Introduction

The Bati Raman field located in southeast Turkey, which is known as the highest oil accumulation in Turkey, contains very viscous and low API (9.5 – 13.5) gravity oil in the Upper Cretaceous Garzan limestone that is a very challenging geological environment (Arslan et al., 2007). The gross thickness of the reservoir changes from 60 to 80 meters. The height of the oil column is about 210 m with a 100% Sw OWC at -630 m ss. Due to the fact that the recovery factor by primary recovery was limited to only 1.5% of more than 300 MM m^3 oil in-place, several EOR techniques had been proposed and tested including water flooding, steam flooding and CO_2 injection in pilot level in the 70's and 80's (Kantar et al. 1985, Sahin, 2007).

Based on the success in the lab tests and significant amount of CO_2 available in a neighboring field (Dodan), which is just 80 km away from the Bati Raman field, field scale huff-and puff injection was started in the early 80's. Due to early breakthrough of CO_2 in other wells in a short period of time, the project was converted to field scale random pattern continuous injection. Over more than 20 years of injection, the recovery peaked at ~14,000 bbls and began to decline reaching approximately 6,000 bbls in the late 2000's (Akin et al., 2009).

The goal of this research is to investigate and compare the ultimate recovery from the largest oil reserve in Turkey (1.85 billion barrels) using a new method called mining-assisted heavy oil production (MAHOP) with conventional steam assisted gravity drainage (SAGD). Declining tunnels will be excavated from the surface to the reservoir. Fan-shaped holes will then be drilled in the reservoir from the top of the declines (Chertenkov et al., 2012).

Heavy oil production through these tunnels will be explored using the well-known SAGD method. In order to reach this goal, several numerical models have been designed using CMG's STARS numerical simulator. In our study, since the fan wells are opened vertically and opened at certain intervals along the tunnel, both a tight vertical fracturing of these fan wells and a separate fracture network formed by micro fractures in the vicinity of the fan holes are formed.

The validation of these hypotheses has been conducted in the numerical modeling. Numerical simulations showed that MAHOP gave better results compared to conventional SAGD where two horizontal wells are used. MAHOP gave better recovery values with less steam oil ratios. With the results of the simulation study a laboratory model was designed. Experimental operational parameters using three different wettability cases were simulated to observe recovery by considering several possible physical effects such as steam distillation and in-situ upgrading. Saturation and pressure distributions were also obtained.

Mining Assisted Heavy Oil Production

Declining tunnels will be excavated from the surface to the reservoir. Fan-shaped holes will be drilled in the reservoir from the top of these declines. There will be 5 fan-shaped radially excavated steam injection wells connected to these horizontal tunnels. The steam chamber is physically formed with fan shaped perpendicular wells along the tunnels by the proposed method. When these radial steam injection wells are operated it is expected to have an improved and larger steam chamber around the declining tunnels.

Due to depth of the Bati Raman field (1500m) the declining tunnels will be significantly long. As a result, the cost of these tunnels to be excavated horizontally and in parallel is the main obstacle. Furthermore, due to low the permeability of the Bati Raman area, especially the eastern region, (Karaoguz et al. 2004), the application of SAGD method would be challenging. However, in MAHOP, the steam chamber in the reservoir is developed using physically excavated underground tunnels with underground steam generators. In this way, the quality of the steam to be produced in the tunnel will be higher, which will enable the steam to efficiently heat the formation. In this way heavy oil can be produced with gravity due to reduced viscosity.

Design of Experimental Study with Numerical Simulations

The numerical simulations were performed using CMG's STARS. The petrophysical parameters for Bati Raman (Turkey) heavy oil reservoir are used in the simulations. The physical model sizes are scaled with respect to Bati Raman field. The lengths of the horizontal wells are fixed at 18 cm (Figure 1a). Standard SAGD horizontal wells were used, with the producers located at the bottom of the reservoir and the injectors located 5 cm above the producers. The distances between the well pairs are 20 cm. In order to achieve this, the reservoir in the numerical simulations is assumed to be 48 cm wide (i direction), 50 cm thick (k direction), and 18 cm along the horizontal well (j direction). A no flow boundary was used, but heat loss to the overburden was permitted (Figure 1b).

