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Steam Assisted Gravity Drainage: A Recipe for Success

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***Abstract*—**In this paper, Steam Assisted Gravity Drainage (SAGD) is introduced and its advantages over ordinary steam injection is demonstrated. A simple simulation model is built and three scenarios of natural production, ordinary steam injection, and SAGD are compared in terms of their cumulative oil production and cumulative oil steam ratio. The results show that SAGD can significantly enhance oil production in quite a short period of time. However, since the distance between injection and production wells is short, the oil to steam ratio decreases gradually through time.

***Keywords*—**Thermal recovery, Steam injection, SAGD, Enhanced oil recovery

I. Introduction

HEAVY oil is often overlooked as a resource because of the difficulties and costs involved in its production. But the more than 6 trillion barrels of oil in place attributed to the heaviest hydrocarbons- triple the amount of combined world reserves of conventional oil and gas- deserve a closer look [1].

Most operators try to produce as much oil as possible under primary recovery, called cold production at reservoir temperature. Typical recovery factors for cold production range from 1 to 10%. Choosing the optimal cold-production strategy requires an understanding of fluid and reservoir properties and production physics [2].

Once cold production has reached its economic limit, the next step is usually thermally enhanced recovery. Here again, several methods are available. Thermal recovery generally comprises the techniques of in-situ combustion, hot-water floods and steam processes. Until very recently, heavy oil fields were produced either by primary production techniques, or through "huff-and-puff". These techniques improve the percentage of reserves recovered but still leave behind significant quantities of the original oil in place [3]. For overcoming this problem, different new thermal recovery techniques have been proposed. SAGD method is a relatively new approach which will be discussed in detail.

In Steam Assisted Gravity Drainage(SAGD), two horizontal wells separated by a vertical distance are placed near the bottom of the formation [4]. The upper well is known as the "injection well" and the lower well is known as the "production well" (Figure 1). The process begins by circulating steam in both wells so that the bitumen between the well pair is heated enough to flow to the lower production well. The freed pore space is continually filled with steam forming a "steam chamber".

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The steam chamber heats and drains more and more bitumen until it has overtaken the oil-bearing pores between the well pair. Steam circulation in the production well is then stopped and injected into the upper injection well only. The cone shaped steam chamber, anchored at the production well, now begins to develop upwards from the injection well [5].

As new bitumen surfaces are heated, the oil lowers in viscosity and flows downward along the steam chamber boundary into the production well by way of gravity [5]. During the rise period the oil production rate increases steadily until the chamber reaches the top of the reservoir, this point on steam chamber begins to grow laterally. The process leads to a high recovery and high oil rate at economic oil-to-steam ratios (OSR) [4].

The rate of upward growth of the vapor chamber is higher than sideways growth of the vapor chamber. Ultimately the upward growth is restricted by the top of the reservoir, and the sideward growth then becomes crucial. The steam chambers grow to the top of the reservoir and then spread sideways. After a period they form a single steam layer above the oil and continuous heating compels the oil to drain to the horizontal wells. This method allows almost complete coverage of the reservoir volume, representing a fantastic aspect of SAGD [6].

Although the injection well and the production well can be very close, the mechanism will cause the steam chamber to expand gradually and eventually allow drainage from a very large area. In conventional steam flooding, the oil that is displaced from the steam chamber is cooled and is hard to push to the production well but in SAGD the oil remains heated as it flows around the steam chamber. The injector and producer do not have to span the drainage area and this is a novel change compared to the most of the enhanced oil recovery methods [6].

In addition, it is possible to inject steam quite near to the bottom for displacing cold oil or higher up if the oil is mobile. It is also used for removing liquids as they drain to a lower location. When liquids are removed the vacant pores are filled with steam. In some situations, there may be an advantage in employing two horizontal injection wells, with one located close to the producer to initiate steam chamber formation and a second located higher in the reservoir to be used as the steam chamber grows to it [7].

