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Performance of SAGD with Nitrogen in Oil Sands Reservoirs

Yanpeng Zhang, Zhangxin Chen and Jinze Xu
University of Calgary

Summary

This research is focused on advantages of nitrogen injection during steam assisted gravity drainage (SAGD) in oil sands reservoirs. Reservoir simulation results indicate that the oil recovery factor of SAGD with nitrogen injection is better than that of the conventional SAGD method. The conventional SAGD and the SAGD with nitrogen are compared in oil sands reservoirs with initial water. SAGD with nitrogen injection is better in terms of cumulative oil recovery and a steam-oil ratio; with an increase in initial water saturation, the advantage of SAGD with nitrogen becomes more significant. Being a noncondensable gas, nitrogen is able to stay at the edge of a steam chamber and decrease the amount of steam that penetrates into the initial water in a formation, which is validated by changes in a steam chamber during production.

Introduction

In recent years, thermal recovery becomes the most effective method in enhanced oil recovery (EOR) for heavy crude oil and bitumen; SAGD is the most effective method in the in situ recovery of bitumen. SAGD involves steam injecton into a reservoir, and the heated oil and steam condensate can be recovered from a bottom horizontal well.

Nitrogen is a noncondensable gas and has some advantages as an assisted gas of SAGD. Nitrogen has a wide distribution in air and is not restricted by regions and resources. The nitrogen extraction technique is matured and has low costs. Initial water in oil recovery can be used in a SAGD process (Zhou et al. 2016). In the world, SAGD with nitrogen was used in oil fields and achieved good results (Gao et al. 2009; Wu et al. 2013; Heucke et al. 2015).

Theory and Method

The main reasons to choose nitrogen as an assisted gas of SAGD are as follows:

- Injection of nitrogen can replenish stratum energy and maintain the reservior pressure.
- Nitrogen has a low thermal conductivity and thus has good heat insulation. It is applicable as a heat insulation measure during the process of SAGD, and can enhance an oil recovery factor.
- Because exsolution makes the steam condense water, nitrogen is difficult to dissolve in the steam condensate and can retain the heat in a steam chamber.

In this paper, the CMG (Computer Modelling Group) software STARS is employed to build numerical simulation models of SAGD and SAGD with nitrogen. By comparing and analyzing the simulation results, the models can display the effects of nitrogen injection in a steam chamber.

Examples

Numerical Simulation Models

The basic reservoir parameters employed in the numerical simulation models include: depth (429m), thickness (24.9m), porosity (32%), horizontal permeability (6.5D), initial reservior pressure (2,500kPa), and initial reservior temperature (14^{o}C) that are suitable for the reservior characterization. In order to study the relationship between SAGD and SAGD with nitrogen, a simplified model is used in this paper. A 2D model with fewer parameters makes the comparion more feasible. The parameters of SAGD include BHP (bottom hole pressure), STW (surface water rate), SteamTrap, STL (stock tank liquid) and Pre-heating days. These parameters are key factors in the SAGD process. The optimal production data can be seen in Table 1.

Table 1 Original steam injection parameters in SAGD

BHP	STW	STEAMTRAP	STL	PRE-HEATER DAY
3400 Pa	50 m^3/day	10	70 m^3/day	90 day

Nitrogen retains heat during the SAGD process. Injecting more nitrogen can reduce the oil recovery factor and extend the recovery rate. Injecting less introgen can impact the insulation layer formation. Based on the analysis of the simulation model of SAGD with nitrogen, the nitrogen injection volume is 5% of the gas injection volume that is a suitable value.

Comparison of the Oil Recovery Factor of SAGD and SAGD with Nitrogen

The results of simulation show that the SAGD with nitrogen is an optimum process to enhance oil recovery. By comparing the SAGD and the SAGD with nitrogen with different water saturations, the SAGD with nitrogen has a distinct advantage, and this advantage is enlarged when the water saturation increases, which can be seen in Figure 1. In the SAGD model, the oil recovery factor value is from 67.2% to 38.9% when the water saturation value is from 0.2 to 0.6. In the model for the SAGD with nitrogen, the oil recovery factor value is from 68.3% to 43.0% when the water saturation value is from 0.2 to 0.6. The difference value between these two models is from 1.1% to 4.1% when the water saturation value is from 0.2 to 0.6.