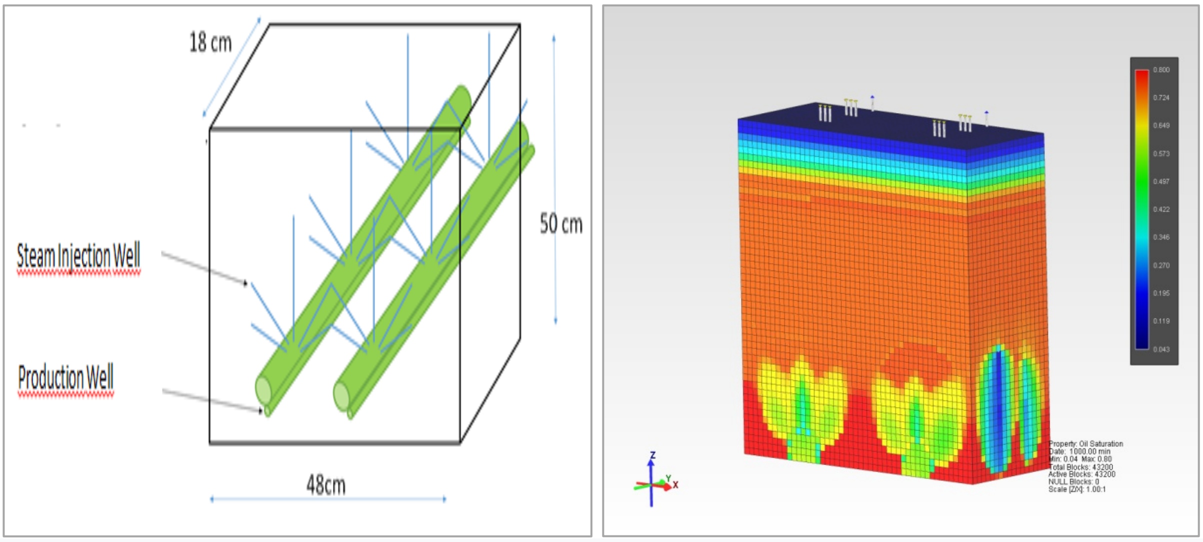

Figure 1 *__a.__ The Physical Scaled Model* *__b__. The Numerical Model*

In the experimental scenario, recovery obtained from SAGD was compared with that of MAHOP. Different steam injection rates (20, 25 and 30 cc/min) were applied for 1000 minutes. Fan shaped injection wells angles and numbers were compared. Four or 6 uphole wells drilled with differing angles (25°, 30°, 45° and 60°) were considered (Figure 2). Cumulative oil production and CWOR's of both methods at the end of 1000 minutes were compared (Figure 3 and 4).

