INTERNATIONAL JOURNAL OF
NUMERICAL ANALYSIS AND MODELING, *SERIES B*
Volume 5, Number 1-2, Pages 31–45

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Computing and Information

# EXPERIMENTAL AND SIMULATION STUDIES ON STEAM STIMULATION WITH MULTIPLE FLUIDS FOR OFFSHORE HEAVY OIL RESERVOIRS

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**Abstract.** Steam flooding and stimulation processes have proven to be the most promising method for the commercial in situ recovery of heavy oil. For high quality and thick oil reservoirs, these processes can achieve an oil recovery factor of over 30% OOIP. However, for thin, deep and offshore oil reservoirs, they are uneconomic due to the excessive heat loss to the overburden and great heat requirement to heat the reservoir rock. A new process, Steam and Multiple Fluids (SMF), is being developed to improve the efficiency of the steam stimulation process for offshore heavy oil reservoirs. It involves a combination of steam and non-condensable gases. The injected gases accumulate in the region away from the well and lower the temperature. Only the regions temperature near the well is close to the temperature of steam. The heat loss to the overburden and the heat requirement to heat the reservoir rock can be significantly reduced due to a lower temperature requirement. Considerable saving can be achieved from the reduction in the quantity of steam required for the process. This process is studied by using laboratory experiments and numerical simulations via a 3D thermal model for an offshore heavy oilfield. The results show that, compared to the cold production and standard steam stimulation processes, the oil recovery factor from the SMF is the highest. The application of this process makes the production of offshore heavy oil economic and should extend the range of reservoirs that can be produced economically. A pilot test for calibrating this new process is also reported.

**Key words.** offshore heavy oil, steam stimulation, multiple fluids, SMF, oil recovery, laboratory experiments, numerical simulation, pilot test

## 1. Introduction

Abundant heavy oil and bitumen exist in the globe. More than ten trillion barrels of oils in place are attributed to the heaviest hydrocarbons - triple the combined world reserves of conventional oil and gas [2, 5]. These vast heavy oil and bitumen resources are produced primarily using cold production and enhanced recovery methods. The cold production involves two key recovery mechanisms: foamy oil and wormhole network [7, 11, 12], while the enhanced recovery methods involve steam-based processes (steam flooding and stimulation) and solvent-related processes (solvent flooding and stimulation) [1, 8, 4]. Among them, the steam flooding and stimulation processes have proven to be the most promising method for the potential commercial in situ recovery of heavy oil. For high quality and thick oil reservoirs, these processes can achieve an oil recovery factor of over 30% OOIP (original oil in place). However, for thin, deep and offshore oil reservoirs, they are uneconomic due to the excessive heat loss to the overburden and great heat requirement to heat the reservoir rock.

The offshore oil in the Bohai Bay in China contains very rich heavy oil; the heavy portion is more than 70% of its total proven reserves. Under cold production, its recovery factor is very low. In particular, for those parts with a depth of 900-1,000 m and viscosity of 350-1,000 mPa.s, their recovery factor is even worse. For

Received by the editors January 15, 2014 and, in revised form, March 10, 2014.

2000 *Mathematics Subject Classification.* 65Y05, 65N30, 76D05.

Table 1: Production data for the south block of NB35-2 oilfield

| Total oil wells | Producing wells | Monthly production $10^4$ $m^3$ | Daily rate $m^3/d$ | GOR (gas-oil ratio) | Water cut % | Production rate % | Current recovery factor % |
|---|---|---|---|---|---|---|---|
| 25 | 17 | 0.79 | 308 | 2 | 56 | 0.3 | 1.2 |

example, the NB35-2 oilfield in the Bohai Bay that was started in October 2005 has a recovery factor of only 2.8 by the end of March 2010 [10, 3]. For the more viscous block of this oilfield that is called the south block, the recovery factor is only 1.2%. The detailed production data for this field is shown in Table 1. In addition, the operating and capital costs in the offshore oilfield development are extremely high. For example, the average facility construction and well drilling costs per platform in the China offshore are usually 1-10 billion RMB [9, 13]. Furthermore, the lifetime for the production facilities is as short as 15-20 years. Therefore, the offshore oilfields must have a high recovery factor for the ultimate recovery to be economic. If an offshore oilfield producing in a production method is not profitable, a new production technology must be utilized.

As mentioned above, thermal recovery technologies are the best choice for the heavy oilfields development. They could produce the heavy oilfields with high recovery factors, and increase the development profits. Due to the offshore nature of the heavy oilfields in Bohai, however, implementing a thermal recovery process must take into account many critical factors; for example, the process must have a high thermal and volume sweep efficiency in order to offset the large well spacing and large drainage areas in an offshore oilfield, and must be equipped with a small and light heat generator because of limited space and operating and crane capabilities on a platform. Health, safety and environmental issues and economic feasibilities must be strictly examined because of the marine environment and high capital and operating costs on the platform that is remote from shore.

Unfortunately, there has been no satisfactory recovery process that can overcome the above challenges for the offshore heavy oilfield development. In this paper, a new process, Steam and Multiple Fluids (SMF), is being developed to improve the efficiency of the standard steam stimulation process. It involves a combination of steam and non-condensable gases ($CO_2$ and $N_2$). The injected gases accumulate in the reservoir region away from the well, act as insulation between reservoir formation and overburden, prevent heat losses and thus lower the temperature. Only the region near the well is heated to the temperature of steam. The heat loss to the overburden and the heat requirement to heat the reservoir rock are significantly reduced due to the lower temperature requirement. Furthermore, the co-injection of non-condensable gases with steam can further reduce the oil-water interfacial tension to achieve higher production because these gases accumulate at the interface and form an adsorbed film that lowers the interfacial tension. Compared to the standard thermal recovery processes, this new process improves the steam-oil ratio so considerable saving can be achieved from the reduction in the quantity of steam required. We mention that while the concept of mixed steam and non-condensable gas was used early [2, 6], it all involved the single non-condensable gas $CO_2$. As shown in this paper, the proposed SMF process involves multiple fluids and potentially has more thermal and volume sweep efficiency.