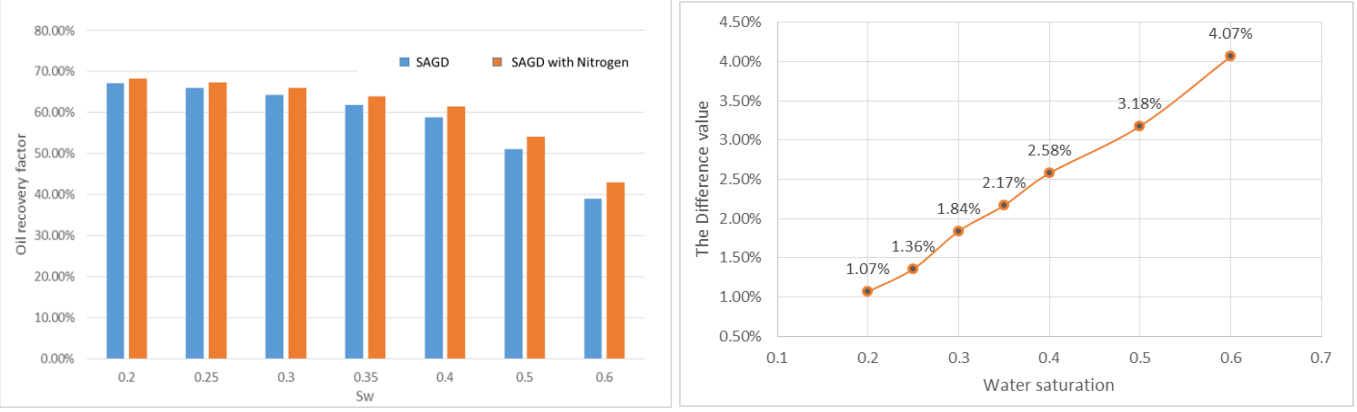

Figure 1 Difference value change between the models of SAGD and SAGD with nitrogen

The results indicate that the nitrogen in the steam chamber is distributed at the top of the steam chamber (Reid et al. 1987). The nitrogen can form an insulating layer. The insulating layer can reduce the thermal transfer speed to the overlying stratum and prevent the heat loss of the steam chamber. The viscosity of nitrogen is bigger than steam, and with an increase in temperature, the difference value trend increases (Bonilla et al. 1951). The viscosity difference makes the injected gas expand the sweep volume.

