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Review

Progress in pilot testing of microbial-enhanced oil recovery in the Daqing oilfield of north China

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A B S T R A C T

Microbial-enhanced oil recovery (MEOR) is a biotechnology that utilizes biogas, biosurfactants, and biopolymers produced by, and degradation by subsurface fermentation process of microorganisms for enhancing oil production from substratum reservoir. In this report, we describe the progress made in pilot testing of MEOR in the Daqing oilfield of north China in recent decades and analyze suitable reservoir conditions and application requirements. By the end of 2012, cumulative oil increments reached 1.2×10^5 t using MEOR in the Daqing oilfield; of the oil produced, 518 wells of single-well microbial huff-and-puff yielded a cumulative incremental oil production of 6.3×10^4 t, and 10 projects with 45 well patterns adopted microbial flooding and profile modification to achieve a cumulative incremental oil production of 5.7×10^4 t. Thus, MEOR has proven to be an effective technique for routine operations in enhanced oil production in oil fields.

Contents

Introduction

Microbial-enhanced oil recovery (MEOR) is a new promising tertiary recovery process after water flooding that can be used to enhance oil extraction from subsurface strata. Research on MEOR has been carried out in some major Chinese oil fields previously (Guo, 2011; Wang, 2012a) and promising results had been observed and reported in recent years (Huang, 2011; Wang, 2012b). Preliminary studies on MEOR were initially performed in the Daqing oilfield in the mid-1960s for assessment of flooded layers to improve yield (Chen et al., 1980). Subsequently, the first field testing of single-well microbial huff-and-puff technology was carried out in the late 1980s; these data confirmed that increased oil production could be achieved by injection of microorganisms in an attempt to promote microbial subsurface fermentation and alteration of physiochemical condition in favor of oil mobility (Zhang et al., 1995).

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Additionally, later studies have shown that microbes can transform hydrocarbons from the indigenous chemical forms to fatty acids and carbohydrates, enhancing oil production and improving the test results (Sui et al., 2001). Microbial processes are responsible for biochemical transformation of oil hydrocarbons are known and have other potential in conversion of immobilized oils to smaller molecular weight molecular and methane (Mbadinga et al., 2012). Further investigations on production water from oil fields also support the view that microbial community in the production system are rich and diverse with capabilities of methanogenesis (Mbadinga et al., 2012; Wang et al., 2012a,b, 2013; Zhou et al., 2012, 2013). Within the last decade, field trials of microbial huff-and-puff and microbial flooding technologies have been performed, and the characteristics and laws of MEOR have been analyzed, improving our understanding of some key techniques and providing an experimental and theoretical basis for future large-scale field applications.

Microbial huff-and-puff

Microbial huff-and-puff technology involves injecting microbes and nutrient solutions after culturing in reactor into production wells, closing off the wells for a period of time, and then continuing to produce oil. The aim of the microbial huff-and-puff method is to facilitate the growth and reproduction of microbes in the reservoir environment, leading to degradation of paraffin and recalcitrant molecular components via microbial metabolism, fermentation, sulfate-reducing and methanogenesis. Microbial metabolic processes can produce organic acids, organic solvent molecules, and biosurfactants, which can reduce the viscosity of reservoir oil and oil–water interfacial tension, thereby increasing the solubility and also mobility of a fraction of the oil. As a result, oil production near wellbore zones can be increased and further extension of such biologically influenced area/zone can be visualized with increasing time of incubation and proper management of the production process. This technology has been widely used in China in particular and abroad, and it was recently applied to field tests in the Daqing oilfield.

Basic information about field tests

According to statistical analysis (Table 1), field tests of microbial huff-and-puff for 518 wells allowed for a cumulative incremental oil production of 6.3×10^4 t in the Daqing oilfield from 1998 to 2012, including 2.0×10^4 t of incremental oil from 140 wells in the placanticline transition zone, with an average of single-well increment of 141.2 t (Zhang et al., 1999; Hou et al., 2002; Le et al., 2005; Zhong and Ma (2007); Liu, 2008; Bai, 2012), and 3.6×10^4 t of incremental oil production from 378 wells in peripheral low-permeability oil fields, with 115.4 t of average single-well increments (Xing et al., 2000; Han et al., 2001; Li et al., 2003; Le et al., 2004; Zhao, 2005; Xiao, 2006; An, 2010). Testing wells for microbial huff-and-puff were successful in more than 70% of cases and were effective for a period of 3–20 months, with an input–output ratio higher than 1:5.

Application characteristics of microbial huff-and-puff

In comparison with bacterial population before microbial huff-and-puff, the injected bacteria were able to adapt to the subsurface environment. Assessed by enumeration, average bacteria population decreased from 3.0×10^6 cells/mL to 1.3×10^5 cells/mL after 7 days of closing off the wells. The quantities further decreased to 6.2×10^3 cells/mL after 15–30 days and 2.0×10^2 cells/mL after 60 days.

Oil properties were significantly altered before and after microbial huff-and-puff treatment. Specifically, the average viscosity of crude oil decreased by 30.6%, the setting point decreased by 3–8 °C, and the wax content decreased by 7.1%. Changes in terms of oil–water interfacial tension, organic acid content, and pH reflected the effects of subsurface microbial activity and fermentation taking place and their contribution to the changes in physiochemical properties of the oil.

Additionally, tubing pressure, pump efficiency, and submergence depth were shown to be significantly improved by microbial huff-and-puff. In the Pubei oilfield, microbial huff-and-puff was tested in 10 wells; the average tubing pressure increased from 0.35 to 0.39 MPa, the average pump efficiency increased from 33.89% to 46.96%, and the average submerge depth increased from 413.12 to 551.62 m. Hot wash cycles of test wells were extended, thereby having an energy-saving effect positively on the production system.

The successful effects of microbial huff-and-puff were also related to geological conditions and production conditions of the testing areas. The average success rate was above 70%, and the period of effectiveness in operation ranged from 2 to 20 months among 518 wells, as shown in Fig. 1. The differences in oil

Table 1
Statistics of single-well microbial huff-and-puff test wells in Daqing oilfield.

Applied blocks		Well number (well)	Incremental oil production (t)	Effective rate (%)	Validity period (mon)	Reference
Placanticline	Lamadian transition zone	4	463		4–8	Hou et al. (2002) Zhang et al. (1999)
	Sabei transition zone	12	1642		3–7	Lin and Chen (2003)
	Sanan transition zone	69	10,124	73.5	3–18	Liu (2008) Le et al. (2005)
	Sazhong transition zone	30	4500		3–10	Zhong and Ma (2007) Bai (2012)
	Xingnan ultra-low permeability reservoir	25	3032	72.0	4–12	Gai et al. (2011) Wu et al. (2008)
	Pubei fault block	67	9240.8	73.3	6–16	An (2010) Sun (2008)
Peripheral	Songfangtun low permeability reservoir	16	1479	75.0	6–20	Ding (2004) Zhao (2005)
	Low permeability + heavy oil reservoir	84	15,441.4		12	Xing et al. (2000)
	Chaoyanggou ultra-low permeability reservoir	123	13,437.4	71.7	8–12	Li et al. (2002) Ma et al. (2004)
	Toutai ultra-low permeability reservoir	88	4026.3	61.5	3–8	Han et al. (2001)
Total		518	63,385.9	70.2		