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SAGD Pad performance in a point bar deposit with a thick sandy base

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ABSTRACT

The McMurray Formation in Alberta, one of the largest oil accumulations in the world, hosts bitumen with viscosity typically greater than 1 million cP. This formation is heterogeneous containing sedimentological elements such as point bar deposits which in turn consist of inclined heterolithic strata of interlayered sand-shale/siltstone sequences and abandoned mud channels. Due to shale/siltstone interbeds, the reservoir presents severe lateral and vertical lithological heterogeneity which limit vertical flow of steam ascension and bitumen drainage. As part of an ongoing study on the performance of SAGD in point bar systems, we have evaluated the impact of the geology on pad performance in a clean sand unit (on average 30 m thick) with an overlying highly heterogeneous point bar deposit (on average 20 m thick). The results demonstrate that the performance of a SAGD pad depends on the orientation of the wellpairs within the reservoir even when it contains a thick clean sand interval where the wellpairs are placed near the base of the clean sand. Improved steam-to-oil ratio performance is achieved when the well pairs cut across the shale layers where steam can access multiple layers of oil-laden sand between the shale layers. Even when the steam chamber is relatively uniform in the basal sand zone, steam 'fingers' into the heterolithic point bar leading to chamber non-uniformities and less efficient utilization of steam along the well pair, as reflected by the steam-to-oil ratio.

1. Introduction

In the Steam-Assisted Gravity Drainage (SAGD) process, shown in cross-section in Fig. 1, steam is injected into an upper well and fluids are produced from the reservoir through a lower well that is positioned below and largely parallel to the injection well (Gates, 2011). SAGD is used in reservoirs where the oil is viscous, such as bitumen, and cannot be produced under primary or flooding processes. The oil sands in the Lower Cretaceous McMurray Formation in Alberta is one of the largest bitumen accumulations in the world (Peacock, 2009; Hubbard et al., 2011). The bitumen in this formation has viscosity typically between 1 and 7 million cP and thus, the oil must be heated to lower its viscosity so that it can be produced from the reservoir. In SAGD, when heated by injecting steam into the reservoir to over about 200 °C, the viscosity of the bitumen drops to about 10 cP and together with the density difference between the mobilized bitumen and the steam, the bitumen drains within the reservoir (Gates et al., 2007) to the production well. As bitumen is drained from the reservoir, the steam replaces it within the oil sand and as the process evolves, the depletion chamber extends within the reservoir.

In a perfect reservoir, the steam chamber grows uniformly within the system. However, Middle McMurray Formation oil sands reservoirs in Alberta are heterogeneous due to a point bar depositional environment (Strobl et al., 1997; Fustic, 2007; Fustic et al., 2012; Hubbard et al., 2011; Labrecque et al., 2011; Musial et al., 2012; Su et al., 2013). The heterogeneity takes the form of sandwiched sand and shale intervals, referred to as Inclined Heterolithic Strata (IHS) in the reservoir (Nardin et al., 2013). Steam injected into the formation will flow readily within the sand intervals as steam rises and bitumen drains but will be blocked by the shale layers. This implies that steam movement within the reservoir will not be uniform and thus the steam conformance in the reservoir is not ideal. IHS is the major cause of steam chamber non-uniformities in SAGD operations which means that the thermal efficiency and well utilization is compromised (Yang and Butler, 1992; Chen et al., 2008; Gotawala and Gates, 2010).

Su et al. (2013) have shown how IHS can affect the shape of the steam chamber and the resulting impact on the steam-to-oil ratio (SOR, where steam is expressed as cold water equivalent). Su et al. discovered that the orientation of the SAGD well pair within the point bar deposit can affect the performance of SAGD. Su et al. (2014) showed that the performance of a pad of SAGD wellpairs depended on the orientation of the pad within the point bar deposit. However, the geological models that Su et al., (2013, 2014) examined were entirely IHS and thus represent the worst case scenario with respect to the impact of IHS on SAGD performance.

Here, we examine the more common situation where there is a

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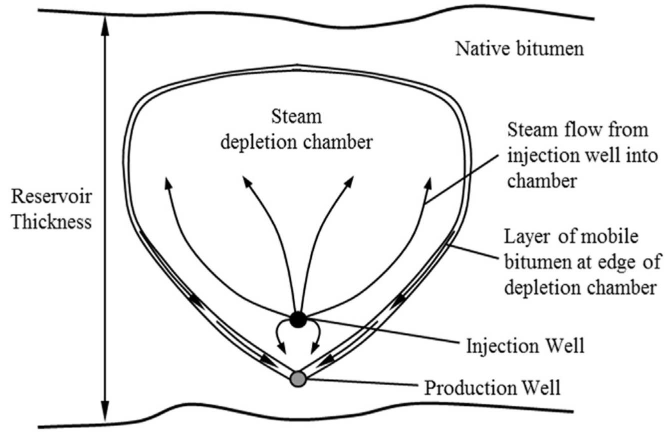

Fig. 1. Cross-sectional view of the Steam-Assisted Gravity Drainage (SAGD) recovery process. The separation between the injection and production wells typically ranges from 5 to 7 m and the length of the wells is generally from 500 to 1000 m.

