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Journal of Petroleum Science and Engineering 55 (2007) 74–82
JOURNAL OF PETROLEUM SCIENCE & ENGINEERING
www.elsevier.com/locate/petrol

Laboratory investigation of thermally-assisted gas–oil gravity drainage for secondary and tertiary oil recovery in fractured models

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Received 18 April 2005; accepted 18 April 2006

Abstract

Heavy oil in Middle East fractured carbonate reservoirs account for 25–30% of the total oil in place in the region. Production of heavy oil from such reservoirs is thought to play an important role in the future of the ever-growing world's energy consumption. Besides, having very active water drives, some of these reservoirs are already depleted resulted in high residual oil in place. To enhance the oil recovery efficiency, the mechanism of thermally-assisted gas–oil gravity drainage for secondary and tertiary oil recovery was investigated on a fractured laboratory model. Very high recovery efficiencies were achieved due to oil viscosity reduction as well as gravity stability of the gas–oil contact in both oil-wet and water-wet fractured porous media. It was also noted that a combination of waterflooding and thermal recovery is very effective to enhance heavy oil recovery from fractured water-wet and oil-wet models.

Keywords: GOGD; Fractured reservoirs; Gas injection; Thermal enhanced oil recovery

1. Introduction

Heavy oil represents abundant potential of the world's oil reserves, the Middle East included. High oil viscosity, which leads to poor mobility and relatively low recovery efficiency, is by far the major hurdle facing production. High oil prices and concerns about future oil supply are leading to a renewed interest in heavy oil recovery using thermal enhanced oil recovery methods by utilizing heavy oil viscosity reduction. In fact, at a relatively high temperature of 200 °C, the viscosity of most heavy oils reduces to as low as 1 cP and that of semi-solid bitumen comes down to 10 cP (Farouq Ali, 2003).

1.1. Gas–Oil Gravity Drainage (GOGD)

For many years, it has been known that injection of either water or gas into a petroleum reservoir can improve its production (Bradley, 1992). However, the existence of natural fractures in heavy oil reservoirs has significant effects on the oil recovery and production efficiencies. For a water-wet matrix, supplying enough amount of water would help the oil recovery from naturally fractured reservoirs governed by capillary imbibition (Babadagli,

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0920-4105/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.petrol.2006.04.013

2003a). Unfavorable conditions such as high oil viscosity, oil-wet matrix, large matrix size, unfavorable boundary conditions, low permeability, and high interfacial tension (IFT) require additional efforts to enhance oil recovery. Besides, gas injection is increasingly applied as a secondary/tertiary oil recovery scheme, especially for fractured carbonate reservoirs, as gravity drainage enhances oil production in oil-wet matrix (Saidi, 1996). The main purpose of gas injection into naturally fractured reservoirs (NFR) is the recovery of substantial quantities of oil trapped in the matrix by maximizing the effect of gravitational forces due to density difference between oil and gas within the matrix/fracture network. It has been also stated that gas injection hinders the movement of oil–water contact (OWC) upward especially in reservoirs with strong aquifers (Kuo and Eliot, 2001), or even forcing it downwards leading to additional oil drainage from the gas invaded zone (Ayatollahi et al., 2005a). Besides, in NFR, the existence of gas cap would help it drain more oil with the assistance of gravitational forces. The GOGD process yields slower recovery rates leading to higher ultimate recovery compared to other possible mechanisms and should be enhanced thermally, especially for heavy oil (Maccauly et al., 1995; Al-Shizawi et al., 1997).

1.2. Thermally-assisted gas–oil gravity drainage

It has been stated that significant heavy oil reserves are found in carbonate formations (Issever and Topkaya, 1998) and that the use of thermal gravity drainage process is being considered recently to improve the oil recovery efficiency from such reservoirs (Briggs et al., 1988; Reis, 1992). The combined effect of steam assisted gravity drainage (SAGD) and cold production (CP) to heavy oil unconsolidated sandstones reservoir have the advantages of reasonable early oil production rates, continued long-term production, and excellent long-term oil recovery (Dusseault et al., 1998). Field scale thermal applications were also reported (Sahuquet and Ferrier, 1982; Maccauly et al., 1995). And it was also indicated that the use of the thermal gravity drainage process may lead to more oil recovery from naturally fractured carbonate reservoirs (Al-Hadhrami and Blunt, 2001).

1.3. Tertiary gravity drainage

It has been reported that significant quantities of oil remain in fractured, carbonate oil reservoirs after water-flooding as a result of the oil/water contact moving upward before completely sweeping the matrix. Oil-wetness is another cause of oil trapping in fractured, oil-wet formations. It has been postulated that if the formation is preferentially oil-wet, the matrix will retain oil by capillarity. For example the oil recovery efficiency for the Omani oil field of Qarn Alam, with a naturally-fractured Shuaiba carbonate formation and 213 million cubic meters of heavy crude (16°API and 220 cP) reserve, was less than 2% under primary water drive depletion (Al-Hadhrami and Blunt, 2001). Different techniques have been investigated in the past to improve oil recovery efficiency from such depleted reservoirs. It has been reported from laboratory experiments (Chatzis et al., 1988; Naylor and Frorup, 1989; Dullien et al., 1991; Oren and Pinchewiski, 1992; Ayatollahi et al., 2005a) and field performance analysis (King and Stile, 1970; Carlson, 1988; Eikmans and Hitchings, 1999) that remarkable amounts of residual oil have been recovered by tertiary gas–oil gravity drainage process. Besides, high oil recovery efficiency, during tertiary GOGD process from water-wet media when oil has a positive spreading coefficient, stems from the fact that a continuous oil film establishes as the oil spreads on the water surface in the presence of gas (Chatzis and Ayatollahi, 1993). In addition, Bonin et al. (2002) presented the performance of a full-field tertiary gas injection of a carbonate field in the border between UAE and Iran, reporting significant oil recovery efficiency.

The application of thermally-assisted gravity drainage process on water-wet and oil-wet fractured media for secondary and tertiary oil recovery was rarely mentioned in the literature. For that matter, it was deemed necessary to investigate the capability of thermally-assisted gravity-stable gas injection scheme in a fractured laboratory model. The experiments were performed on water-wet and oil-wet sands utilizing both secondary and tertiary drainage processes.

2. Experimental work

2.1. Experimental setup

The experimental setup, shown in Fig. 1, was used to simulate vertical gravity drainage process from a matrix block in fractured laboratory models. The main part of the experimental setup is a vertically-mounted core holder with a thermal jacket that maintains a constant temperature in the core. The core holder is equipped with several pressure and temperature gauges to monitor the important parameters associated with oil recovery from the cores. A 70-cm long, 6.5-cm in diameter sand pack was centred in the middle of a core holder with an internal diameter of 7.36 cm; 0.86 cm larger than the sand pack. The annular space of 0.43 cm from both sides of the sand pack simulated vertical fracture in the