SPE 116038

Thermally-Enhanced Evaporation Process in Fractured Reservoirs—A Pore-Network Study

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This paper was prepared for presentation at the 2008 SPE Annual Technical Conference and Exhibition held in Denver, Colorado, USA, 21–24 September 2008.

Abstract
We study evaporation processes in fractured reservoirs under thermally enhanced conditions using pore-network models. The emphasis is on understanding evaporation phenomena and the combined effects of capillarity and viscous forces as are modified by the presence of thermal gradients and an applied heat flux. The temperature dependence of equilibrium vapor concentration and surface tension and macroscopic corner films are included.

The phase distribution evolution, liquid saturation, film flow and recovery rates are obtained as functions of dimensionless parameters in the two cases of positive and negative temperature gradients. The results are obtained without the use of empirical or ad hoc coefficients and parameters.

Strong evaporation effects under thermal conditions, associated with the variation of equilibrium concentrations, are clearly shown. The influence of surface tension variation induced by thermal gradients leads to destabilizing or stabilizing invasion percolation fronts, depending on the direction of the thermal gradient.

The paper finds application to the recovery of volatile oils from fractured or heterogeneous reservoirs by thermal processes, such as steam injection.

1- Introduction
Naturally fractured reservoirs contain a large portion of discovered hydrocarbon reserves worldwide. During primary production, the matrix-fracture pressure differential is the dominant driving force for matrix depletion [1, 2]. Waterflooding is a successful secondary process in water-wet fractured reservoirs, where water can imbibe into the matrix and oil counter flows to the fracture network [3, 4, 5]. However, for oil-wet reservoirs, injected water preferentially flows through the fracture network, resulting in low recovery efficiency [6]. For such reservoirs, improving the recovery efficiency can be obtained by implementing gas injection [7, 8].

The complexity of recovery phenomena in such cases emphasizes the need for sophisticated analysis tools, capable of modeling the intricate physical phenomena and sharply changing fluid interfaces. The development of the models for evaporation in porous media has been the subject of many studies at both macroscopic and microscopic scales. In the macroscopic approaches, the momentum, heat and mass balance equations are applied on continuum porous media, using volume averaging techniques [9, 10]. The weakness of the macroscopic models is the lack of understating of the phenomena at the pore and pore-network scales. More recently, the studies have been focused on microscopic modeling and comprehensive physics of the process (i.e. thermodynamics and transport events) are incorporated with the geometric descriptions of the void space of porous media. [11-15]. Immiscible displacement during drying of porous media was treated as a drainage process [16] and described by invasion percolation theory [17]. Sophisticated pore-network models have been developed for *isothermal* evaporation process in porous media that accounts for the viscous flow of the macroscopic films. It was demonstrated that film flow is a major transport mechanism in the drying of porous media [18-20].

The purpose of this study is to demonstrate the effect of temperature on the evaporative recovery of the matrix fluid by simulation of evolution of the temperature profile and dynamics of gas-liquid displacement front during *non-isothermal* gas