1 oilfield, and Nanbao 35-2 oil field. The major target heavy oil formation of these oilfields is the Minghuazhen formation. The keycharacteristics of this formation are reported in Table 1.

Several main aspects of the Minghuazhen formation can be obtained from the statistical data in Table 1 as follows:

(1) The median grain size of the formation is in the range of 70–250 μm, indicating the formations are sand to fine-sand formations.
(2) The uniformity coefficient is in the range of 3–15, indicating the formations are relatively homogenous.

Fig. 2. Gravel packing combination for 52 mm gravel thickness (tests 3, 4 and 8).

Fig. 3. Gravel packing combination for 38 mm gravel thickness (tests 2, 6 and 7).

(3) The total content of clay minerals ranges between 5% and 30%, with the majority around 15%, indicating the formations are clay-rich. The main clay types are montmorillonite and illite.

3. Experiment description

As aforementioned, the major sand control method used in the oilfields in Bohai Bay is gravel packing, with only a few wells using independent quality screens. This is because the service life of independent quality screen is relatively short compared with the gravel packing. Therefore, the experimental study in this paper focuses on gravel packing.

The prerequisite of a successful gravel packing operation is a proper design of the accuracy of sand screen, the corresponding number, and the corresponding thickness of the gravel. These 3 parameters must reach appropriate match with each other to maximize the production of heavy oil reservoirs. To this end, a laboratory sand control experiment is carried