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Original article

Study of reservoir properties and operational parameters influencing in the steam assisted gravity drainage process in heavy oil reservoirs by numerical simulation

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ABSTRACT

This study was originally aimed at suggesting a two-dimensional program for the Steam Assisted Gravity Drainage (SAGD) process based on the correlations proposed by Heidari and Pooladi, using the MATLAB software. In fact, the work presented by Chung and Butler was used as the basis for this study. Since the steam chamber development process and the SAGD production performance are functions of reservoir properties and operational parameters, the new model is capable of analyzing the effects of parameters such as height variation at constant length, length variation at constant height, permeability variation, thermal diffusivity coefficient variation and well location on the production rate and the oil recovery among which, the most important one is the thermal diffusivity coefficient analysis. To investigate the accuracy and authenticity of the model outcomes, they were compared with the results obtained by Chung and Butler. The privilege of this method over that proposed by Heidari and Pooladi lies in its ability to investigate the effect of thermal diffusivity coefficient on recovery and analyzing the effect of temperature distribution changes on thickness diffusivity. Based on the observations, results reveal that the proposed model gives more accurate predictions compared to the old model proposed by Chung & Butler.

1. Introduction

SAGD is one of the best methods for heavy oil recovery and this has been proved by several authors such as Aguilera and Artindale [1], and Mendoza et al. [2,3]. The SAGD process attempts to reduce the oil viscosity by decreasing the temperature. In this way, a SAGD process includes two parallel horizontal wells drilled at a distance of about 4 m from each other, as shown in Fig. 1. The hot steam is injected from the injection well which is completed above the other well, namely the production well, and the heated oil and the condensed steam are produced from the production well.

Generally, the simulation of a reservoir in a SAGD process culminates in two methods. The first method of simulating arise from some kinds of tedious numerical calculation to which a wide range of equations and conditions must be applied so that researchers could find logical results [4]. Prevalently, commercial softwares in the petroleum engineering field take the advantage of this method in their structures. It is believed that thanks to summing up all governing equations including all transform phenomena expressions and thermodynamic equation of states, numerical method would fulfill accurate results in various EOR manners [4–6]. However, the significant drawback which numerical methods almost have is its inabilities to converge on final results in a short time [5]. This weakness impelled researchers to

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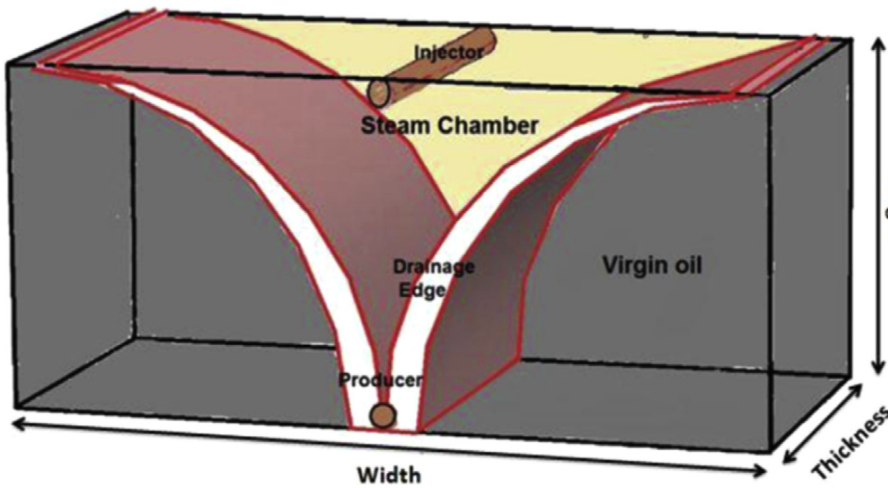

Fig. 1. Concept of the SAGD process, from Sabeti et al., in 2016.

find another way. Consequently, petroleum engineers have always been pursuing an alternative as a second method to tailor this issue. In the analytical method, it was tried the SAGD process to be adopted with main in-situ mechanisms and processes happening during the oil recovery operation. As a result, several simplified assumptions usually were considered by researchers to obtain an equation to estimate the oil production rate. Analytical methods lead to pretty accurate outcomes in a flash, and to do so they do not require a lot of raw data about reservoirs. Hence, the advantage of analytical method largely outweighs the disadvantage of numerical method in the SAGD process.

