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Production Improvement of Heavy-Oil Recovery by Using Electromagnetic Heating

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Abstract

Heavy oil is produced primarily by reducing its viscosity using well-known processes such as steam injection, steamsoak, and in situ combustion. A recent technique for recovery consists of resistively heating the reservoir using electrical energy. Resistive heating can be particularly beneficial for reservoirs in which conventional steam operations are uneconomic.

Resistive heating is a special case of a more general form of heating based on electromagnetic energy (EM). EM has the following advantages over steam injection: it can be used to recover extremely heavy hydrocarbon, is not susceptible to heat losses through a wellbore, and its water requirements are far less than for steam. Compared to resistive heating, EM heats within the formation. Thus (for downhole generation) larger well spacing may be possible.

Although its potential was recognized in the late 70's, there are relatively few field applications of EM heating and even fewer engineering studies. The purpose of this paper is to examine how the performance response of EM compares to resistive heating.

This paper presents a model for single-phase flow to calculate the temperature distribution, and the productivity improvement obtained when an EM heating source (an antenna) is placed in a well. We consider both counter-current flow, in which the well with the antenna is also a producer, and co-current flow where the flow is opposite to EM energy flow. Flow is taking place concurrently with the addition of EM energy.

Steady-state solutions for counter-current flow showed a relative productivity index (PI) increase of 2.5 - 12.0 times cold oil production when the input power was varied from 20 to 150kw. A peak improvement occurred when the adsorption coefficient was between $1e^{-3}$ and $1e^{-1}$ m^{-1}, which indicates that there is an optimum adsorption coefficient. Resistive heating is the special case of an infinite adsorption coefficient and the existence of an optimum suggests that EM heating can be more effective than resistive heating. For co-current flow, the improvement was even greater for the same input power. Calculated energy gains (the ratio of produced to injected energy) were in the 8 to 163 range; successful steam injection processes have gains of around 10.

Introduction

Conventional thermal recovery processes such as steam injection, steam soak, and in situ combustion inject one fluid to change oil properties in situ to make it flow easier. Therefore, there are complications of generating, transporting (while avoiding excessive heat losses), and disposing the injected fluid. Electromagnetic heating (EM) does not require a heat transporting fluid, which can be particularly beneficial for deep reservoirs and thin pay-zones where conventional methods are not cost-effective due to excessive heat loss through the adjacent formations (Chakma and Jha 1992). Furthermore, conventional oil field and electrical equipment can be used, which makes this technique attractive where available space is limited as would be the case on offshore facilities. The components of the equipment required for EM heating has been described elsewhere (Bridges et al. 1985; Haagensen 1986; Sierra et al. 2001) and will not be covered in this paper. Since EM heats instantaneously from within, this method is independent of the low thermal conductivity of the oil sand and is unaffected by permeability variations within the formation (Kim 1987).

Electrical heating applications can be divided into two categories based on the frequency of the electrical current used by the antenna:

(1) Low frequency currents are used in electrical resistive heating (ERH) and are less than 60 Hz so that, resistance heating dominates the process;