Discussion of the New Models for Composite Reservoir Pressure Transient Analysis

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Abstract *Enhanced oil recovery (EOR) projects such as steam injection into an oil reservoir are usually analysed using composite reservoir models consisting of two regions separated by a vertical front. This simplification may lead to errors in the estimates. To overcome this, analytical models have been recently proposed taking into account some of the effects such as gravity, heat loss and gradual change of properties that are overlooked in the conventional models. In this paper, description and comparison of the recent models is given showing the differences due to different ways of treating gravity effect and variation of properties in the intermediate region(s). For a better representation of the composite reservoirs, it is suggested to apply these new models with tilted fronts and smooth change of the properties in type curve matching for improved well test analysis. Multi-region multi-layer composite model is an extension of the conventional models that can be improved by adding more intermediate regions and thin skin at the front locations. This model can reasonably match the recently developed models and should be used instead of the simpler models in the case of application of the conventional well test analysis.*

Keywords— *well test analysis, composite reservoir, gravity override, heat loss, tilted front*

I. INTRODUCTION

In well test analysis, the obtained pressure data are matched to the model type curves. Selection of the model is therefore a crucial part of the analysis. A composite reservoir may be formed either naturally or artificially such as in the application of various enhanced oil recovery (EOR) methods.

The model developed by Satman et al. in [1] is usually used for the analysis of the pressure data in composite reservoirs. This model consists of two regions, each defined by particular properties that are much different from the other region to model the condition of no-flow boundary at the front (pseudo steady state method). Falloff test data are analysed by this model for estimation of the swept volume and reservoir properties.

The simplification of the composite reservoirs was improved by various analytical models (e.g. [2]-[7]). Recently, Jahanbani and Jelmert ([8] and [9]) developed analytical models for the pressure behavior of a three-region composite model with power-law variation of properties in the intermediate region using the fractal theory. These models were then validated and used to explain some pressure trends that could not be accounted for by the previous models. It is recommended to use these general models with realistic assumptions in type curve matching to obtain improved results.

The mathematical model of a multi-region composite reservoir developed by Acosta and Ambastha in [4] was further modified in [10] by Jahanbani and Jelmert. This model can reasonably match the pressure responses of the two analytical models of [8] and [9]. The new models are briefly described and compared in this paper to be applied in type curve matching using new set of parameters for improved analysis.

II. DESCRIPTION OF THE NEW MODELS

Figs. 1 and 2 represent the recently developed models by Jahanbani and Jelmert in [8] and [9], respectively. Mathematical formulations of the models can be found in these two papers.

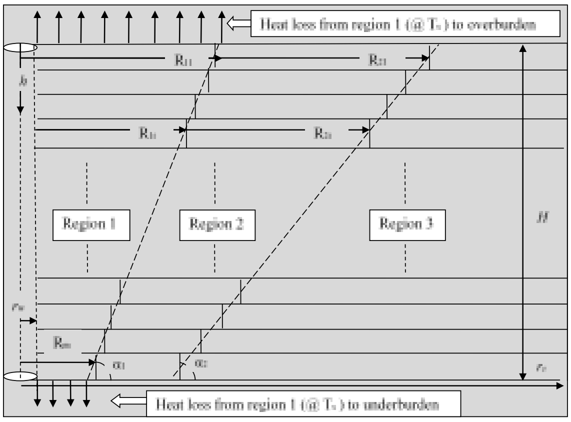

Fig. 1 Representation of the 3-region composite reservoir multi-layer model with tilted fronts and heat loss effect [8]

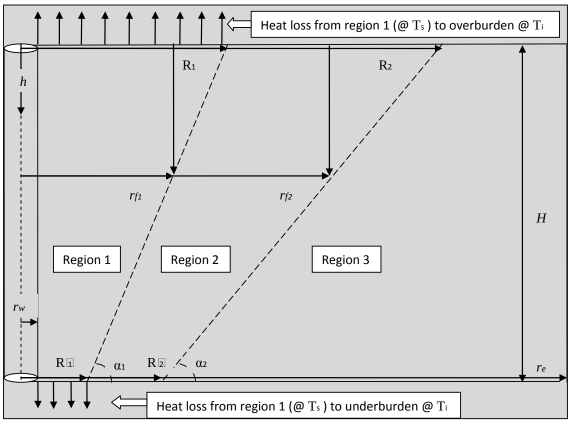

Fig. 2 Representation of the 3-region composite reservoir continuous model with tilted fronts and heat loss effect [9]

