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Modeling and Simulation of 3D Black Oil Flow Accounting for Asphaltenes Effect of Precipitation and Dissolution in Porous Medium

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ABSTRACT

Asphaltene precipitation causes formation damage in various scales in the porous medium which has unfavorable effects on crude oil production rate, reservoir rock permeability, porosity, viscosity, and wettability. Asphaltene precipitation typically begins to occur at a pressure higher than bubble point pressure. Then, as reservoir fluid pressure decreases, the amount of asphaltene which is precipitated increases. The maximum precipitation occurs at the reservoir bubble pressure. In depositional cases, asphaltene precipitates first, then it deposits near the wellbore, while in non-depositional cases, asphaltene precipitates but there is no asphaltene deposition. In fact, in the non-depositional case, oil and precipitated asphaltene are in equilibrium that means the oil phase is saturated with precipitated asphaltene. Hereafter, when reservoir pressure falls below the bubble point pressure, asphaltene tends to dissolve back into the crude phase. Asphaltene precipitation happens by changing the reservoir conditions and its properties. Three factors contribute to asphaltene precipitation rate including deposition on the surface, deposits entrainment, and plugging of the pore throat. In our study, it is of particular interest to include the asphaltenes effect mentioned before as a plugin to the system of the black oil model. So besides uses of the systems of three equations for black oil, we will share them with another one that is the equation of asphaltenes precipitation and dissolution.

INTRODUCTION

Asphaltenes are a serious problem not only inflow inside the reservoir deterring the fluid flow, but also in the zone near-wellbore when they are deposited in larger quantity, inside the wellbore and in the system of transport of crude oil. So, modeling rigorously their effects in eventually coherent coexistence with the black oil flow is essential. It is important to mention that not all precipitated asphaltenes depose. There are two ways to take account of asphaltenes effects. The first one is that in the system of the equations of black oil to take account or better say to update the main changed parameters like reservoir rock permeability, porosity, viscosity, and wettability. But even as primary judgment this is simple, in practice this is impossible just to mentioned changes in wettability. For the other parameter exist some empirical formula to update permeability, porosity, viscosity. By the judgment of the author of this work, this empirical formula must be used only when does not exist in other ways. In our case, we will follow the most theoretical possible model that is a system of three equations for the black oil and another for EOS modified (because we suppose now the presence of asphaltenes).

So, we have to develop a modeling approach for asphaltene precipitation based on the equations of state, which account for association forces between molecules, for example, the CPA and PC-SAFT equations of state. The modeling approach should be as simple as possible and easy to be implemented into reservoir PVT simulation software.

METHODOLOGY:

FollowingAlay Arya [1] we can summaries as bellow from the standard EoS:

The Cubic Plus Association (CPA) equation of state (EoS), proposed by Hunter et al [8], can be expressed for mixtures in terms of pressure P, as shown in equation (1). The addition of the association term in the CPA EoS can fairly describe the polar and hydrogen bonding forces between molecules. The CPA EoS has been successful to describe the association system.

$$P = \frac{RT}{V_m - b} - \frac{a(T)}{V_m(V_m + b)} - \frac{1}{2}\frac{RT}{V_m}\left(1 + \rho\frac{\partial lng}{\partial \rho}\right)\sum_i x_i \sum_{A_i}\left(1 - X_{A_i}\right) \qquad (1)$$

Where P is pressure, R is gas constant, T is temperature, V_m is volume, b is the Co-volume parameter of the mixture, *a* is the Energy parameter of the mixture (temperature dependent), g is Radial Distribution Function, x_i is Mole fraction of component *I*,X_{A_i} is Mole fraction of site-A in molecule *i* not bonded to any other site/s.

