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Comparison between Compositional and Modified Black-Oil Simulation

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Abstract

The compositional simulation is still much more expansive than black-oil simulation. Therefore, for full-field reservoir simulation of volatile/near critical oil and gas condensate fluid systems, it was attempted to avoid compositional models by using modified black oil (MBO) models. In the paper there are presented, in short, the main works in which comparisons between compositional and MBO simulation have been made, and, consequently when a MBO model is adequate for full-field reservoir simulation of volatile/near critical oil and gas condensate fluid systems.

Key words: *black-oil simulation, compositional simulation, modified black oil model.*

Introduction

Petroleum reservoir fluids contain thousands of chemical components that affect their physical properties and phase behavior during production. Initially, all simulations were based on the black-oil fluid model, where the hydrocarbon system is represented by two pseudo-components, oil and gas, according to their status at standard conditions. In the compositional simulation the hydrocarbon system is represented by an arbitrary number of components and pseudo-components, phase behavior is represented by an Equation of State (EOS) and phase equilibrium relations, and this requires flash calculations. As we go from black-oil to compositional models, the number of equations and components increases, and the choice of equations and variables gets more complex. Therefore, for full-field reservoir simulation of volatile/near critical oil and gas condensate fluid systems, it was attempted to avoid compositional models by using modified/extended black oil (MBO) models or, recently, by using compositional streamline simulation [10]. The MBO simulation considers three components (dry gas, oil, and water). The main difference between the conventional black-oil simulation and the MBO simulation lies in the treatment of the liquid in the gas phase. The MBO approach assumes that stock-tank liquid component can exist in both liquid and gas phases under reservoir conditions. It also assumes that the liquid content of the gas phase can be defined as a sole function of pressure called vaporized oil-gas ratio, R_v. This function is similar to the solution gas-oil ratio, R_s, normally used to describe the amount of gas-in-solution in the liquid phase.

Both in the fully compositional and MBO formulations of reservoir simulation, an accurate description of the hydrocarbon system and its properties is important. In the compositional case the phase behavior of the hydrocarbon system is an integral part of the simulation. Equal phase fugacity conditions or flash calculations are used to determine the phase split and composition.

The first comparisons between compositional and MBO simulation were made by Coats [1] and McVay [12] for the single-well radial models and only under natural depletion process.
After that, in the next works (El-Bambi and McCain [6], Fevang et. al. [8], and Izgec and Barrufet [9]), there have been made comparisons between compositional and MBO simulation for full-field reservoir simulation of volatile/near critical oil and gas condensate fluid systems. Black-oil PVT properties have been generated, in these works, with an EOS model using the Whitson-Torp procedure [18]. It is known that by using Coats' method [1] it is not possible to obtain the PVT properties of the liquid phase at the saturation pressure.

Comparisons Between Compositional And MBO Simulation

1. El-Banbi and McCain [6] presented the results of a full field simulation study for a rich gas condensate reservoir with complex fluid behavior. The MBO model performance was compared with the performance of a compositional model in the water influx and also a field wide history match study was conducted for above and below the dew point.

Reservoir description. It is a high-temperature, high-pressure offshore reservoir. The reservoir has a north-south fault that separates it into two isolated fault blocks.

Fluid characterization. Two surface fluid samples were originally collected before any significant production took place. The two samples underwent complete gas-condensate PVT analysis. EOS model for the fluid was constructed using the Soave-Redlich-Kwong (SRK) EOS [15] with volume shifts as suggested by Peneloux et al [14]. Fluid viscosity was calculated using the Lohrenz-Bray-Clark (LBC) [11] correlation. The procedure suggested by Coats and Smart [2] was used to match the laboratory measurements for the constant composition expansion (CCE) and constant volume depletion (CVD) experiments; 14-component fluid models were used to match the near-critical fluid behavior. The match was considered satisfactory given the high volatility of the fluid. Finally they suggested that the MBO approach should be used regardless of the complexity of the fluid. Their paper presents an accurate match of average reservoir pressure and water production rates. However, the gas-oil ratio and condensate saturation plots were not provided.

2. Fevang et al. [8] compared for a variety of reservoir fluids, ranging from a medium rich gas condensate to a critical fluid, to slightly volatile, simulated production performance both for injection and depletion from MBO and compositional. Both reservoirs with constant composition and compositional grading reservoir with depth have been simulated.

Reservoir description. In this work, it was used a "generic" reservoir containing a fluid system with compositional grading from a medium-rich gas condensate upstructure, through an undersaturated critical mixture at the gas-oil contact, to a volatile oil downstructure. The generic reservoir simulation model contains three geological units. Each geological unit generally has ten numerical layers and each layer has a constant permeability. The average permeability in each geological unit is 5, 50, and 200 mD (top, middle and bottom). The reservoir has a dip of 3.8 degrees. The base numerical model for one geological unit has 50x10x10 grid cells. The base case has a vertical producer, which is located downdip in cell (50,10) and is perforated in all layers.

