Case Study of ES-SAGD in Oil Sands Reservoirs with Lean Zones

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Summary

Steam assisted gravity drainage (SAGD) is a proven thermal recovery method in heavy oil and bitumen reservoirs. Expanding solvent (ES)-SAGD is an enhanced recovery method which is to inject solvent together with steam and is more efficient than SAGD for thin reservoirs. Reservoir heterogeneities (i.e., water zones or shale layers) influence the performance of these thermal processes. The correlations of these thermal processes with variable lean zones have been investigated to find the impact of lean zones on them. The simulation results indicated that ES-SAGD is a more effective thermal recovery method than SAGD in oil sand reservoirs with lean zones.

Introduction

Canada has heavy oil and bitumen reserves of 1.7 trillion bbl., which is the third largest oil reserves country in the world. Most of the heavy oil and bitumen resources are in the province of Alberta. The extremely high viscosity is a key property of bitumen. It ranges from one million centipoise to six million centipoise at reservoir temperatures of 7-11^{o}C (Gates 2008). Temperature is an important parameter affecting the viscosity of heavy oil and bitumen. Steam Assisted Gravity Drainage (SAGD) is a primary thermal method that has been extensively applied in the heavy oil and bitumen recovery in Alberta.

SAGD (Butler 1981) employs a pair of parallel horizontal wells, which are drilled in a reservoir, to heat and produce bitumen. The producer is located approximately 2 meters above the base of the reservoir and the injector is about 5 to 10 meters above the producer. Steam is injected into the reservoir through the injection well to create a steam chamber. With the steam continually injected into the reservoir, steam heats the cold bitumen and condensates at the edge of the chamber. Heated bitumen and condensate water drain to the producing well by gravity along the edge of the chamber (Butler 1991). ES-SAGD, which injects hydrocarbon additive at low concentration into a reservoir with steam, was proposed by Nasr et al. (2003). They showed that the hydrocarbon of low concentration injected together with steam could substantially increase the oil recovery and upgrade bitumen in the reservoir. Additionally, this method is able to reduce energy consumption and greenhouse gas emission. Reservoir heterogeneities (i.e., shale layers or water zones) have negative impacts on oil recovery. They hamper the growth of a steam chamber or adsorb latent heat to the water zones. Xu (2014) and Wang (2015) have conducted numerical studies to investigate the effects of lean zones on SAGD performance. They indicated that the sizes, location, and distribution of lean zones have different effects on oil production. In this paper, ES-SAGD and SAGD will be conducted in these type of reservoirs to study the impacts of lean zones.

Theory and Method

A reservoir model was built by using the Computer Modelling Group (CMG) software STARS. It is a three-dimensional, rectangular, single well pair, and homogenous model. The lean zone layers are mobile water zones and placed into reservoir model before the SAGD and ES-SAGD proceses. The lean zones are spreading above the injiection well. The number of lean zone layers is ranging from 1 to 20 with an even number order. The thickness of each lean zone layer is 0.5m. The simulations will be run for 15 years to investigate the efficiency of the SAGD and ES-SAGD processes.