And the other terms are given as below:

$$a(T) = \sum_i \sum_j x_i x_j a_{ij}(T) \qquad (2)$$

$$a_{ij}(T) = \sqrt{a_i(T) a_j(T)}\left(1 - k_{ij}\right) \qquad (3)$$

$$b = \sum_i x_i b_i \qquad (4)$$

When the CPA EoS is used for mixtures, the conventional mixing rules are employed in the physical term (Soave-Redlich-Kwong: SRK) for the energy and co-volume parameters. The geometric mean rule is used for the energy parameter $a_{ij}(T)$. The pure compound energy parameter (a_i) of the EoS is given by temperature dependency proposed by Mathias-Copeman [9], while co-volume parameter(b_i) is temperature independent.

$$a_i(T) = a_{0,i}\left[1 + c_{1,i}\left(1 - \sqrt{\frac{T}{T_{c,i}}}\right) + c_{2,i}\left(1 - \sqrt{\frac{T}{T_{c,i}}}\right)^2 + c_{3,i}\left(1 - \sqrt{\frac{T}{T_{c,i}}}\right)^3\right]^2 ; for \frac{T}{T_{c,i}} < 1; \quad (5)$$

$$a_i(T) = a_{0,i}\left[1 + c_{1,i}\left(\sqrt{\frac{T}{T_{c,i}}}\right)\right]^2 ; for \frac{T}{T_{c,i}} \geq 1; \qquad (6)$$

where$T_{c,i}$ is the critical temperature of the *i*th component

The energy parameter temperature dependency proposed by Mathias-Copeman can be reduced to temperature dependency proposed by Soave [2] as below

$$c_{l,i} = 0.480 + 1.574\omega - 0.176\omega^2;\ c_{2,i} = c_{3,i} = 0; \qquad (7)$$

The key element of the associated term is X_{A_i}, which represents the mole fraction of site-A in the molecule of component *i* not bonded to other sites, while x_i is the mole fraction of component *i*. X_{A_i} is related to the association strength $\Delta^{A_iB_j}$ between two sites belonging to two different molecules, e.g. site A on molecule A and site B on molecule *j*, determined from

$$X_{A_i} = \frac{1}{1 + \rho \sum_j x_j \sum_{B_j} X_{B_j} \Delta^{A_iB_j}} \qquad (8)$$

where the association strength $\Delta^{A_iB_j}$ in CPA is expressed as:

$$\Delta^{A_iB_j} = g(\rho)\left[exp\left(\frac{\varepsilon^{A_iB_j}}{RT}\right) - 1\right] b_{ij}\beta^{A_iB_j} \qquad (9)$$

Where

$$b_{ij} = \frac{b_i + b_j}{2} \qquad (10)$$

with the radial distribution function:

$$g(\rho) = \frac{1}{1 - 1.9n};\ \ n = \frac{1}{4}b\rho; \qquad (11)$$

In the expression for the association strength $\Delta^{A_iB_j}$, the parameters $\varepsilon^{A_iB_j}$ and $\beta^{A_iB_j}$ are called the association energy and the association volume, respectively. These two parameters are used only for associating components, and along with the three additional parameters of the SRK term, they are the five pure-compound parameters of the model. They are obtained by fitting vapor-pressure and liquid density data. For inert components such as hydrocarbons, only the three parameters of the SRK term are required, which can either be obtained from vapor pressures and liquid densities or be calculated conventionally (from critical data, acentric factor).

(i) CR-1

$$\varepsilon^{A_iB_j} = \frac{\varepsilon^{A_iB_i} + \varepsilon^{A_jB_j}}{2}; \quad \beta^{A_iB_j} = \sqrt{\beta^{A_iB_i}\beta^{A_jB_j}}; \tag{12}$$

(ii) Elliott CR:

$$\Delta^{A_iB_j} = \sqrt{\Delta^{A_IB_i}\Delta^{A_jB_j}} \tag{13}$$

Now the equations of the black oil model that include classic EoS are given as below:

The black-oil model

The three equations of the flow of black oil are given as bellow for 3 phases: w, g, o

Water phase:

$$\frac{\partial(\emptyset\rho_w S_w)}{\partial t} = -\nabla\cdot(\rho_w\vec{u}_w) + q_w \tag{14}$$

Oil phase:

$$\frac{\partial(\phi\rho_{O_o}S_o)}{\partial t} = -\nabla\cdot(\rho_{O_o}\vec{u}_o) + q_O \tag{15}$$

Gas-phase

$$\frac{\partial\left(\overbrace{(\emptyset\rho_{Go}S_o}^{dg} + \overbrace{\emptyset\rho_g S_g)}^{fg}\right)}{\partial t} = -\nabla\cdot\left(\underbrace{\rho_{Go}\vec{u}_o}_{flow\ dg} + \overbrace{\rho_g\vec{u}_g}^{flow\ fg}\right) + qG \tag{16}$$

