Numerical Simulation of Undulating Shale Breaking with Steam-Assisted Gravity Drainage (UB-SAGD) for the Oil Sands Reservoir with a Shale Barrier

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Summary

A thick oil sands reservoir separated into two thin oil sands reservoirs by a shale barrier, particularly when the separated reservoir thickness is less than 10 m, is inefficient for economic steam-assisted gravity drainage (SAGD) applications. Several studies, such as solvent-based SAGD and hydraulic fracturing with SAGD, have attempted to develop this type of reservoir, but there are limitations. This paper proposes undulating shale breaking with SAGD (UB-SAGD) to improve the economics in an oil sands reservoir with a shale barrier.

The UB-SAGD is a novel in-situ recovery method that applies undulating drilling to break the shale in the parallel direction and the above SAGD well pairs. In addition, it adds an extra injector to facilitate thermal communication between the upper and lower parts of the shale barrier, and the steam chamber can be expanded into the upper the oil sands layer along a flow path.

Numerical simulations were conducted to evaluate the effects of the area and permeability of breaking zone and the steam injection pressure of the UB-SAGD on the recovery factor (RF), cumulative steam-oil ratio (CSOR), and maximum NPV (M_NPV).

A comparison of various steam injection pressures revealed the M_NPV of 3.2 MPa to be higher than that of 2.4 MPa at an area of 0.05 m^2 and a permeability of 500 Darcy because a high injection pressure facilitates flow in a smaller area of the breaking zone. The RF, CSOR, and M_NPV of the best UB-SAGD result were 0.84, 2.93, and \$5.54MM, respectively, under the following conditions: area of 0.30 m2, permeability of 500 Darcy, and a steam injection pressure of 2.4 MPa. The RF and CSOR of this result were improved by 24.65% and 10.21%, respectively, compared to two well-pairs (0.67 and 3.26) of SAGD without undulating drilling. In addition, the M_NPV of this result was \$3.05MM higher than that of two well-pairs (\$2.48MM).

The UB-SAGD will be very useful for the economic development of shale interbedded oil sands reservoirs using conventional SAGD.

Undulating Shale Breaking with Steam-Assisted Gravity Drainage (UB-SAGD)

The UB-SAGD is a novel in-situ recovery method that applies the undulating drilling to break the shale in the parallel direction and above SAGD well-pairs [producer (Prod_1) and injector (Inj_1)] and adds an injector (Inj_2) to facilitate thermal communication between the upper and lower parts of the shale barrier, and the steam chamber can be expanded into the upper oil sands layer along a flow path, as shown in Fig. 1. The following procedure was used for the UB-SAGD:

(1)   Start preheating at the SAGD well-pairs and Inj_2;
(2)   Start the SAGD process;
(3)   Shut-in the Inj_1 after six months;

(4)   Keep injecting steam at Inj 2.

Undulating Drilling to Break the Shale Barrier + Additional Injector = UB-SAGD

| - - - - Undulating drilling | Shale Barrier | Oil Sands |

Step. 1. Start the preheating at the SAGD well-pairs and Inj_2

Thermal Communication between upper and lower parts of shale barrier

Step. 2. Start the SAGD process

Step. 3. Shut-in the Inj_1 after six months and keep injecting steam at the Inj_2

Trajectory of Undulating Drilling
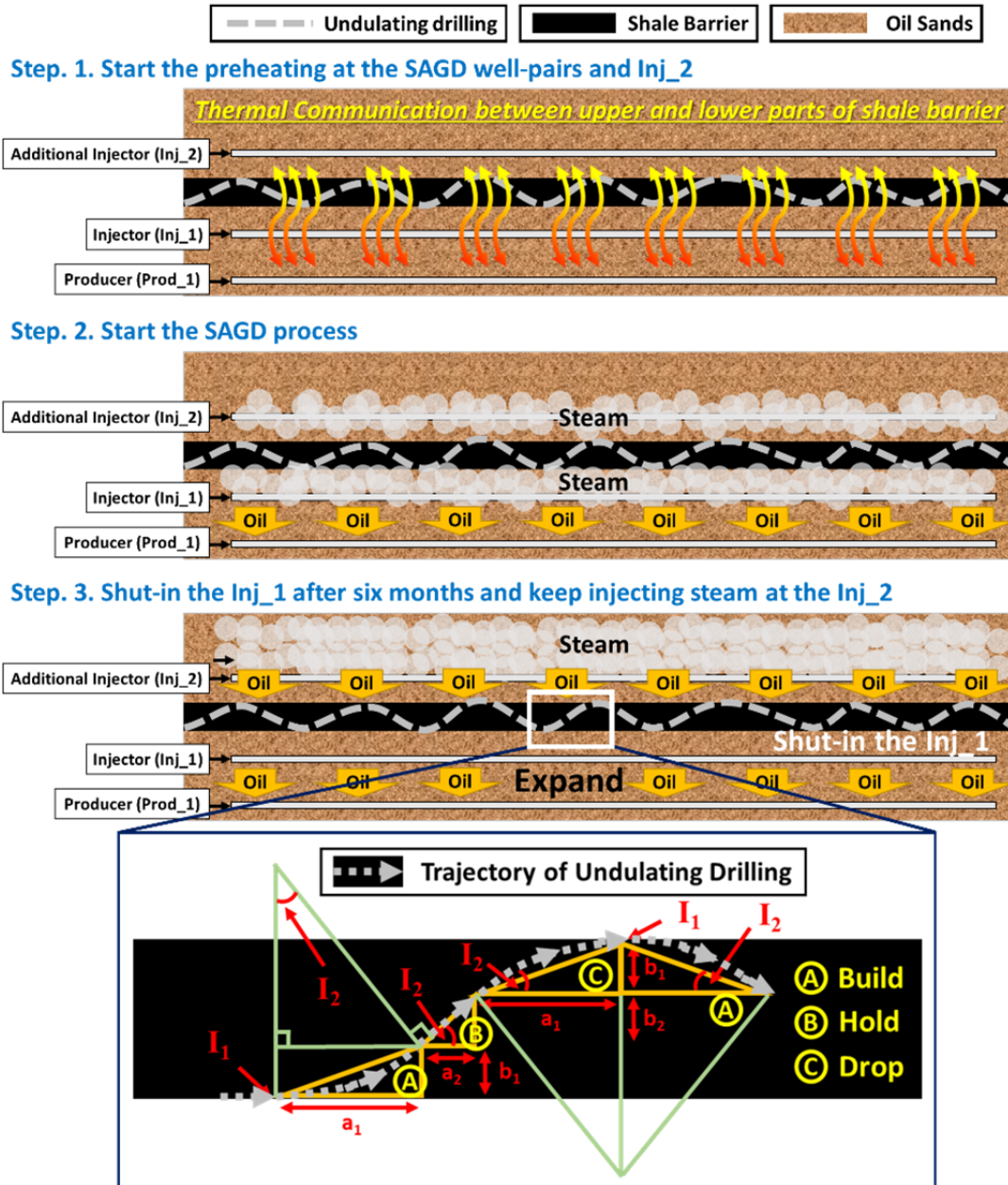
Ⓐ Build
Ⓑ Hold
Ⓒ Drop

