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Case studies on the CO_2 storage and EOR in heterogeneous, highly water-saturated, and extra-low permeability Chinese reservoirs

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ABSTRACT

The CO_2 storage and CO_2 enhanced oil recovery (EOR) in reservoirs often face challenges due to a high heterogeneity, high levels of water saturation, or low permeability. Based on the evaluation method of the CO_2 storage capacity and EOR, three typical reservoirs representing these challenges are introduced to study their effect on the CO_2 EOR potentials and CO_2 storage capacities. The properties of these reservoirs were analyzed in detail, and geological models were built. The reservoir simulation method is adopted to analyze and validate the CO_2 injection process and the storage effect for different types of reservoirs. From the examples in this paper, the low permeability reservoirs appear to have a higher EOR potential and CO_2 storage capacity than highly heterogeneous reservoirs. These results support the premise of injecting CO_2 into reservoirs to decrease atmospheric greenhouse gas emissions while enhancing oil recovery.

1. Introduction

CO_2 flooding technology was introduced in the 1930s, and a large number of experiments and field tests were performed in the 1950s (Gao and Yingfu, 2009). Thomas (1998) proposed a CO_2 flooding reservoir screening criteria that considered the phase behavior characteristics, interfacial tension, flow influence, pore size distribution, wettability, and relative density of the reservoir (Thomas, 1998). Sehbi et al. (2001) suggested that a low injection rate, a longer in-reservoir CO_2 retention time, and good pore structure can improve the micro-displacement efficiency (Sehbi et al., 2001). Shaw and Bachu (2002) developed a program to determine the applicability of different reservoirs by CO_2-flooding and established the evaluation criteria for CO_2 EOR potential and CO_2 storage capacity (Shaw and Bachu, 2002). In 2006, Chakravarthy et al. (2006) experimentally injected a polymer into the core of block fractures and improved the CO_2 sweep efficiency (Chakravarthy et al., 2006). Chen (2009) experimentally studied the CO_2 miscible displacement process and showed that CO_2 can enter the micropores and be stored there safely (Chen and Jishun, 2009). Wu and Shang (2012) derived a CO_2 storage capacity calculation model for CO_2 miscible flooding and showed that the storage capacity increased with an increasing cumulative gas injection and an increasing slug length (Wu and Shang, 2012). A number of experimental and theoretical studies suggest that the storing of CO_2 in subsurface reservoirs is an important way to decrease atmospheric greenhouse gas emissions (Carbon Sequestration Leadership Forum, 2007; Zhao and Liao, 2012). However, the geological characteristics of real reservoirs are complex. Challenges such as CO_2-flooding in reservoirs arise from the complexities in reservoirs with high levels of heterogeneity, high levels of water saturation, or low permeability. Three typical reservoirs that represent these types of complexities are selected to study their respective CO_2 EOR potentials and CO_2 storage capacities. The reservoir simulation method is adopted to analyze the injection process for CO_2 and its effects. The Eclipse software was chosen to implement the reservoir simulation in this study.

2. Evaluating CO_2 storage mechanisms and storage capacity

2.1. CO_2 storage mechanism in reservoirs

The mechanisms for CO_2 storage in reservoirs can be divided into physical and chemical mechanisms (Zhao and Liao, 2012).

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Physical storage or displacement of oil includes structural, stratigraphic and residual trapping processes that occur when CO_2 is being injected. When injecting CO_2 into an underground formation, CO_2 will migrate upwards because of its buoyancy. However, a layer of impermeable rock can prevent it from escaping allowing CO_2 to be stored safely for millions of years (Hu, 2008). Chemical storage mechanisms include solubility and mineral trapping. The first of these involves CO_2 dissolving into formation water (storage by dissolution). Mineral trapping involves the weak carbonic acid that dissolution forms reacting with other reservoir minerals to form solid carbonates. However, mineral trapping is known to only occur over very long periods (Goodman et al., 2011; Grigg, 2002).

2.2. CO_2 storage capacity evaluation methods in reservoirs

Based on previous work by the U.S. DOE, a new method for evaluating the effective storage capacity (Eq. (1)) was introduced by Zhao and Liao (2012)

$$M_{CO_2e} = \rho_{CO_2r} \times A \times h \times \phi \times (1 - Sw) \times S_{CO^2} \tag{1}$$

$$S_{CO^2} = C_e \times \Big[\Big((1 - S_w) \times R_f + S_w \times R_w\Big) + E_f \times S_{pw} \times (1 - R_w) \times m_{CO2in\ water} + E_f \times (1 - S_{pw}) \times (1 - R_w) \times m_{CO2in\ oil}\Big]$$

where A is the reservoir area; h is the reservoir thickness; ϕ is porosity; S_w is the initial water saturation; $\rho_{CO2}r$ is the CO_2 density