The pressure equation

$$c_T\frac{\partial p}{\partial t} + \nabla\cdot\underline{u} = \sum_{\alpha}\frac{1}{\rho_\alpha}\{q_\alpha - \rho_\alpha^o c_\alpha \underline{u}_\alpha\cdot\nabla p\}, \quad \alpha = w, o, g, \tag{17}$$

The saturation equation

$$\rho_\alpha \emptyset \frac{\partial_{S_\alpha}}{\partial t} + \rho_\alpha \nabla \cdot \underline{u}_\alpha = -\left(s_\alpha \rho_\alpha \emptyset^0 c_p + \emptyset S_\alpha \rho_\alpha^0 c_\alpha\right) \frac{\partial p}{\partial t} \qquad (18)$$

Substituting the classic EoS with the new formulation to the file of AD-GPRS software that contains the EoS procedure we obtain the following result in the graphical frame.

We refer to two cases like following:

1) Flow black oil **not** taking into account asphaltene deposition

2) Flow black oil taking account asphaltene deposition

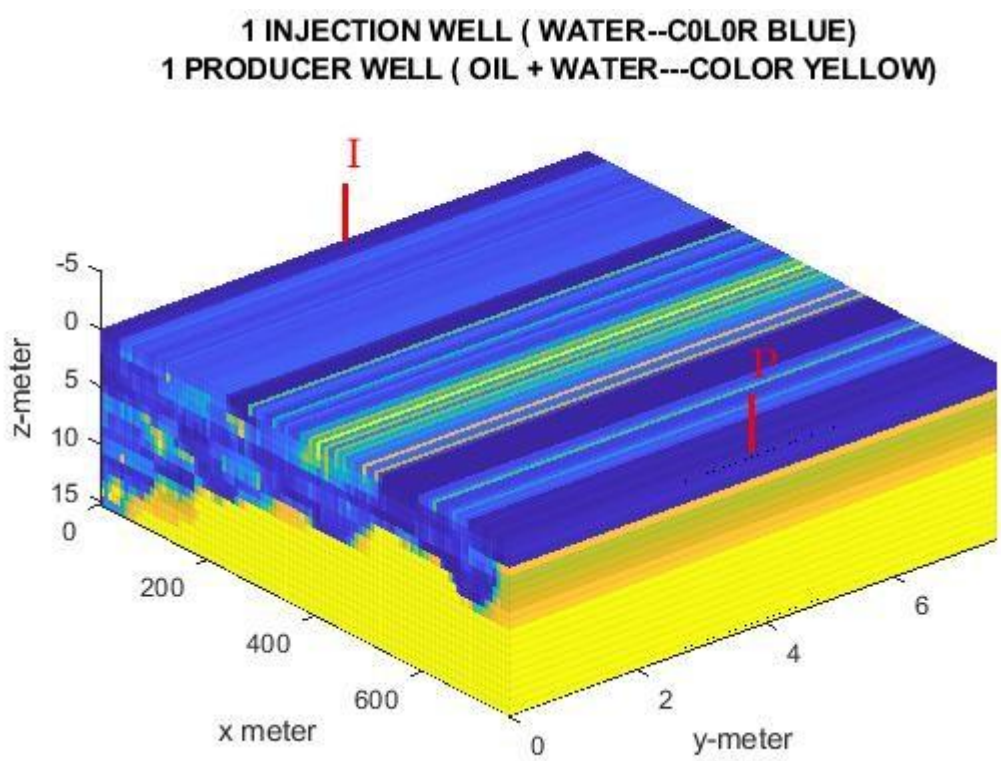

Figure No. 1: A synthetic reservoir with black oil and with 1 injector and 1 producer well (yellow-oil)

