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Experimental study and numerical simulation of a solvent-assisted start-up for SAGD wells in heavy oil reservoirs

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A B S T R A C T

Effective communication in the well pair during the preheating period has a significant effect on the success of the production period by using steam-assisted gravity drainage (SAGD) technology in heavy oil reservoirs. However, the time-consumption and the economic cost associated with steam generation and circulation limit the application of this technique. Because of these limitations and concerns, we have investigated the effectiveness of the solvent injection-assisted start-up period. A sand-pack physical experiment was designed to evaluate the effect of solvent on heavy oil-viscosity reduction. Different solvents were tested to examine the effects on viscosity reduction and asphaltene precipitation. Xylene was selected as asphaltene-soluble solvent for this experiment. The solvent was injected at different injection rates and diffused into the bitumen during the soaking period. Furthermore, a numerical model was constructed to simulate the performance of the preheating and early production period with or without solvent injection in the start-up process. The observations and simulation results indicate that the injected solvent diffuses to improve the sweep area to further reduce oil viscosity significantly in the soaking time. However, too long soaking time results in lower concentrations of solvent has the opposite effect on oil-viscosity reduction. The relative permeability of the oil phase increases as well. Whereas, according to numerical simulation, the solvent-assisted start-up process of SAGD shortens preheating time and reduces steam consumption. Both the production rate and the cumulative oil production improve during the early production period.

1. Introduction

As the reserve and production of conventional oil decrease gradually, the oil industry has turned its attention to heavy oil and bitumen reservoirs with high initial viscosity. To enhance the mobility of oil by the strong temperature sensitive of viscosity, the steam-assisted gravity drainage (SAGD) technique is one of the major EOR (enhanced-oil recovery) processes applied to heavy oil reservoirs (Butler and Stephens, 1981; Butler, 1994). In general, before the SAGD production process, it is necessary to preheat the formation by steam circulation and to establish effective thermal hydraulic connectivity between the two horizontal wells to provide drainage channels for the production phase (Gates and Leskiw, 2010; Zhu et al., 2012). However, the warm-up time is too long, which usually lasts for more than 6 months. Whereas, this process requires huge amounts of water for steam generation and circulation, resulting in high energy consumption and CO_2 emissions (Mohsenzadeh et al., 2014; Ji et al., 2015). The cost of the start-up process by conventional steam cycle is an expensive and economically unfeasible application, particularly in the highly fractured oilfield (Souraki, et al., 2013; Kazeem, 2014; Mohammed and Babadagli, 2014; Zendehboudi et al., 2014).

Improving the efficiency and economy of the start-up process has become the focus of this research. A simple, economic method is needed to quickly warm up the formation and establish well communication so that the start-up period can be turned to the production process. To solve these problems, much research has involved variations in the operating methodology (Kaiser and Taubner, 2015; Saks et al., 2015). Parmar et al. (2009) presented a sensitivity analysis about the effects of circulation time, steam circulation rates, and pressure differences on start-up time. A similar SAGD project was conducted in East Senlac with a steam soak in the start-up process, indicating that a soak mechanism is an effective method for enhancing thermal communication between the well pairs (Boyle et al., 2003). Anderson presents a bullheading technique to decrease start-up time by leaving the injected steam deep into the formation for heat transfer (Anderson and Kennedy, 2012). However, the method likely forms a flow channel

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Nomenclature

SAGD	Steam Assisted Gravity Drainage
ES-SAGD	Expanding-Solvent Steam Assisted Gravity Drainage
EOR	Enhanced oil recovery
RF	Recovery Factor
CSOR	Cumulative Steam-to-Oil Ratio
CMG	Computer Modeling Group
EOS	Equation of State
T	Temperature, °C
f	Fraction
μ_o	Oil viscosity, mPa s
μ_s	Solvent viscosity, mPa s
S_w	Water saturation
k_{rw}	Relative permeability of water phase in Oil–water
k_{row}	Relative permeability of oil phase in Oil–water
S_l	Liquid saturation
k_{rg}	Relative permeability of gas phase in gas-liquid
k_{rog}	Relative permeability of liquid phase in gas-liquid

for the steam and is more applicable for a thicker reservoir. These studies about start-up process were all considered as possibilities for changing the well designs or working operations. However the costs of steam consumption and heat loss were still expensive.

