Effect on SAGD Performance of Horizontal Well Orientation with Respect to Inclined Shale Layers and Point Bars*

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Abstract

This article describes geomodel preparation and results of simulation studies on the effect on steam assisted gravity drainage (SAGD) performance of horizontal well orientation in inclined heterolithic stratification (IHS) units in point bar systems. Simulation results from models with inclined shale layers show that as the fraction of shale volume increases, the role of wellbore orientation with respect to the shale layers becomes important. At high shale volume fractions (e.g. 10%), the recovery factor for wellbores oriented across the inclined shale layers is higher than the recovery factor for wellbores oriented along the shale layers. It was found that modeling a reservoir that has inclined shale layers but is modeled using horizontal shale layers underestimates the performance of the SAGD process. This difference increases as the shale volume fraction increases.

A 3D point bar system was modeled using non-orthogonal grid systems and a deterministic object base approach. Simulation results of the model show that horizontal wells across the dip of point bar beds yield higher SAGD recovery compared to horizontal wells that are parallel to the strike of the point bar beds.

Introduction

Understanding the effect of horizontal well orientation with respect to inclined shale beds in point bars on performance of the SAGD process is essential for field development decisions. It is important to know whether SAGD horizontal well-pairs need to be drilled parallel to the strike of the point bar beds, or they should be drilled into the dip of the point bar beds (Figure 1). For that purpose, a model which captures the structure of the point bar system is needed. The model needs to account for the dip of the inclined IHS units of the point bar and the 3D structure of the IHS clinoforms. Moreover, the final simulation model obtained from the geomodel needs to be efficient for the reservoir simulator in terms of the number of grids and heterogeneous complexities, but must retain important features of the geology. The following will discuss two separate studies. The first study is related to the modeling and 3D simulation of inclined shale layers, and the second study is on the modeling and 3D simulation of a point bar system.

Theory and Method

1) Inclined Shale Layers

Three Roxar RMS® geostatistical models with random distribution of sand and shale bodies were generated. These models include shale volume of 2%, 5% and 10% in the reservoir and that shale layers have 30º dip angle. It was assumed that shale is saturated 100% with water, and sand is saturated with 75% oil and 25 % water. In the RMS project, shale layers were created by object modeling of shale being ellipsoid in shape. The length and width of each object fall in a distribution of: minimum 5 m, maximum 150 m, with an average of 27.5 m. The thickness of each shale object is between 0.05 m to 0.75 m. In order to model inclined shale the grid size had to be changed significantly from those that are normally used to model horizontal shale. When the shale is horizontal, the minimum shale thickness that can be modeled is equal to the shale layer thickness. When the shale is dipping, the minimum shale thickness that can be modeled is the greater of the layer thickness times the cosine of the dip angle or the horizontal grid width times the sine of the dip angle. If large grid size is used in the geomodel, the shale appears as discontinuous blobs along the shale body path. The small grid size used in the RMS model made the modeling challenging because the RMS model contained about 40 million cells.

A model with the dimension of 400 m x 400 m x 20 m (LxWxH) was considered for the simulation grid up-scaling. In order to have a good resolution of shale layers with the specified dip angle, a fine discretization of the reservoir by 400 x 400 x 20 cells (total of 3.2e6 cells) was generated after up-scaling of the RMS models. The up-scaled RMS model was exported directly to the SAGD simulation model in CMG STARS®. Each model was built with well orientations along and across the shale layers. Figure 2 shows slab or block views of distribution of vertical permeability in grids generated with 10% shale volume and with horizontal well orientations across and along the shale layers.

Figures 3a, b and c show that increasing the percentage of shale volume results in a lower recover factor, a reduced rate of oil production and a higher cumulative steam oil ratio (CSOR). When the percentage of shale volume is increased, the performance difference of the two wellbore orientations becomes more significant. At 2% shale volume, both wellbore orientations have comparable recovery factor performance. However, at higher shale volume fractions, the oil recovery factor for wellbore orientation across the inclined shale layers is higher than the oil recovery factor for wellbore orientation along the inclined shale layers.

It is clear from Figure 3b that for 2% and 5% shale volume models, the rates from two well orientations are close to each other. However, as the shale volume increases to 10%, the difference between oil rates from two well orientations becomes noticeable. As we see in Figure 3b, in the first half of this SAGD process, the rate from wells oriented across the shale bodies is higher than the rate from wells oriented along the shale bodies. But, in the second half of the process we have higher rate from wells oriented along the shale bodies. Both models with different well orientations are producing from the same volume of oil in place. This is the reason both models show a similar recovery factor at the end of 10 years of the SAGD process (Figures 3a). However, from a perspective of net present value, the earlier high production rates from wells oriented across the shale beds is more advantageous

Similarly, the difference between CSORs (Figure 3c) in both models becomes noticeable as the shale volume fraction increases. This follows the same trend observed in the oil production rate. At the higher shale volume, a higher CSOR occurs in wells oriented along the shale layers for the first half of the process and then in the second half of the process, a higher CSOR occurs in wells oriented across the shale layers. However, from a perspective of operation's costs, the early low CSOR from wells oriented across the shale beds is more advantageous.