Examples

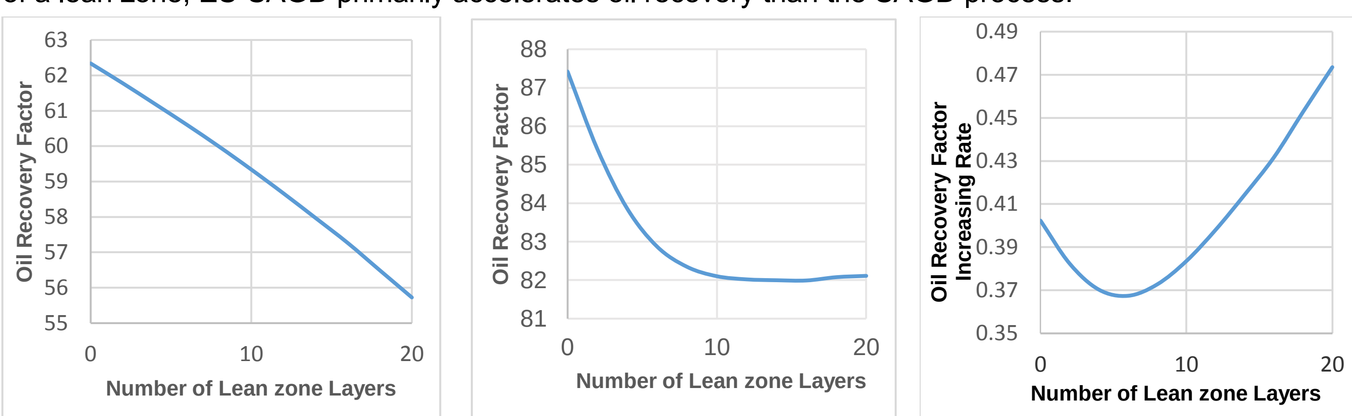
The CMG STARS 2015 version simulator is used for simulating both the SAGD and ES-SAGD processes. A right half simulation model is established. The dimensions of the model are 50x50x40m. The model is divided into 8,000 blocks with 100x1x80 blocks in the i, j, and k directions, respectively. The dimensions of each block are 0.5x50x0.5m in the i, j, and k directions, respectively. The input parameters for this reservoir model are listed in Table 1. These parameters are from the McMurray Formation in northeast Alberta**.**

The producer and injector are placed at the center of left side model with 50m length in j direction. The injector is 5 meters above and paralleled to the producer. The producer is located 5 meters above the reservoir base. Steam is injected at temperature of 223.8^{o}C with quality of 0.9. The SAGD and ES-SAGD processes have the same input parameters except for solvent injected with the steam in the ES-SAGD process. The injection well and production well need to be preheated before bitumen is produced. The period of preheating is 90 days.

Table 1 Reservoir Parameters

Parameters	**Value**
Reservoir top	230m
Initial reservoir temperature	7 °C
Initial reservoir pressure	1,050 kPa
Porosity	0.307
Permeability (Horizontal)	6,292 mD
Permeability (Vertical)	4,892 mD
Connate water saturation	0.25
Lean zone water saturation	0.7

As seen, Figure 1(a) shows a quick ramp down in the oil recovery factor in the SAGD process. With increasing of the number of the lean zone layers, there is more decreasing in oil recovery. The relationship between recovery and the number of lean zone layers forms a straight decline curve . Figure 1(b) shows a higher oil recovery rate than that in the SAGD process. When running the simulation model with increaing the number of lean zone layers, it is observed that the thickness of a lean zone slightly impacts the ES-SAGD performance for the initial simulaiton cases and hence this parameter is important for a small number of lean zone studies. After the lean zone layers are more than 10 layers (5 meters), it does not appear to have an effect on the ES-SAGD process. Figure 1(c) shows the oil recovery increasing rate (Equation 1) vs. the number of lean zone layes . It does confirm that there is a quite difference in the amount of the oil recovery increased rate for ES-SAGD as opposed to SAGD. With increaing the thickness of a lean zone, ES-SAGD primarily accelerates oil recovery than the SAGD process.