When pressure gradients are imposed upon the gravity drainage process, the recovery decreases and the drainage rate increases. However, increasing the rate by lowering the production well pressure will leave additional liquid behind in the gas-saturated region. Although the dynamic hold-up of oil

in the gas-saturated steam chamber is significant, it is relatively small, since the viscosity of the oil within the chamber is very low compared to the average viscosity of the oil draining below and around it [6].

Steam is always injected below the fracture pressure of the rock mass. Also, the production well is often throttled to maintain the temperature of the bitumen production stream just below saturated steam conditions to prevent steam vapor from entering the well bore and diluting oil production this is known as the SAGD "steam trap". The SAGD process is able to economically recover 55% of the original bitumen-in-place.

The gravity drainage idea was originally conceived by Dr. Roger Butler [6], an engineer for Imperial Oil around 1969. But it wasn't until 1975 that he pursued the concept. The idea didn't work well on paper until he hit on the idea of using horizontal instead of vertical wells.

In this paper, the natural production of a heavy oil reservoir is simulated. The natural production is then compared with two thermal oil recovery scenarios; ordinary steam injection and steam assisted gravity drainage.

II. Procedure and simulation data

The reservoir system to be modeled consists of an inverted nine-spot pattern of eightproduction wells surrounding each injection well as in figure 2 [8]. However, the symmetry of the system allows us to model $1/8^{th}$ of the model comprising two production and one injection wells as in figure 3. Note that $P_{near}$and P_{far} are the two production wells and Inj is the injection well.

Rock and reservoir properties have been taken from the fourth SPE comparative solution project by Aziz et al [9]. The most important reservoir properties are shown in table 1. Figure 4 shows how the oil viscosity is reduced whenthe reservoir temperature rises.

Three cases were simulated and compared. Reservoir was allowed to produce naturally in the first case. The injection well was closed and oil was produced with a bottomhole pressure of only 14.7 psia. This value might not seem practical in real fields, but the idea was to produce with the full field energy. The model was simulated for 3000 days.

In the second case, the injection well was set to inject saturated steam with a quality of 70 percent and at a temperature of 450 F. The steam was injected at a bottomhole pressure of 1000 psia and the model was simulated for 3000 days.Well configuration was then changed to steam assisted gravity drainage in the third case. Vertical wells were changedto a pair of horizontal wells. The injector was defined in the second layer and the producer was drilled in the fourth layer. Figure 5 shows this configuration. The figure is shown in wireframe so that the internal connections are visible. The simulation began by circulating steam in both wells for 80 days so that the oil between the well pair was heated enough to flow to the lower production well.Steam circulation in the production well was then stopped and steam was only injected through the upper injection well.

III. Results and Discussion

Figure 6 shows cumulative oil production for the three simulated models. As can be seen, the reservoir can produce more than 20000 stb of oil with SAGD method. This figure for ordinary steam injection and natural production is 15000 stb and 1700 stb respectively.

Cumulative water production of the three models is represented in figure 7. Since the producer and the injector wells are much closer in the SAGD configuration than in the ordinary steam injection, it is just natural that more water is produced in SAGD operations. This is also evident in figure 8 where cumulative oil-steam ratio of the three models is shown. In SAGD recovery, the oil to steam ratio increases sharply until the steam front reaches production well. From this point forward, the value drops gradually. Even though oil to water ratio is decreasing for most of the simulation time, but its overall value for SAGD recovery stays greater than that of ordinary steam injection for at least 3000 day.

IV. Conclusion

The role of steam assisted gravity drainage as a thermal enhanced oil recovery was discussed. Three simulation models, a natural production, an ordinary steam injection, and a SAGD operation were run and their results were compared. The results showed that the SAGD operation can result in a higher oil production. It was also illustrated that although oil to steam ratio of SAGD operation is decreasing through most of the production time,but its overall value stays greater than that of ordinary steam injection.

