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Study on CO_2 huff-n-puff of horizontal wells in continental tight oil reservoirs

Tang Mingming [a], Zhao Hongyu [b], Ma Huifang [a], Lu Shuangfang [a,*], Chen Yuming [b]

[a] China University of Petroleum (Huangdao), No. 66 Changjiangxi Road, Qingdao, China
[b] Research Institute of Petroleum Exploration & Development of Jilin Oilfield, Jilin, China

HIGHLIGHTS

- A poro-elasticity simulation model of tight oil reservoir was developed.
- Biot's coefficient has a significant influence on oil recovery factor.
- Sensitivity analysis of the injection parameters is conducted.

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ABSTRACT

A poro-elasticity reservoir simulation model was developed to analyze the huff-n-puff operations in the Fuyu continental tight oil layer. The model was based on the "two-way" coupling of a geomechanical model and a compositional model. The pressures induced from the compositional model were set as input for the geomechanical model, and the effective stresses calculated from the geomechanical model were set as input for the compositional model. The results show that under specific assumptions, effective stress increases during the depletion and production period and decreases during the injection and soaking period, resulting in corresponding changes to the displacement and effective stress. Biot coefficient also has a significant and systematic influence on the resulting oil recovery factor of CO_2 huff-n-puff. In addition, a sensitivity analysis of the injection parameters, including injection timing, production time, and soaking time, was performed in detail. This work provides a better understanding of the mechanisms of the CO_2 huff-n-puff operations of horizontal wells in a continental tight oil sandstone formation.

1. Introduction

The Songliao Basin is a large, fault-depression superimposed basin in NE China. The Fuyu layer is one of the major tight oil reservoirs of the Songliao Basin [1]. Many authors have investigated the geological features and oil-gas reservoirs of the Songliao Basin [2,3], particularly in the southern area, which is predominantly a continental sediment environment ranging from pro-delta facies to delta-front facies [4–7]. Unconventional continental tight oil sandstone reservoirs of the Fuyu layer in the south Songliao Basin have been developed via multi-stage hydraulic fracturing and horizontal wells drilling (Fig. 1). Fifty-one horizontal wells have been drilled, and hydraulic fracturing has also been carried out at these horizontal wells.

However, owing to the low oil recovery factor of natural depletion, a more efficient form of development method is required. Many enhanced oil recovery (EOR) methods such as water flooding and gas injection have been studied in conventional reservoir. However, because the ultra-low permeability, most EOR methods are not suitable for a tight reservoir. Water flooding and gas flooding are widely used EOR methods in conventional oil reservoirs, however, many studies have shown that it is difficult to apply these methods to a tight reservoir because of low injectivity and poor sweep efficiency with hydraulic fracture networks [10]. Two field tests have been conducted in the Fuyu layer to test water flooding and CO_2 flooding. Fig. 2(a1) and (a2) shows the CO_2-flooding field test in the Fuyu layer. Owing to the low sweep efficiency of gas flooding, there are not changes in the gas components mole fraction from some nearby wells. Fig. 2(b1) and (b2) shows the water flooding field test in the Fuyu layer. The test results indicate that water flooding exhibits poor performance owing to the early breakthrough of some nearby wells. CO_2

* Corresponding author.
E-mail addresses: tangmingming@upc.edu.cn (M. Tang), lushuangfang@upc.edu.cn (S. Lu).