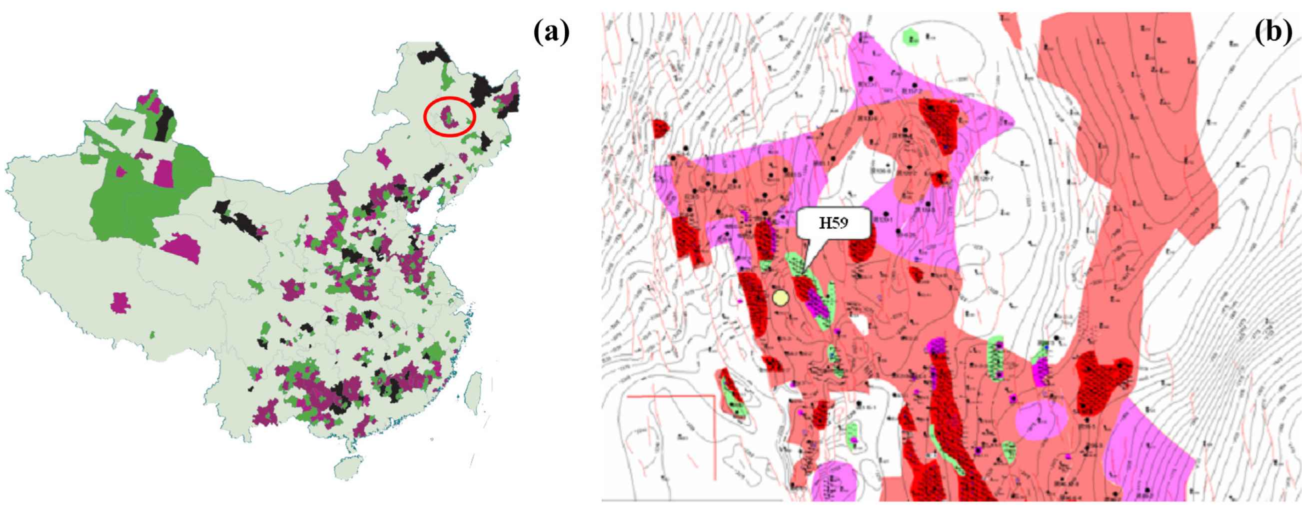

Fig. 1. Location of (a) the Jilin oilfield and (b) the H59 Block.

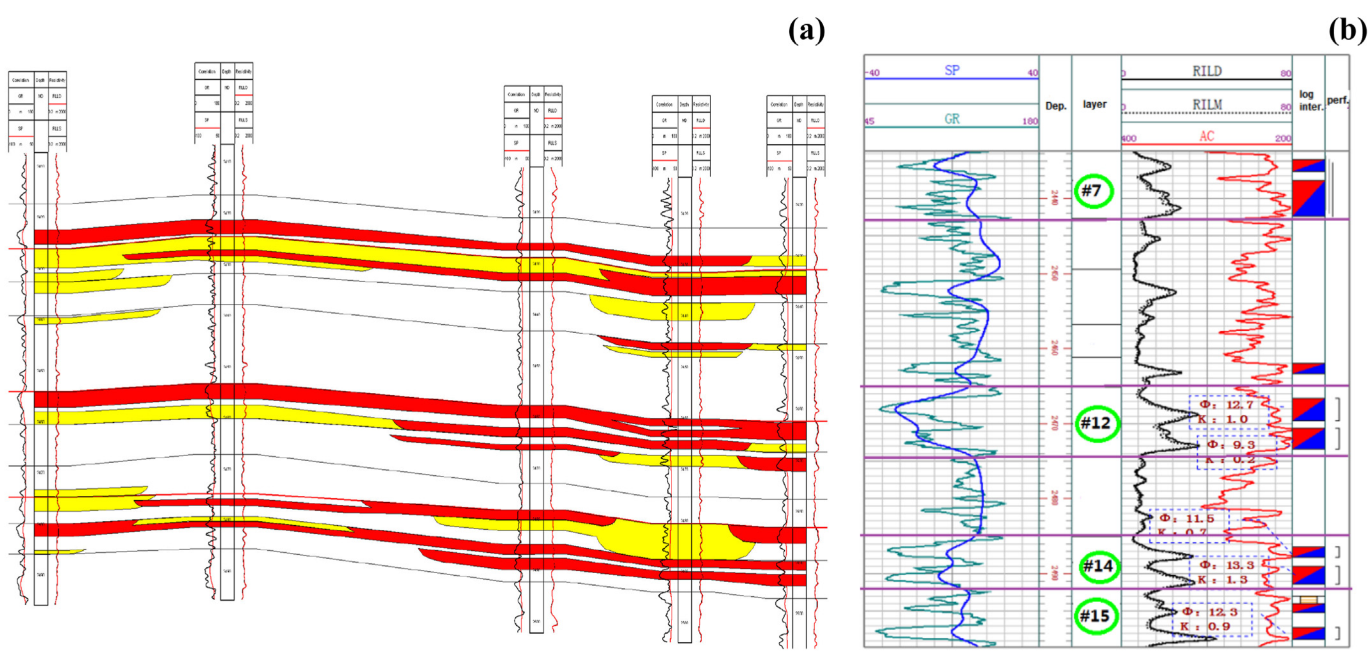

Fig. 2. Strata information of the H59 Block. (a) Illustration of a vertical well section; (b) Well log information of the target layers.