In contrast to models with inclined shale beds, geomodels with horizontal shale beds and the same fractions of shale volumes were built and up-scaled for the simulation. Figure 3d shows a comparison of recovery performance between models with 0º and 30º dip angle shale layers. The amount of original oil in place for each shale volume fraction model is the same for the 0º and 30º dip angle models. Figure 3d shows that if a reservoir with inclined shale layers is represented by a model with horizontal shale layers, the SAGD simulation will underestimate the reservoir performance. This underestimation is more important as the shale volume fraction is increased. The under estimation of recovery is due to the fact that horizontal shale layers impair the gravity drainage mechanism in the SAGD process.

2) Point Bar System

A hypothetical point bar system was modeled using object-based deterministic approach. Figure 4a shows the circular arcs used for creating inclined surfaces, with the dip of 10 degrees with respect to the horizontal surface, that mimic lateral accretion beds of a point bar system. In this Figure, 5 pairs of surfaces exist. The distance between two surfaces in each pair is 20 meters, and pairs are 100 meters away from each other. This system of surfaces helps to create non-orthogonal grids (depicted in Figure 4b) which follow the 3D structure of inclined surfaces. This way mud and sand bodies can be distributed in the model following the exact dip and arc structure of the surfaces. By using non-orthogonal grids shown in Figure 4b, the small gap between two arcs of each pair in Figure 4a is filled with 50% volume of mud bodies creating the facies F4, and the large gap between the pairs (Figure 4a) is filled with 3% volume of mud bodies creating the facies F1. It was assumed that shale is saturated 100% with water, and sand is saturated 90% with oil and 10% with water. Shale objects are considered to be ellipsoid with length and width similar to previous section.

Figure 5a shows a model of a point bar system using the aforementioned approach of circular arcs and non-orthogonal cells, (Model (a)). The dimension of Model (a) is 500 m x 50 0m x 20 m (L x W x H) with non-orthogonal cells of 1 m x 1 m x 1 m (similar to the grid pattern shown in Figure 4b). In Figure 5a, Model (a) consists of a 3D point bar system with 5 clinoforms having 10° dip. This model contains more than 7 million cells and sufficiently captures the 3D structure of the point bar system. A comparison between the point bar Model (a) and the inclined shale model used in the previous section, shows that the structure in point bar Model (a) is more complicated than structure in the inclined shale model but the point bar Model (a) uses fewer cells to capture the structure because the cells are non-orthogonal.

Figure 5b illustrates the rescaling of the Model (a) using orthogonal grids of 1 m x 1 m x 1 m (total of 5 million cells). This model is called Model (b). Models (a) and (b) are nearly comparable and their facies histograms are almost similar. Figure 5c shows a model with the grid size of 25 m (across the point bar) x 1 m, (along the point bar) x 1 m using orthogonal grids and up-scaling the Model (a) across the point bar. This model is called Model (c). Model (d) depicted in Figure 5d is similar to Model (c), except that the up-scaling has done along the point bar strike to create grids of 1 m (across the point bar) x 25 m (along the point bar) x 1 m. To make the grid size of models (c) and (d) clearer, grid sizes for each direction are shown with arrows on the corner of the Figures 5c and d.

Models (c) and (d) are exported for simulating SAGD process by CMG STARS® using four horizontal well-pairs. From simulation results we see that when SAGD well-pairs are placed across the beds' dip, steam moves upward following a pathway along the dip of the beds. However, in the case where SAGD well-pairs are placed parallel to the strike of the beds, a continuous shale barrier can significantly obstruct steam chamber growth. The result of this non-uniform chamber growth affects the cumulative oil produced shown in the following figure, Figure 6 shows that placing the SAGD well-pairs across the dip of the point bar beds results in higher recovery compared to placing the SAGD well-pairs parallel to the beds strike.

Conclusions

Based on the results of this study, it is concluded that SAGD well-pairs are better placed across the dip of point bar beds to achieve the maximum ultimate recovery factor. It is important to note that items such as geologic heterogeneity, non-flat pay base, surface facility limitations and economic aspects of an *in situ* project were not considered in this study. In some cases local conditions will dictate a different well orientation from the conclusion of this study.

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