TABLE I
RESERVOIR PARAMETERS USED IN THE SIMULATION MODEL

Parameters	Units	Values
Reservoir Dimensions	--	9*5*4
Reservoir Depth	ft	1500
Reservoir Thickness	ft	80
Porosity	--	0.3
Oil Density	lb/cu ft	60.68
Water Density	lb/cu ft	62.4
Thermal Conductivity	btu/ft/day/°F	24
Rock Heat Capacity	btu/ft3/°F	35
Oil Specific Heat	btu/lb/°R	0.5
Flowing Bottomhole Pressure	psia	14.7
Injection Rate	stb/day	15
Steam Quality	%	70

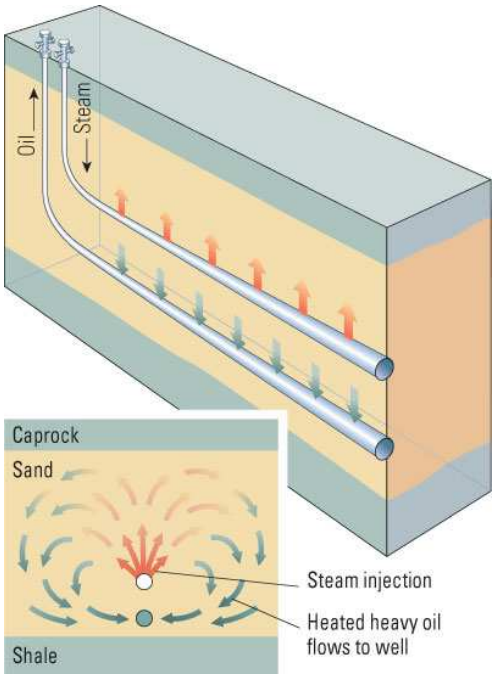

Fig. 1 General configuration of well pairs in SAGD process[10]

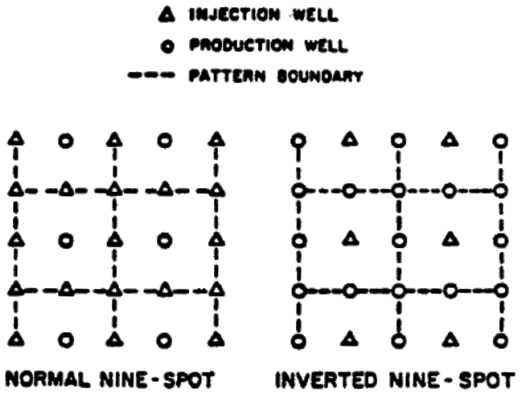

Fig. 2 Normal and inverted nine-spot patterns [8]