Heat loss to the formation can distort the pressure behavior. This effect may be misinterpreted as linear flow due to the presence of fractures or channel flow, since the corresponding heat loss term in the pressure equations takes the mathematical form of the linear flow (detailed analysis can be found in [11]). This can cause errors in the interpretation and calculations. Therefore, inclusion of heat loss in the model for a thermal project is necessary.

The intermediate region assumed in these models is assigned a power-law decline of properties with distance from the first front that will prevent abrupt changes and abnormal pressure responses at the front location. The reservoir models are also assigned tilted fronts due to gravity override. The first model (Fig. 1) was developed using the concept of multi-layer systems assigning different front radii to each layer. The second model (Fig. 2), however, assumes a continuous tilted front over the entire reservoir thickness, mathematically implemented in the flow equations.

Application of the conventional method of falloff test analysis (i.e. pseudo steady state method) for volume estimation should be reconsidered for the conditions that cause deviations from the simple composite reservoir model pressure behavior. Several cases presented in [8] and [9] show smooth pressure transition from the inner to the outer region. These cases discuss the increased size of the intermediate region and continuous decline of properties in this region that in fact dampen the assumption of sharp variations in pseudo steady state model, due to the presence of the intermediate region. Therefore, type curve matching method using the parameters applied in the development of the new models can serve as an alternative to the conventional models for reservoir characterization to obtain better estimates.

Acosta and Ambastha in [4] developed a mathematical model for a multi-region composite reservoir with thin skin at the fronts. This model is further improved in [10] by Jahanbani and Jelmert to include the effect of gravity in the form of tilted fronts, using the concept of multi-layer reservoirs with no cross-flow between the layers (or commingled reservoir systems that assume communication between the layers is possible only through the wellbore). This model (Fig. 3) consists of m regions in each layer to account for the gradual change of properties from the inner to the outer region. In Fig. 3, effect of heat loss to the formation is not considered.

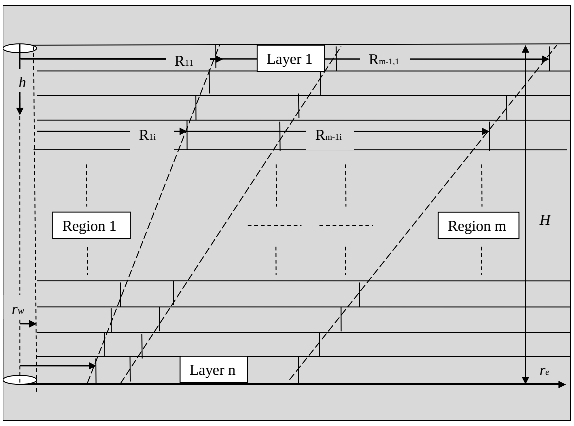

Fig. 3 Representation of the multi-layer multi-region composite reservoir model with tilted fronts [10]

III. DISCUSSION

The multi-layer multi-region composite reservoir model (Fig. 3) is compared with the new models presented in Figs. 1 and 2. Pressure derivative responses are shown and compared in Fig. 4.

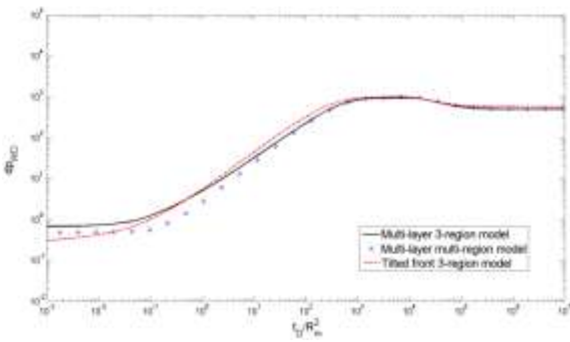

Fig. 4 Comparison of the composite reservoir models of [8], [9] and [10] discussed in this study

The tilted front three-region composite reservoir continuous model (presented in Fig. 2) is theoretically the best model because it has the least simplifying assumptions in the development of the model. As can be observed, there is a good match of the responses of the three models except at the early and middle times. This mismatch is possibly due to different modes of treating the gravity effect as well as the differences in property changes. In the multi-layer multi-region model, constant properties are assumed in each region with changes at the front locations while in the other two models, a power-law decline of properties is assumed in the intermediate region.