Steam Chamber Analysis

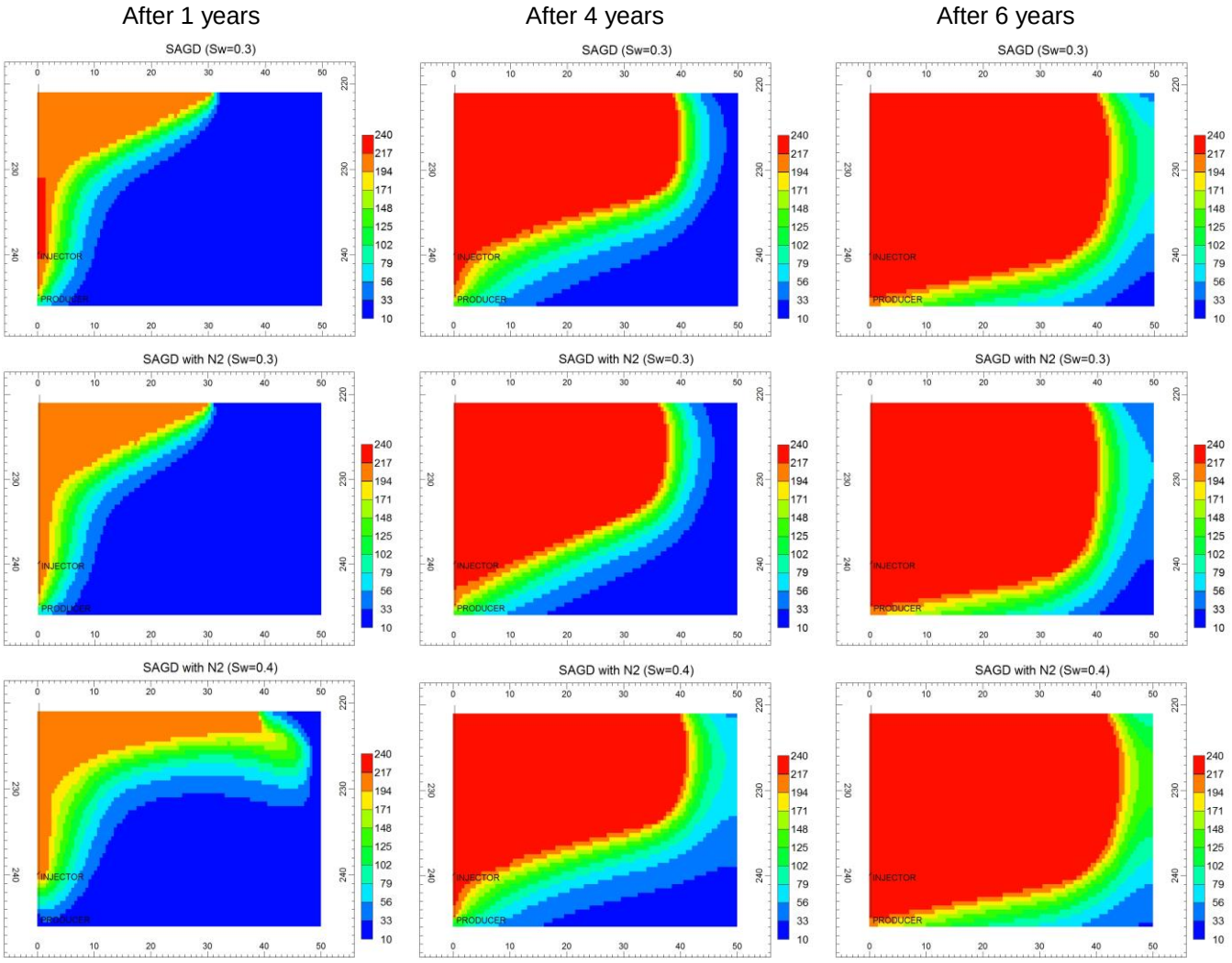

Figure 2 Variation of steam chamber with time

By comparing the three conditions of numerical simulation models (SAGD at Sw=0.3, SAGD with nitrogen at Sw=0.3, and SAGD with nitrogen at Sw=0.4) from Figure 2, the analysis results are as follows:

- During the SAGD process heat loss is more than SAGD with nitrogen. From the chart after one year, comparing the temperature distribution in the steam chamber, the SAGD process needs more heat to replenish energy.
- During the SAGD process a horizontal spread rate is larger than that in SAGD with nitrogen. From the chart after four years, comparing the horizontal distance, the insolation layer that was formed by nitrogen can reduce the heat spread rate in the horizontal direction.
- During the SAGD process heat travelling to the steam chamber border is faster than that in SAGD with nitrogen. From the chart after six years, this phenomenon is obvious in the steam plot.
- Because of the nitrogen retaining heat, the heat travelling in the steam chamber is slower than that in the SAGD process. Before reaching the steam chamber border, it can spread into a bigger area in the steam chamber.
- Comparing the SAGD process with nitrogen injection in different water saturation, the heat spread rate is bigger when the water saturation is bigger.

Conclusions

From the above analysis, the conclusions are as follows:

- Optimizing the parameters of a numerical simulation model made the research results obtained easily.
- Nitrogen was located at the top of a steam chamber and formed an insulation layer that reduced heat loss and increased the oil recovery factor.
- SAGD with nitrogen can reduce the velocity of heat transfer in the horizontal direction, make heat spread wider in the steam chamber before heat travels to the steam chamber border, and benefit for residual oil production.
- When the water saturation is higher, the oil recovery rate is larger.

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