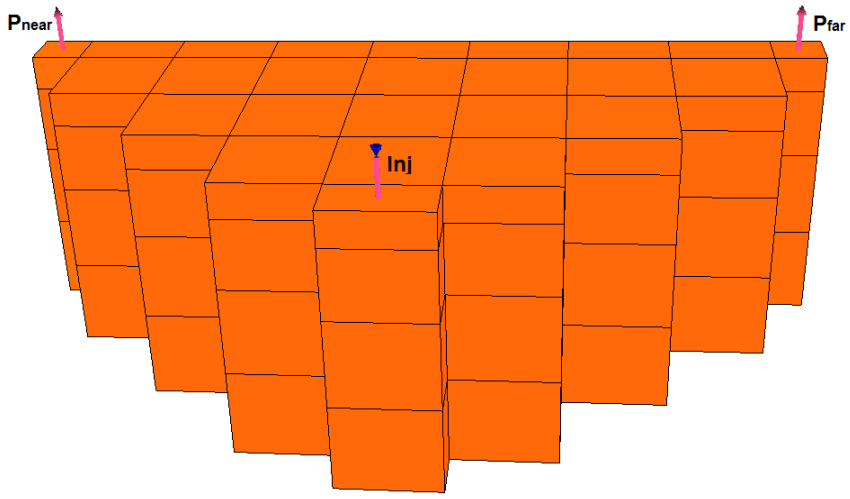

Fig. 3 one eighth of an inverted nine-spot pattern

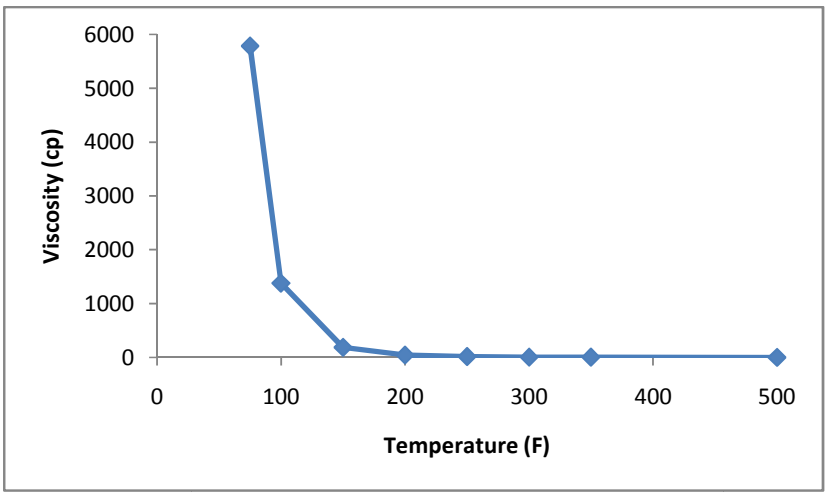

Fig. 4 Viscosity variation against temperature

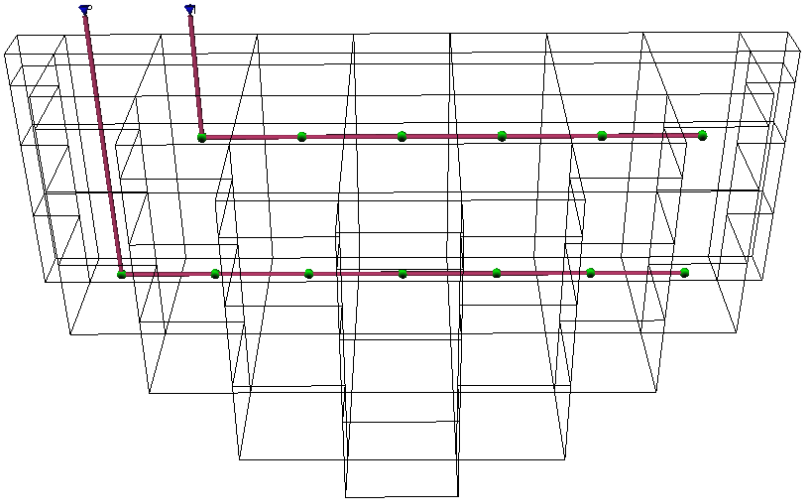

Fig. 5 SAGD well configurations. The injections well lies above production well

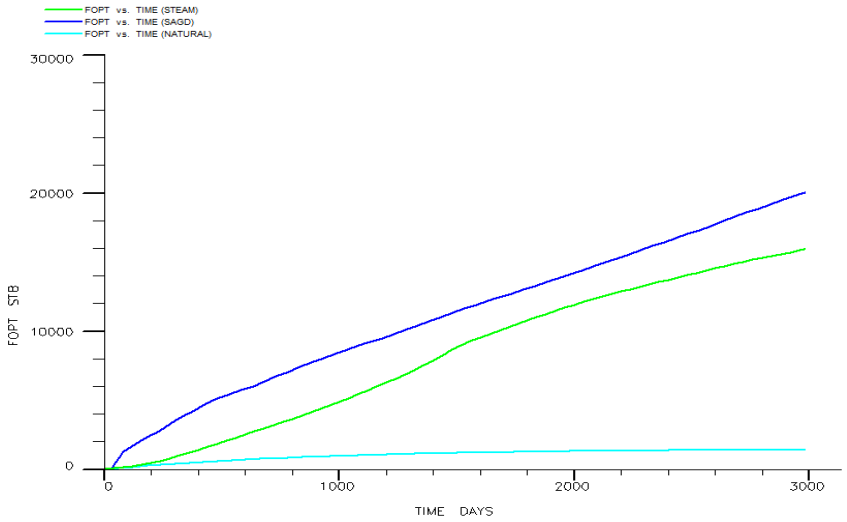