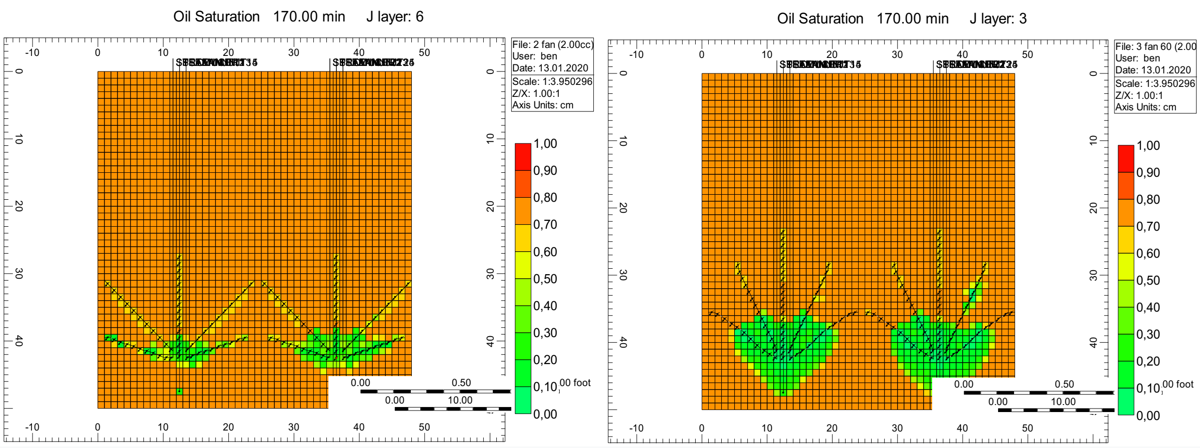

Figure 2 *Fan Shape Steam Injection Wells Angles and Numbers Comparison.*

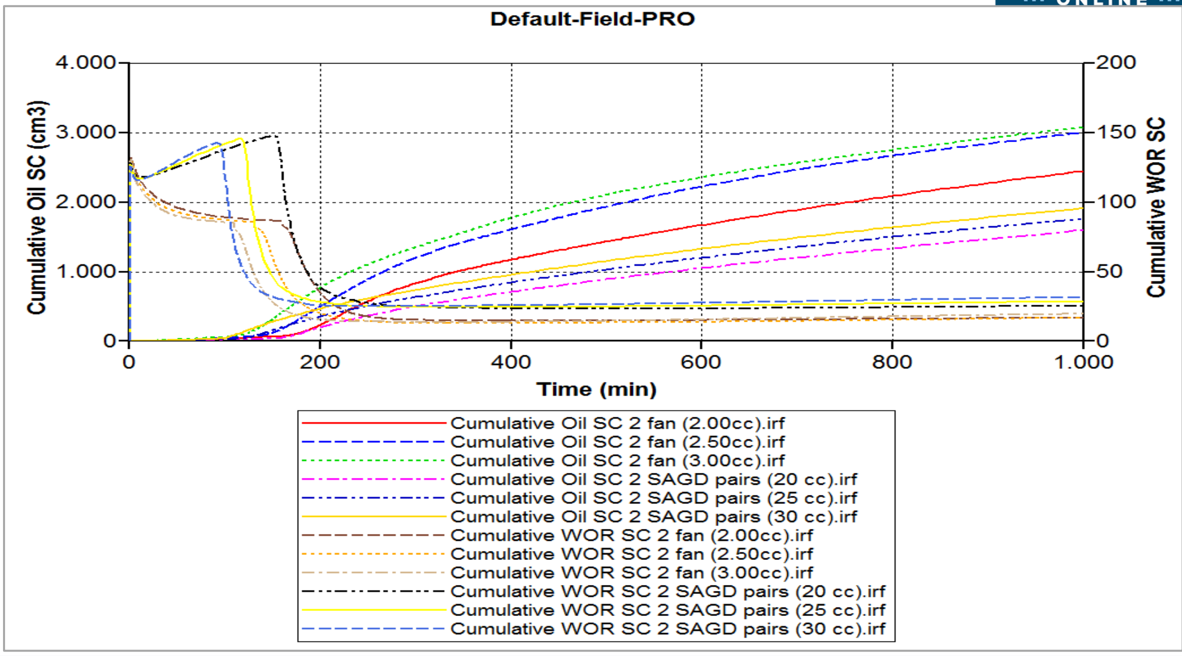

Figure 3 *Cumulative Recovery, Cumulative WOR, Injection Rate of Fan Shape Steam Injection Application in Physical Model*

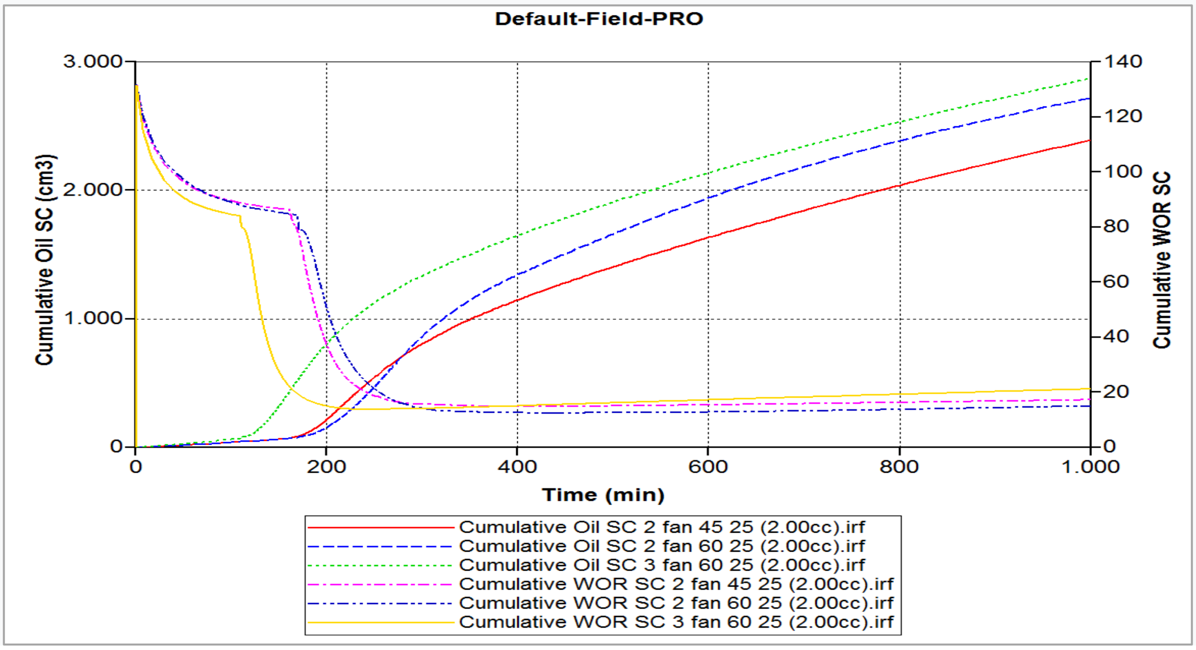

Figure 4 *Cumulative Recovery, Cumulative WOR, at 2.cc/min Injection Rate of Fan Shape Steam Injection Application in Physical Model*

Conclusions

Numerical simulations showed that MAHOP gave better results with respect to SAGD. MAHOP results gave better recovery values with less steam oil ratios with fan-shaped holes drilled in the reservoir from the top of the declines due to physically created steam chambers. The angles of the fan shape injectors for 60°-25° gave the best recovery and less steam oil ratio with respect to other designs due to fast heating and viscosity reduction. With the results of the simulation study experimental work will be designed for three different wettability environments to observe the ultimate recovery with other steam effects causing in-situ upgrading and saturation distribution.

Acknowledgements

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