Table 2
Reservoir simulation model properties for each geological body.

Item	Point Bar	Sandy Base
Reservoir thickness, m	20	30
Porosity, %	0.3 (sand)	0.35
Permeability, mD	4800 (sand)	5530
Oil Saturation	0.5 (sand and shale)	0.65
Original Oil In Place (OOIP), Sm^3	5,280,000	4,840,000

blocky sand zone at the base of the IHS interval; this is the case for many commercial oil sands operations where towards the bottom of the reservoir there is a sand-rich, oil-rich interval over which there is an IHS interval (Strobl et al., 1997; Nardin et al., 2013; Strobl, 2013). In the research reported here, we combined a single point bar (IHS) model with a basal clean sand deposit and examine how the orientation and position of a SAGD pad affects individual wellpair and pad scale performance.

2. Methods and materials

2.1. Geological setting

The geological setting is described in detail in Leckie and Smith (1992), Smith et al. (2009), Patruyo (2010), and Su et al., (2013, 2014). In brief, the McMurray Formation is contained within the Lower

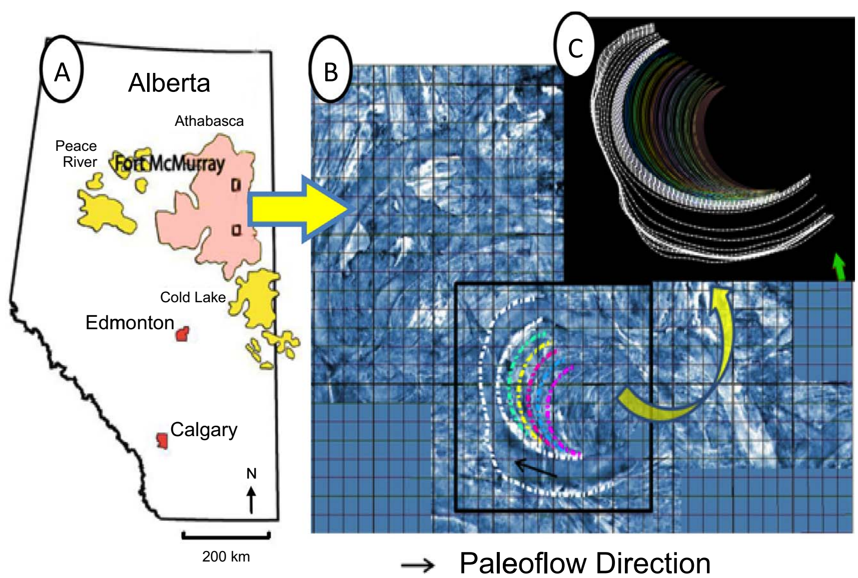

Fig. 2. Overview of study area and regional geological context: (A) location of study area in Alberta, Canada; (B) three-dimensional (3D) seismic time slice across the study with mud filled channel and point bar deposit; (C) 3D view of mud-filled channel geometry and circular arcs used for creating inclined surfaces that mimic lateral accretion beds are shown on the upper right (modified from Su et al. (2013)).

Table 1
Facies used in geological model.

Facies A	Description	Breccia-dominated sandstone with subangular to subrounded clasts. Insignificant bioturbation with mudstone clasts occupying about 30%. Grain sizes typically 3–4 mm in diameter.
	Permeability range	Sand 0.5–4 D
Facies B	Description	Mudstone clasts with angular to sub-rounded mud rip-up clasts in matrix of fine to medium-grained bitumen-saturated sand with up to 0.5% coarser grained sands
	Permeability range	Sand 0.25–1 D
Facies C	Description	Medium-grained sandstone and coarse grains with ripple cross-stratified sands and planar laminated sands evident with low-angle cross stratification also present near the top of the IHS. bitumen saturates most of the sand although some gas-containing sands are found at the top of the IHS unit capped by the upper McMurray Formation argillaceous sands.
	Permeability range	Sand 4–10 D
Facies D	Description	Interbedded fine-grained bitumen-saturated sandstone and siltstone. Planar laminated siltstone intervals which are extensively bioturbated with local soft sediment deformation and mud rip-up clasts.
	Permeability range	Sand 3.5–8 D