Butler [2,7] should be considered the first person who developed a sturdy analytical method for the SAGD process. In 1981, Butler [7] conducted some experiments and admitted the existence of steam chamber. Assuming a constant temperature in the steam chamber and a steady state temperature distribution outside the steam chamber corresponding to the instantaneous rate of interface advance, Butler derived his first model for SAGD production process. Butler [2] further improved his own theory by locating the tangent line of the original steam interface curve. In 1987, Butler [8] also made a completely new model, called steam fingering model, which could anticipate the steam chamber development rate. Afterward, Reis [9] simplified Butler's model. He assumed that the steam chamber shape to be an inverted triangle. The temperature and oil viscosity in front of the steam chamber were considered to be steady state. What Reis suggested was totally easy to understand.

In 2007, Edmunds and Peterson [10] supposed that the steam chamber was an inverted triangle and the steam chamber expansion rate remained constant. Edmunds and Peterson employed the energy balance equation and the material balance equation to yield the system oil ratio for the horizontal expansion period of steam chamber. Later, Miura et al. [11] extended the analytical model to the steam chamber developing downwards period on the basis of Edmunds and Peterson's work. Furthermore, in 2014, Wei et al. [12] assumed that the steam chamber shape was a combination of two symmetrical parabolas or an inverted triangle. The oil production rate was expressed by the steam chamber expansion rate as a function of reservoir properties and injection parameters.

Alali et al. [13] showed the steam chamber development by condensing steam at the chamber boundary and giving latent energy to the surrounding reservoir. They observed heated oil and water are drained by gravity along the chamber walls towards the production well. Ji et al. [14] were eager too to observe how drainage happens when a bed reservoir having connate water is under a SAGD operation. They suggested that in a SAGD process near the edge of a steam chamber, the viscosity of bitumen can be decreased by several orders of magnitude by the release of latent heat from injected steam. Consequently, the heated bitumen starts to flow downwards to a horizontal production well, under the action of gravity.

In continuation of the SAGD modeling, Sabeti and et al. [15] recently developed a semi-analytical model using an exponential geometry to predict the exact location of interface at each time step of the steam injection process. Even though the critical mechanism of the oil production in their SAGD modeling has still been introduced the heat transfer ahead of the steam chamber by conduction, the authors made a big change in older models by replacing an exponential function with the linear geometry assumed by Reis [9]. Having modified the Reis model, they accurately could estimate both the oil production rate and the energy required for a SAGD process in Alberta called UTF project.

As reported by authors mentioned above, the existence and growth of the steam chamber in a SAGD process have been proven and agreed upon considering the corresponding effective parameters. Since the chief part of a SAGD process is the formation of steam chamber and since the growth of steam chamber and production from the well are functions of reservoir properties and operational parameters, investigating the formation and development of the chamber look vital. Hence, after presenting the main mathematical formula for simulation of a SAGD process, the authors of this manuscript make analyses the influence of some key fluid and reservoir properties so as to demonstrate the importance of each one in the SAGD process.

2. Model description and assumptions

A SAGD process can be subdivided into three main parts, where it begins with the formation of the steam chamber. At this stage, the chamber starts developing and the diluted oil tends to drain toward the production well. This stage includes a quick unsteady state condition and a non-concurrent flow. The second stage begins with the steam chamber reaching the cap rock. The chamber starts to expand sideways and the interface forms a constant geometrical shape and moves toward the reservoir boundaries in a pseudo steady state manner. With the expansion