Some of the data used to generate Fig. 4 are as follows:

- Dimensionless minimum front radius (bottom layer): R_m=200;
- Skin factor: S=0;
- Dimensionless wellbore storage coefficient: C_D=0;
- Tilted front angle: α=60°;
- Mobility ratio between first and second region: M_{12}=10;
- Mobility ratio between first and third region: M_{13}=1000;
- Storativity ratio between first and second region: F_{12}=10;
- Storativity ratio between first and third region: F_{13}=1000;
- Dimensionless heat loss coefficient: β=0;
- Number of layers: N=3;
- Number of regions: m=3;
- Size of second region/ Size of first region: 2;
- Power-law exponent for mobility variation: θ_1=1;
- Power-law exponent for storativity variation: θ_2=1;
- Skin factor at the front: S_f=0.

Fig. 5 shows a good match of the pressure derivative response of the multi-layer multi-region model with the three-region composite reservoir model of [9] with continuous tilted fronts, in another example with more gravity effect. This match was obtained by adding more intermediate regions between the inner and outer regions (generated for six regions), and by adding a thin skin at the first front.

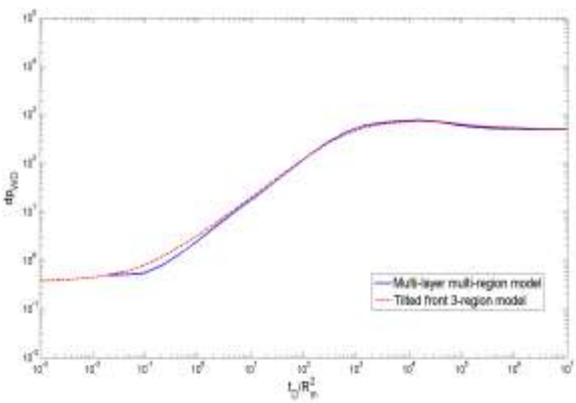

Fig. 5 Comparison of the multi-layer multi-region model of [10] with composite reservoir model of [9]

The data used to generate Fig. 5 are the same as Fig. 4 except:

- Tilted front angle: α=30°;
- Number of regions: m=6;
- Size of second region/ Size of first region: 8;
- Power-law exponent for mobility variation: θ_1=2;
- Power-law exponent for storativity variation: θ_2=2;
- Skin factor at the front: S_{f1}=5.

The multi-layer multi-region model of [10] which is an extension of the conventional composite reservoir models can match the recently developed analytical models of [8] and [9] within reasonable accuracy. This is achieved by increased number of intermediate regions with gradual change of properties between the inner and outer regions. This gradual change of properties will roughly simulate the power-law variation of properties applied in the other two models. Effect of gravity is treated as in [8].

Therefore, any of the three models presented and discussed in this paper can be used in type curve matching to improve the results of pressure transient analysis over conventional models.

IV. Conclusions

Analytical models recently proposed for pressure transient analysis of composite reservoirs with smooth change of properties between the regions, and including heat loss and gravity effects are considered an improvement over the conventional models.

Different types of bounded and unbounded reservoir models are covered in this study. These models can explain some of the anomalies seen on the pressure data. Three recently developed models were briefly described and their pressure responses were compared in this work with the conclusion that a reasonable match of the models can be obtained although the continuous tilted front composite reservoir model of [9] is mathematically the most accurate model.

These new models will replace the conventional models in type curve matching to obtain better results using the parameters related to gravity, heat loss and property changes, considered in the development of the models.

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