Fig. 6 Cumulative oil production for the three simulated models

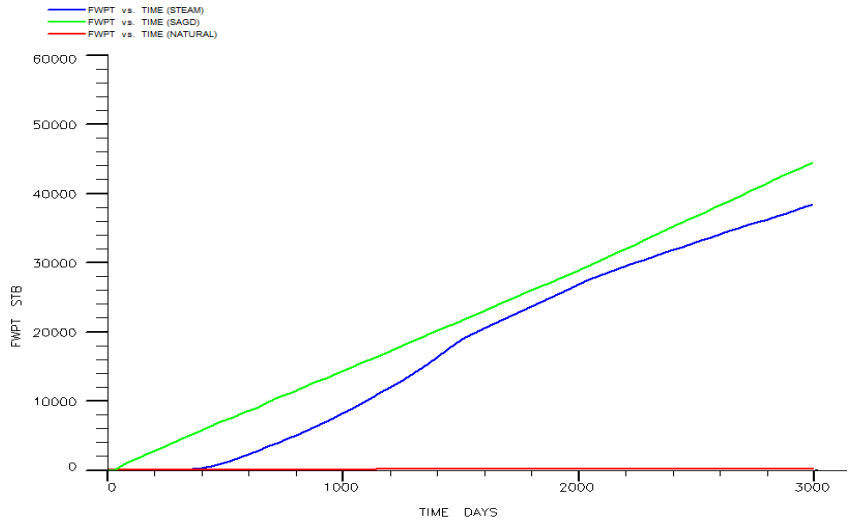

Fig. 7 Cumulative water production for the three simulated models

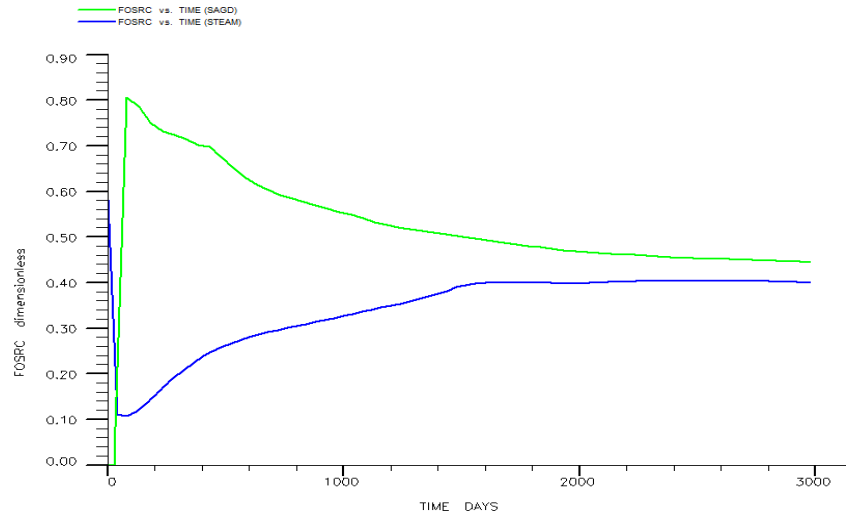

Fig. 8 Cumulative oil steam ratio for the three simulated models

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