SPE 109873

Effects of Reservoir Heterogeneities on the Steam-Assisted Gravity Drainage Process

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This paper was prepared for presentation at the 2007 SPE Annual Technical Conference and Exhibition held in Anaheim, California, U.S.A., 11–14 November 2007.

Abstract

The success of steam-assisted gravity drainage (SAGD) has been demonstrated by both field and laboratory studies mostly based on homogeneous reservoirs and reservoir models. A comprehensive understanding of the effects of reservoir heterogeneities on SAGD performance is required, however, for wider and more successful implementation. This work presents a numerical investigation of the effects of reservoir heterogeneities on SAGD using a stochastic model of shale distribution. Two flow regions, the near well region (NWR) and the above well region (AWR), are identified to decouple the complex effects of reservoir heterogeneities on the SAGD process. Numerical simulations are conducted with various realizations of shale distribution to compare SAGD performance in terms of the effects of NWR and AWR. Hydraulic fracturing is proposed to enhance steam chamber development for reservoirs with poor vertical communication and the feasibility of hydraulic fracturing is discussed in terms of in-situ stresses and well orientations. Fracturing the formation around both the injection and production wells is found to improve steam distribution, oil production rate, and the oil-steam ratio.

Introduction

Vast quantities of heavy and extra-heavy oil (bitumen) resources have been found worldwide. For example, an estimated original heavy oil in place of more than 1.8 trillion barrels is present in Venezuela, 1.7 trillion barrels in Alberta, Canada, and 20–25 billion barrels on the North Slope of Alaska, USA[1]. Due to the significant viscosity of the crude at reservoir temperature, however, the technical and economic recovery of these resources presents a significant challenge. Thermal recovery, and steam injection in particular, is tremendously successful for such resources. To date, more than 4 billion bbl of oil have been recovered as a result of steam injection. Nevertheless, conventional steam injection candidates are limited to on-shore, relatively shallow, low pressure, thick, permeable, and homogeneous sands where benign surface conditions exist. Recent advances in horizontal well technology have emerged that expand the applicabability of thermal recovery[2]. Of the thermal methods, steam-assisted gravity drainage (SAGD) appears to be quite promising, especially for bitumen.

A typical SAGD process is illustrated in Fig. 1. Two horizontal wells are placed close to the bottom of a formation. The injector well is placed directly above the producer a short vertical distance (4–10 m). Steam is injected continuously into the upper well, and rises in the formation, forming a steam chamber. Cold oil surrounding the steam chamber is heated, becomes mobile as its temperature increases, and flows together with condensate along the chamber boundaries toward the lower well that functions as a producer[3]. The SAGD technique enjoys many advantages over other thermal methods, especially the conventional steam flooding methods. SAGD overcomes the shortcomings of steam override by employing only gravity as the driving mechanism, which leads to a stable displacement and a potentially high oil recovery. Moreover, in the SAGD process, the heated oil remains hot and movable as it flows toward the production well; whereas, in conventional steam flooding, the oil displaced from the steam chamber cools and consequently oil-phase viscosity increases as oil flows to the production well.

To design an effective SAGD field project, a good understanding of the complicated physics is needed for reliable prediction of performance. A vast literature on the SAGD concept has been developed since it was first introduced by Butler and his colleagues in the late 1970s[4,5].

Butler developed a gravity drainage theory based on numerous simplifying assumptions, such as steam chamber pressure remains at the original reservoir pressure and the steam chamber must remain connected to the producer. He derived a semi-analytical numerical solution to predict the oil drainage rate. Additinoally, he and his coworkers also reported experimental data obtained with a scaled visual laboratory model. Reiss[6] proposed modifications to Butler's gravity drainage model by using an empirical dimensionless temperature coefficient and the maximum velocity, and Akin[7] also modified the model by incorporating asphaltene content dependent viscosity to better match the experimental data in the literature. Nasr *et al*.[8] studied steam-liquid counter-current and co-current flows for different permeabilities and initial gas saturations with a non-steady state, laboratory steam-front dynamic tracking technique.

Numerical simulation has been widely used by many researchers to investigate the physical process and practical