The Effect of Composition on the Role of Evaporation During Oil Recovery By Combustion

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Abstract

Introduction:
Some reservoirs contain oil that is too difficult to produce with conventional means. One of the methods to recover oil from medium and low viscosity in complex reservoirs uses air injection leading to oil combustion. In this case the oxygen in the air burns the heavier components of the oil, generating a heat wave leading to vaporization of lighter components.
Combustion can be used to improve recovery of heavy, medium or light oil in highly heterogeneous reservoirs. The broad range of applicability is covered because not only the high temperatures increase the mobility of viscous oils but also the high thermal diffusion coefficient spreads the heat more evenly and suppresses heterogeneity effects. For this reason combustion is also used for light oils. We will only consider combustion of medium and light oils and not of heavy oils, where coke formation occurs, which will be subsequently combusted.

Use of COMSOL Multiphysics®:
Numerical modeling of the combustion process is difficult due to the disparity in time and space scales at which processes occur. Consequently high resolution is required in the regions where combustion takes place. The molar mass balance equations for liquid and gas components, the reaction and vaporization equations, Darcy velocities equations, heat balance equation, liquid-gas equilibrium equation, initial and boundary conditions are formulated in weak form and implemented in a mathematical interface of COMSOL Multiphysics®.

Results:
The combustion mechanisms are different for light oils, where evaporation is dominant, whereas for medium non-volatile oils combustion is dominant. It is our goal to study the relative importance of evaporation, by studying a two component mixture of volatile light and non-volatile oil.
We derive a simplified model for the combustion evaporation process, which can be implemented in the COMSOL Multiphysics® finite element package. For one set of conditions, the solution consists of a thermal wave upstream, a combined evaporation/ combustion wave in the middle and a saturation wave downstream. For another set of conditions the sequence of evaporation and combustion is reversed and evaporation moves ahead of the combustion. Indeed, from our simulated results we conclude that for a predominantly light oil mixture, evaporation occurs upstream of the combustion process. Moreover, also for the light mixture, the combustion

front velocity is high as less oil remains behind in the combustion zone (Fig. 1). For oil with more non-volatile components, the evaporation is downstream of the combustion zone. As more oil stays behind in the combustion zone, the velocity of the combustion zone is slower, albeit that the temperatures are higher (Fig. 2).

Conclusion:
A mathematical model was proposed to study the effect of oil composition on the role of evaporation during oil recovery by MTO combustion in porous media. The character of MTO wave changes by changing the composition of the oil. Generally the solution consists of three waves, i.e., a thermal wave, an MTO wave and a saturation wave separated by constant state regions, while the sequence of evaporation and oxidation in MTO wave changes with different set of conditions. For a predominantly light oil mixture, evaporation occurs upstream of the combustion process which is also confirmed by previously obtained analytical and numerical solutions for one component volatile oil. Moreover, also for the light mixture, the combustion front velocity is high as less oil remains behind in the combustion zone. The numerical calculations make it possible to estimate the bifurcation points, where the character of the combustion changes from an evaporation dominated process to a combustion dominated process.

Reference

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2. A.A. Mailybaev, D. Marchesin, and J. Bruining. Resonance in low-temperature oxidation waves for porous media. SIAM Journal on Mathematical Analysis, 43:2230, 2011.

Figures used in the abstract

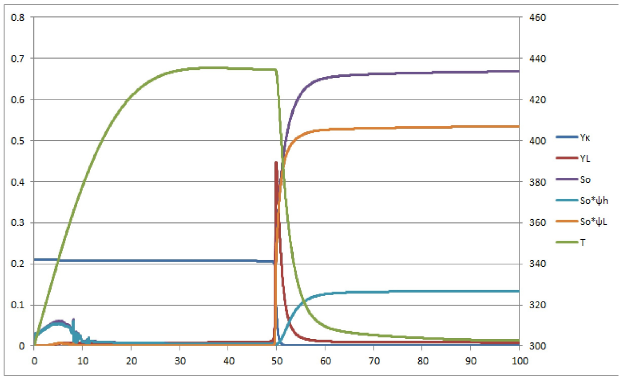

Figure 1: Wave sequence solution with the thermal and MTO regions. Indicated are the distributions of the temperature T, liquid saturation So , oxygen mole fraction Yк, gaseous hydrocarbon mole fraction Yl, light oil saturation So*ψL and heavy oil saturation So*ψL at t=9.7* 10^7 sec in case of ψh=0.2 .

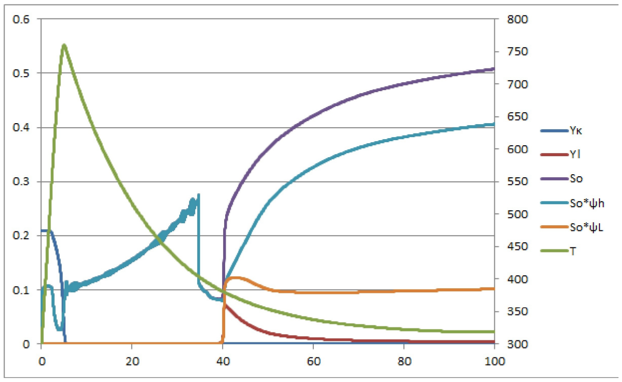

Figure 2: Wave sequence solution with the thermal and MTO regions. Indicated are the distributions of the temperature T, liquid saturation So , oxygen mole fraction Yк, gaseous hydrocarbon mole fraction Yl, light oil saturation So*ψL and heavy oil saturation So*ψL at t=2.1* 10^8 sec in case of ψh=0.8 .