Fluid characterization. A fluid sample was selected from a North Sea field. The reservoir is slightly undersaturated. The Soave et al. SRK [15] EOS characterization method was used to generate the "base" EOS model. Decanes-plus was split into 9 fractions. The Pedersen et al. [13] predicted viscosities as "data" was used to tune the LBC correlation [17]. Isothermal gradient calculation [19] was made using the "base" 22-component SRK EOS model. The 22-component EOS model was first used to generate a large set of PVT data. A total of eight feeds (one reference sample and seven generated from the compositional gradient calculation; four gas samples, one near-critical sample, and three oil samples) were used for generating PVT data. All calculated PVT results using these feeds were treated as "data" for pseudoization (reducing number of components). Several reduced-component EOS models were developed (with 19, 12, 10, 9, 6, 4, and 3 components). At each step in pseudoization, new pseudocomponents were formed from existing components. Regression was used to fine tune the newly-formed pseudo-component EOS parameters and a select number of BIPs. However, from the 4-component model to the 3-component model, PVT properties deteriorated significantly.

Simulation cases analysed. Simulation cases with depletion and with gas injection were simulated first with the full 22-component and the 6-component fluid characterization to verify that the 6-component characterization accurately describes production performance. The depletion performance of the two EOS models are very similar. For the injection case the production performance was very close.
For all subsequent simulation cases were used 6-component EOS model. These simulation cases were: MBO vs EOS reservoir simulation - depletion; MBO vs EOS reservoir simulation - gas injection, either full presure maintenanace (for gas condensate with constant composition, and for oil reservoir with constant composition) or reservoirs with compositional gradients and undersaturated GOC, and partial pressure maintenance (for undersaturated oil reservoirs, and for oil reservoir with gas injection in the gas cap).

3. Izgec and Barrufet [9] tested the MBO against the fully compositional model and performances of both models were compared using various production and injection scenarios for a rich gas condensate reservoir. They have evaluated the performance of MBO model by investigating: the effects of black-oil PVT table generation methods from a tuned EOS, oil-gas ratio (OGR) and saturation pressure versus depth as initialization methods, uniform composition versus compositional gradient with depth, location of the completions, production and injection rates, k_v/k_h ratio, and vertical wells versus horizontal wells.

Reservoir description. A quarter of a 5-spot model with the description of a real gas condensate fluid system was scaled to represent the entire field. The total thickness is represented by 18 layers having different porosity and permeability values. The injector and producer wells are located on the opposite corners of the model. The producer operates under a constraint of a fixed gas production rate until the minimum BHP is reached.

Fluid characterization. The fluid selected for the study was a rich gas condensate taken from Cusiana Field in Colombia. A compositional analysis with hydrocarbon components that includes a heavy fraction of C_{30+}, a set of experimental data obtained from a CCE and a separator test were used to characterize the fluid. Following the procedure proposed by Whitson, Torp and Coats [16], where the groups are separated by molecular weight, 6 pseudocomponents and one non-hydrocarbon (CO_2) were used. For the purposes of CO_2 injection, this component was kept as a separate group. Once the pseudocomponents were defined it was proceeded with the four parameter Peng-Robinson EOS tuning process to the data obtained from the CCE (at reservoir temperature), which includes the liquid saturation, gas density and the relative volume.

Simulation cases analysed. The simulation cases analyzed were: natural depletion and gas cycling. For the last simulation case, when kv/kh ratio is reduced to an extreme value of 10^{-4}, which almost restricts the mass transfer between layers, it is clearly observed that compositional and MBO models showed closer performances both for natural depletion and gas cycling cases. The lower drawdown pressure for horizontal well, compared to the vertical well, for the same flow rate, considerably reduces retrograde condensation [3]. Therefore there is less condensate deposited near the horizontal wellbore. This means less liquid drop-out and smaller amounts of vaporization for MBO model, which in turn makes the models give similar performances.

Conclusions

- The performance of the MBO model is not affected by the initialization method if composition is constant with depth. Also OOIP is the same for all initialization methods if no compositional gradient is used.
- A MBO model is always adequate for simulating natural depletion performance of petroleum reservoirs if (a) Rs and Rv are initialized properly, and (b) the PVT data are generated properly. But unrealistic vaporization can be encountered to some degree depending on the depletion scenario. Also the gas present in MBO has a lower capacity to hold liquid and more oil is left in the reservoir.
- A compositional simulation model is generally recommended for gas injection studies. For gas injection, a black-oil model can only be used in (a) oil reservoirs when there is minimal vaporization and (b) lean to medium-rich gas condensate reservoirs undergoing cycling above the dewpoint for gas condensate fluids.
- Lower k_v/k_h ratios provide a better match between the models.
- The arrival time of displacement front differs for both compositional and MBO models and as well as for different initialization methods among the MBO models.
- Due to reduced retrograde condensation and partial elimination of the error in dew point pressure versus depth, the MBO model with the horizontal wells exhibits better agreement with compositional model.
- Oil saturations distributions around the well and throughout the reservoir may be quite different in two models regardless of a match with the production performance.

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Comparaţie între simularea compoziţională şi simularea black-oil modificată

Rezumat

Simularea compoziţională încă este mai scumpă decât simularea black-oil. De aceea, pentru simularea exploatării unui zăcământ de ţiţei volatil (ţiţei aflat în vecinătatea punctului critic) sau de gaz condensat, s-a încercat evitarea folosirii modelului compoziţional în favoarea modelului black-oil modificat. În articol sunt prezentate succint, principalele lucrări în care s-a făcut o comparaţie între simularea compoziţională şi black-oil modificată, astfel scoţând în evidenţă situaţiile în care modelul black-oil modificat este adecvat pentru simularea exploatării unui zăcământ de ţiţei volatil sau de gaz condensat.