Numerical Simulation of Recovery of Light Oil by Medium Temperature Oxidation in Porous Media

N. Khoshnevis Gargar*[1], A.A. Mailybaev[2], D. Marchesin[2] and J. Bruining[1]
1. Delft University of Technology, Delft, The Netherlands,
2. Instituto Nacional de Matematica Pura e Aplicada, Rio de Janeiro,Brazil

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. For medium viscosity oils, the oxygen in the air burns the heavier components of the oil, generating a heat wave leading to cracking, coke formation and vaporization of lighter components.

Computational Methods: We study a 1-D two-phase flow process possessing a combustion front when a gaseous oxidizer (air) is injected into porous rock filled with light oil. The reaction is simplified in the form of a single reaction, modeled as

ν_l(hydrocarbons)+$O_2 \rightarrow \nu_g$(gaseous products)

The model equations are

$$\frac{\partial}{\partial t}\varphi\rho_l s_l + \frac{\partial}{\partial x}\rho_l u_l = -\nu_l W_r - W_v \qquad (2)$$

$$\frac{\partial}{\partial t}\varphi Y_i \rho_g s_g + \frac{\partial}{\partial x}\rho_g u_{gi} = W_v\delta_{i1} - W_r\delta_{i2} + \nu_g W_r\delta_{i3} \qquad (3)$$

$$\frac{\partial}{\partial t}(C_m + \varphi c_l\rho_l s_l + \varphi c_g\rho_g s_g)\Delta T + \frac{\partial}{\partial x}(c_l\rho_l u_l + c_g\rho_g u_g)\Delta T = \lambda\frac{\partial^2 T}{\partial x^2} + Q_r W_r - Q_v W_v$$

Where s_l s_g are the liquid and gas saturations, Y_i $(i=o,h,r)$ are the oxygen, hydrocarbon and remaining gas mole fractions. W_i $(i=r,v,)$ and Q_i $(i=r,v,)$ are the reaction and evaporation rates and heats. ν_i $(i=l,g)$ are the stoichiometric coefficients. Furthermore, u_i , c_i, and ρ_i are the darcy velocity, heat capacity and molar density for the liquid (l) and gas (g).

Results: The analytical and numerical results are shown in Figs. 1 & 2. Shown are saturation s_l, the reduced temperature $\theta = (T-T^{ini})/(T^b-T^{ini})$ and mole fractions Y_o & Y_h.

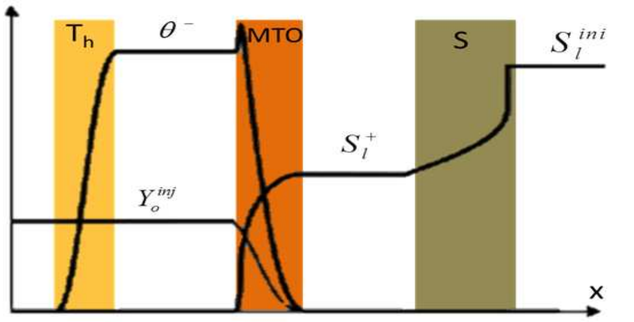

Figure 1. Wave sequence solutions with the thermal wave (T_h), the MTO wave and saturation (S) wave.

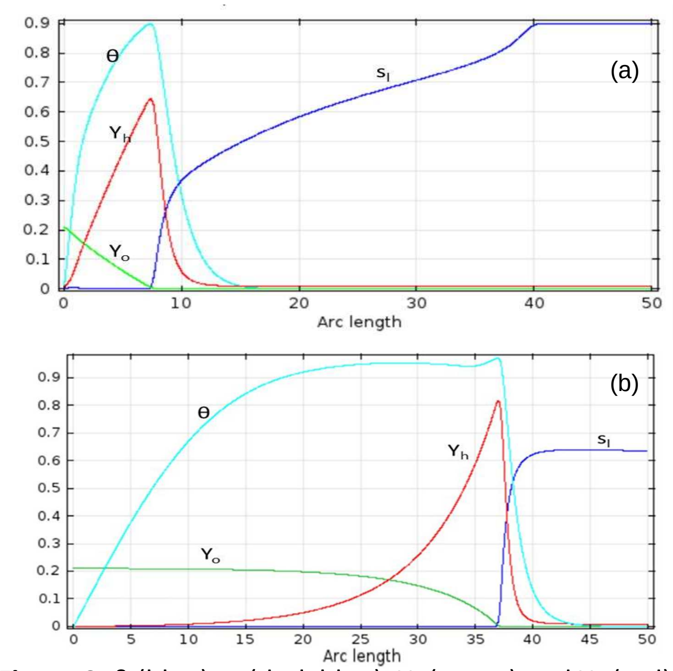

Figure 2. θ (blue), s_l (dark blue), Y_o (green) and Y_h (red) (a) at t=7e6 seconds and (b) at t=3.5e7 seconds

Conclusions:The results show the validity of the numerical results. The main striking insight is that the vaporization occurs upstream of the combustion zone. This is shown both in numerical and in analytical study of the same problem. The initial results indicate that it is possible to study the combustion process in dependence of the combustion rate, vaporization rate and boiling point of the oil.

References:

1. 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.