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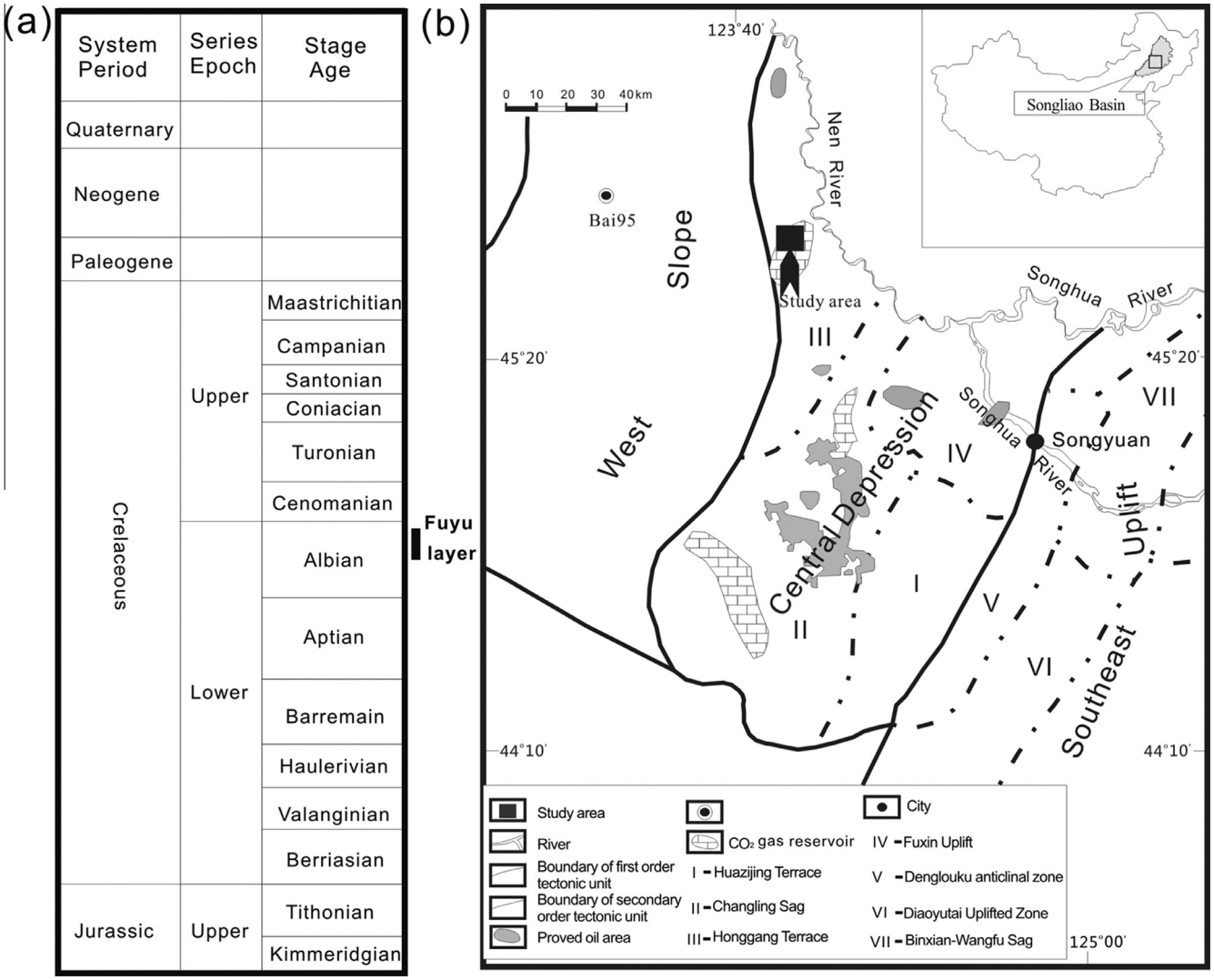

Fig. 1. (a) Stratigraphic column of the Songliao Basin [8] and (b) main CO_2 gas reservoir south of the Songliao basin [7,9].

huff-n-puff is generally considered as a single well EOR operation. Many experiments and simulation demonstrated that CO_2 huff-n-puff is an effective method to increase the oil recovery of Bakken formation [10–13], and it is considered as an efficient EOR method in a tight oil reservoir.

Despite CO_2 huff-n-puff being a well understood mechanism in conventional reservoirs, it is still a new subject in studies on continental tight oil reservoirs such as the Fuyu layer [10]. The Bakken formation is one of the most well-studied tight oil reservoir. Ma et al. [11] investigated the performance of the CO_2 huff-n-puff process in a low pressure tight reservoir by using a 973 mm-long composite tight sandstone core; they suggested that CO_2 huff-n-puff is a viable technique to enhance oil recovery in low-pressure tight reservoirs. Yu et al. [10] have also done many simulation studies on Bakken formation. However there are four major differences between the Bakken formation and the Fuyu layer. (1) The relative permeability of the Fuyu continental formation is different from that of the Bakken marine formation (Fig. 3(a)). The irreducible water saturation and irreducible oil saturation of Fuyu layer is larger than that of Bakken formation, which lead to the movable liquid saturation of Fuyu layer is smaller than that of Bakken formation. (2) The average oil production rate of Bakken is five times higher than that of the Fuyu layer (Fig. 3(b)) [14]. (3) There are abundant CO_2 gas sources in the Jilin oil flied, and the CO_2 gas content is as high as 87%. The nearby Changling sag is the most abundant CO_2 gas source in south of the Songliao Basin (Fig. 1). The Changling sag has gas source of 5.8×10^{11} m^3 (Fig. 1). The inorganic CO_2 content of the Changling sag is up to 98% [15]. (4) The average formation pressure of Fuyu layer is 21 MPa, which is lower than the average formation pressure 55.2 MPa of Bakken formation [11–13]. Rivera et al. [12] studied the cycle profit of CO_2 huff-n-puff, and found that economic considerations, such as the balance of incremental oil recovery and cost of CO_2, play a vital role in determining the optimum number of cycles and other injection strategy. Based on the simulation results, he conclude that only the first Huff-and-Puff cycle is profitable. However, the expenses on CO_2 is greatly cut down [16], owing to the abundant CO_2 gas sources in Jilin oil field, and we can focus on increasing the oil recovery during designing huff-n-puff plans. The permeability, relative permeability and formation pressure of the Fuyu layer are different from that of Bakken formation. Which will influence the oil recovery of CO_2 huff-n-puff [10–12]. We therefor forecast that applying the CO_2 huff-n-puff process in the Fuyu layer will produce different results.

Furthermore, according the poro-elastic theory [17–19], the pore pressure changes is likely to cause changes of effective stress and deformation of the reservoir, and Biot coefficient is the key parameter coupling pore pressure and effective stress [19].