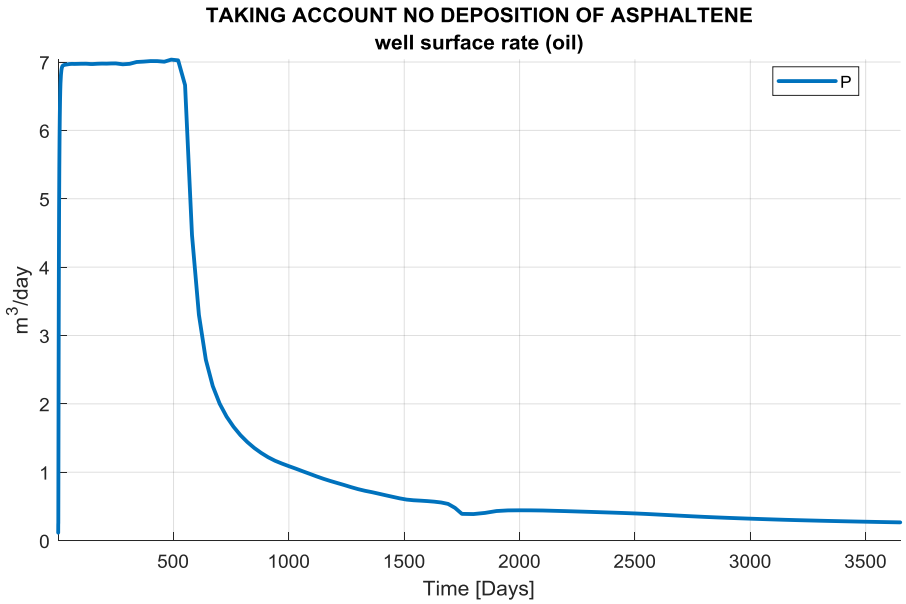

Figure No. 2: Rate of the producer when asphaltene deposition is neglected

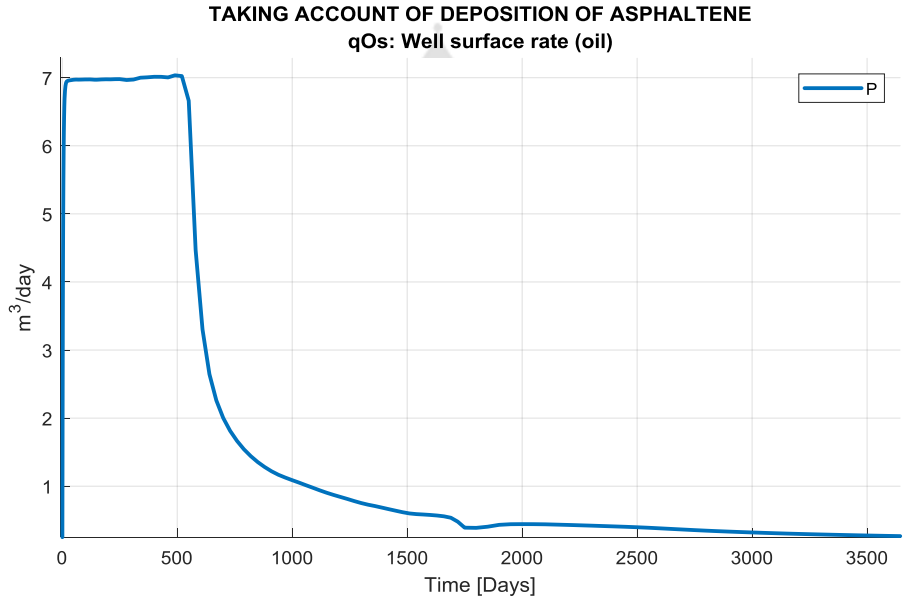

Figure No. 3: Rate of producer when asphaltene deposition is taken accounted

As seen from figure 2 and figure 3 the horizontal part of curbe of production is lower in case of taking account deposition of asphaltene, so we take less oil and this tendence is in growing.

CONCLUSION

Asphaltenes are a serios problem not only inflow inside the reservoir deterring the fluid flow, but also in the zone near wellbore when they are deposited in larger quantity, inside the wellbore and in the system of transport of crude oil. So, modeling rigorously their effects in eventually coherent coexistence with the black oil flow is essential**.** As seen in our demonstration deposition of asphaltene is a problem not only in the wellbore, near wellbore or in the pipelines. It also has a big influence in producing oil. There adifferent ways of avoiding this phenomenon one of which is the injection of soluble agent, CO_2, solvent etc.

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