Fig. 1. Schematic diagram of the UB-SAGD.

As shown in Fig. 1, the well trajectory of undulating drilling is marked with a gray dotted line. While breaking the top from the bottom of the shale barrier, the well trajectory of undulating drilling consists of build, hold, and drop sections, and is S-shaped. The dogleg severity (DLS,

degrees/30.48 m) of the build and drop sections of the well can be calculated based on the radius of curvature method using Eq. (1) (McMillian, 1981; Adams and Charrier, 1985):

$$DLS = \{\cos^{-1}[(\cos I_1 \times \cos I_2) + (\sin I_1 \times \sin I_2) \times \cos(A_1 - A_2)]\} \times \frac{30.48\, m}{CL} \qquad (1)$$

where I_1 and A_1 are the inclination (angle) and azimuth at the top and bottom survey points of the shale barrier, respectively; I_2 and A_2 are the inclination (angle) and azimuth at survey points inside the shale barrier, respectively, and the course length (CL) is the distance between the survey points (I_1 and I_2). The CLs were calculated according to the Pythagorean Theorem using Eqs. (2) and (3).

$$CL^2 = a_1{}^2 + b_1{}^2 \text{ (build and drop sections)} \qquad (2)$$

$$CL^2 = a_2{}^2 + b_2{}^2 \text{ (hold } section) \qquad (3)$$

where a_1 (build and drop sections) and a_2 (hold section) are the distances in the horizontal well direction, respectively; b_1 (build and drop sections) and b_2 (hold section) are the distances in the vertical direction, respectively.

In this study, a_1 and a_2 were assumed to be 20 m and 10 m, respectively, and b_1 and b_2 were 1.5 m. The distance from the build section to the drop section in the horizontal well direction was 50 m (2×20 m + 10 m = 50 m). As a result, the calculated DLS was 12.91°/30.48 m using the radius of curvature method to break the shale barrier from the build section to the drop section. Recently, the rotary-steerable system (RSS)-related research is being conducted actively because a high DLS is required in the development of unconventional resources (Janwadkar et al., 2011). Developed by Schlumberger Ltd., the PowerDrive Archer is a hybrid RSS, and DLS can be expected up to 18°/30.48 m (JPT staff, 2013; Downton, 2014). Baker Hughes Ltd. developed the AutoTrak Curve, which is capable of drilling curves at DLSs of 15°/30.48 m by drilling an 8-1/2 inch hole owing to its geometrical design (Tipu et al., 2015; Wilson, 2016). Kim and Myung (2017) proposed a novel hybrid-type RSS with a high DLS (up to 32°/30.48 m). Therefore, it was assumed that the undulating drilling technology using an RSS tool is applicable to the UB-SAGD required for a high dogleg severity (more than 13°/ 30.48 m) in this study.

Results and Conclusions

The proposed UB-SAGD was studied to improve the economics of an oil sands reservoir with a shale barrier. As the area and permeability were increased, the RF and M_NPV increased, and the CSOR decreased. This had a high M_NPV compared to the two well-pairs of SAGD without undulating drilling when the area and permeability of the breaking zone were more than 0.15 m^2 and 500 Darcy, respectively. A comparison of two steam injection pressures (2.4 and 3.2 MPa) revealed the M_NPV of 3.2 MPa to be higher than that of 2.4 MPa at an area of 0.05 m^2 and a permeability of 500 Darcy because a high injection pressure facilitates flow in a smaller area of the breaking zone. Therefore, for effective UB-SAGD, the steam injection pressure needs to be optimized according to the area and permeability of the breaking zone. The RF, CSOR, and M_NPV of the best result of UB-SAGD were 0.84, 2.93, and $5.54MM, respectively, at the area, permeability, and steam injection pressure of 0.30 m^2, 500 Darcy, and 2.4 MPa, respectively. The RF and CSOR of this result were improved by 24.65% and 10.21%, respectively, compared

to two well-pairs. In addition, the M_NPV of this result was \$3.05MM higher than that of two well-pairs. The UB-SAGD will be very useful for the economic development of the shale interbedded oil sands reservoir with conventional SAGD because they can improve the economics.

Acknowledgements

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