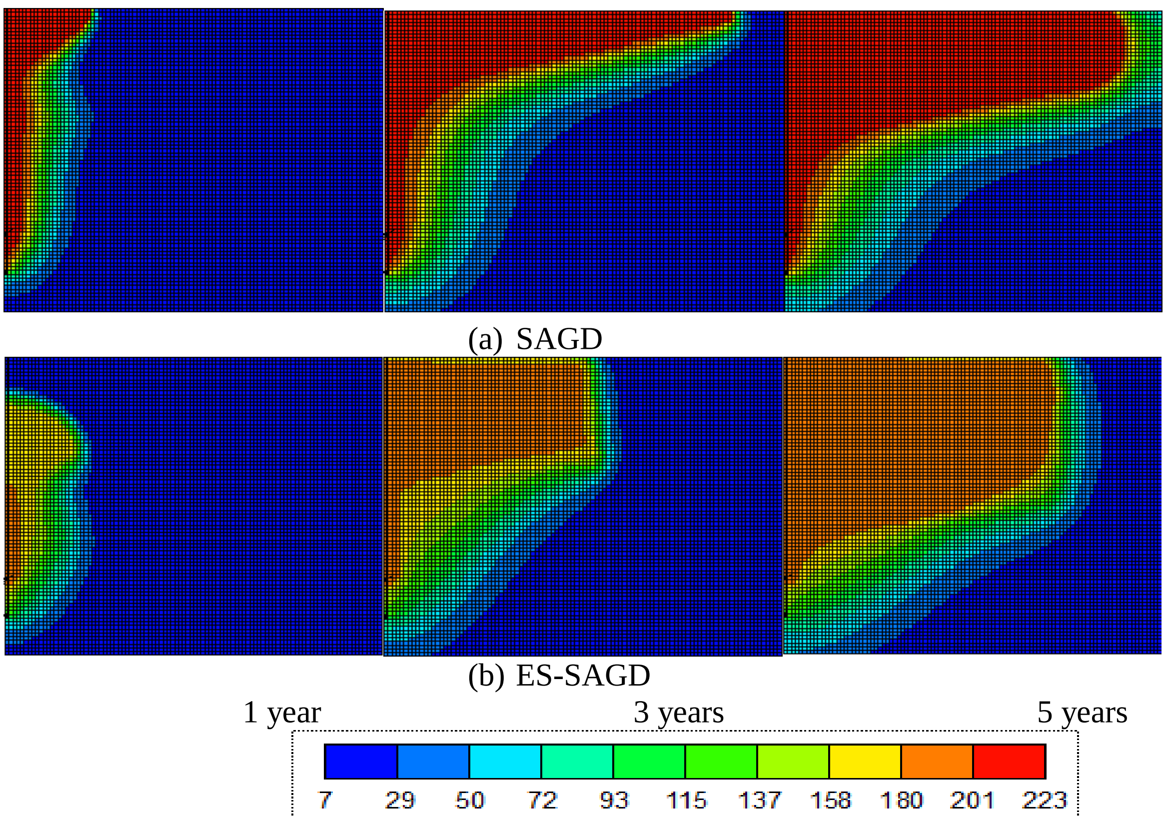


(a) (b) (c)

Figure 1 (a): Oil recovery factor of SAGD process with variable lean zone layers. (b) Oil reovery factor of ES-SAGD process with variable lean zone layers. (c): Oil recovery increaing rate with variable lean zone layers.

$$\text{Oil Recovery Factor Increasing Rate} = \frac{\text{ESSAGD Oil Recovery Factor} - \text{SAGD Oil Recovery Factor}}{\text{SAGD Oil Rcovey Factor}} \quad \text{Equation (1)}$$

Figure 2 (a) shows the temperature profiles of SAGD with 2 meters lean zones. It can be seen that a normal upside down triangle is shaped after 1 year. The steam chamber raised vertically and reached the upper boundary of the reservoir within 1 year. As observed, the steam chamber in the lean zone area formed a convex shape. This phenomenon demonstrates that steam is tending to go into the lean zones that can cause huge consumption of steam due to heat conductivity differences between water and oil. It has a significant effect on steam chamber growth. Figure 2 (b) is a temperature profile in ES-SAGD. As expected, when the steam chamber grows vertically and laterally, the co-injected solvent and steam are transported to the edge of the chamber and results in low temperature in the chamber. The vaporized solvent condensed and accumulated at the chamber edge. As accumulation continues, a part of solvent was diluted into the bitumen and other condensate solvent formed a relatively thin liquid layer at the edge of the chamber. The temperature profile in the first year shows that there is a concave shape in the lean zone area. As mentioned above, the solvent accumulated at the chamber edge can decrease the viscosity of the bitumen and prevent steam move into the lean zones. These are quite differences compared to SAGD.



Temperature scale °C

Figure 2 (a): Impact of lean zone on temperature profiles in SAGD process. (b): Impact of lean zone on temperature profiles in ES-SAGD process (2 meters lean zone layers)

Conclusions

The ES-SAGD process is advantageous due to a higher recovery rate. SAGD and ES-SAGD have significant difference effects on lean zones. Lean zones slightly affect the ES-SAGD process. Solvent has positive effects with lean zone existence. The SAGD process is highly impacted by lean zones, and they can affect the growth of a steam chamber. The thickness of lean zones is a key parameter for the SAGD process.

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