Many attempts have been tested to investigate the efficiency of chemical solvent injection to enhance the recovery factor (RF) in both the laboratory and the oilfield pilot (Mohammadzadeh et al., 2012; Jha et al., 2013; Zhao et al., 2013; Bayat et al., 2015). To take the advantage of the mass transfer by a solvent with a light hydrocarbon component, Nasr et al. (2003) proposed solvent-assisted steam gravity drainage (ES-SAGD), hydrocarbons (alkanes, aromatic hydrocarbons) mixed with steam injected into the reservoir to reduce the amount of injected steam and the steam consumption and to improve oil recovery. As a result, experimental research and industrial operations showed significant increases in oil production compared to the SAGD process (Souraki, et al., 2013; Al-Murayri et al., 2016). The mass transfer and diffusion of solvent is the crucial mechanism. Therefore, the solvent intended to reduce oil viscosity can also be used during the start-up process. However, the amount of experimental research focusing on the start-up period remains limited. In past experimental studies, propane was known as an adaptive solvent to reduce the viscosity of heavy oil (Leyva-Gomez and Babadagli, 2013; Voskovab et al., 2016). However, its solubility depended strongly on temperature and pressure and caused strong asphaltene precipitation. Zhang et al. (2012) tested the effects of different solvents (ligarine, diesel, and toluene) on heavy oil-viscosity reduction. They recommended that ligarine and toluene for the start-up process. Ahmadloo and Yang (2014) conducted a method by injecting xylene into a reservoir after 70 days of pre-heating. The results showed a shorter preheating time and better communication. However, solvent injected into a larger heated formation would be diluted and would impair utilization. Diesel was selected as the solvent to inject into the formation (Wu et al., 2015). However, considering the economic benefit, the cost of diesel was expensive, and the asphaltene precipitation consisted of diesel and bitumen. Thus, the precipitation would fill the pore space and prevent the liquid from flowing.

In this study, a sand-pack physical experimental apparatus was designed to investigate the mechanisms of the solvent-assisted start-up process of SAGD. The main objective was to examine and evaluate the effectiveness of xylene solvent on oil-viscosity reduction and the mechanism of solvent soak. Moreover, the start-up period was simulated by a homogeneous model of 46 × 40 × 57 grids of a heavy oil reservoir in Xinjiang Oilfield, China. Through this innovative technique, solvent is injected initially into the cold reservoir to reduce the viscosity of oil near the wellbore, making it easier for the steam injection that follows. Simulation included preheating and early production with and without solvent injection, which showed

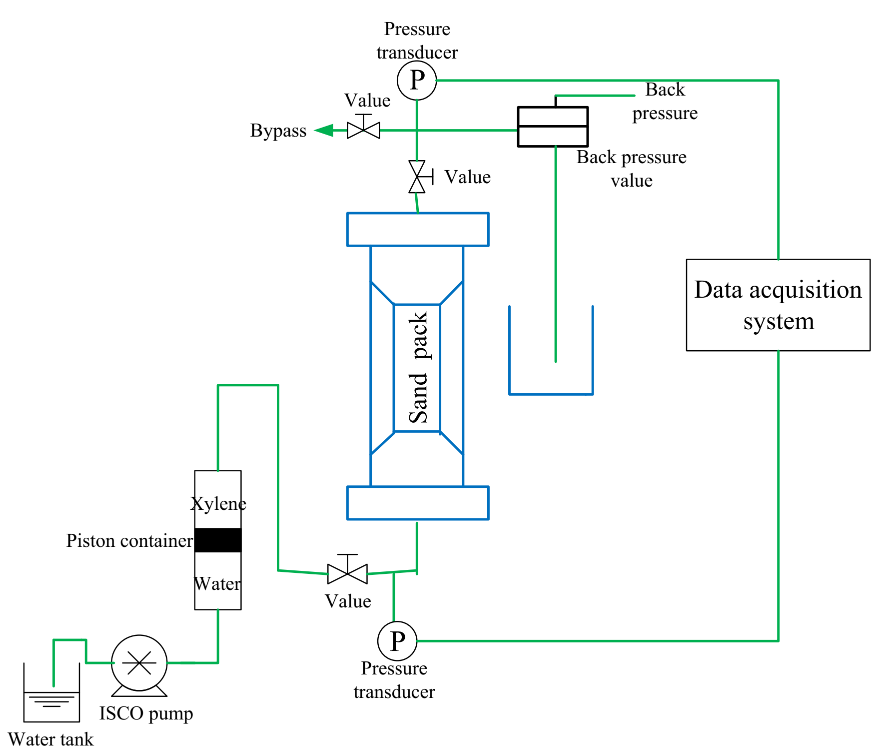

Fig. 1. Experimental apparatus for solvent injection and soak.