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Forecasting production of liquid rich shale (LRS) reservoirs using simple models

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ABSTRACT

Due to the advent of shale reservoirs as important sources of oil and gas production, there has been a critical need for reliable techniques for forecasting production and estimating reserves from these plays. This work presents the results of a study to determine whether simple decline models can be used to forecast production and estimate reserves of both oil and gas in liquid rich shale (LRS) reservoirs with reasonable accuracy. We found that hybrid models (i.e., one model such as the Duong model for transient flow coupled with a different model, such as the Arps hyperbolic model with an appropriate value of the parameter “b”) are appropriate for forecasting oil production and that it is possible to forecast solution gas production with availability of adequate data.

To establish the “truth case” for comparison, we simulated production with four different reservoir fluids using a commercial compositional reservoir simulator. We tested a variety of hybrid and simple DCA models on simulated data (and later on field data) with a work flow that included identifying flow regimes with diagnostic plots for each fluid sample. We analyzed 0.5–3 years of production history to estimate model parameters for forecasting future production. Also, we forecasted gas production using a technique similar to one recently presented in the literature.

Lengthy transition periods between transient linear flow and boundary dominated flow (BDF) were observed on the diagnostic plots. This is presumably due to multi-phase flow effects, as this transition period is typically much shorter in single-phase shale reservoirs. As in single-phase flow, the Arps decline model proved to be good for forecasting in the BDF regime. For transient flow, we examined the Duong model (which includes transient linear flow as a special case) and YM-SEPD (modified form of Stretched Exponential Production Decline model). In some cases, we applied the Arps model for both the transition period and BDF regimes (with different b values). We concluded that hybrid DCA models are more appropriate for multi-phase flow analysis than simple DCA models. In most of the cases, the hybrid YM-SEPD and Arps models led to more accurate oil production forecasts than other alternatives. Our analyses of solution gas forecasts indicated that solution gas production forecasting is possible but there is still need for more research in this area.

1. Introduction

Reliably predicting the long-term production performance of shale reservoirs has been challenging. Ultra-low permeability of shale, complex flow mechanisms and formation heterogeneity contribute importantly to this challenge. Empirical, analytical and reservoir simulation methods can be used to forecast production from shale reservoirs. While reservoir simulation can be thorough, taking into account complex fracture, reservoir and PVT characteristics, inadequate data availability and time can be limitations. Currently applied analytical methods of forecasting production assume single-phase flow, thereby making their application for multiphase flow analysis somewhat inappropriate. This fact makes the use of analytical methods for forecasting production in shale reservoirs quite difficult. The petroleum industry needs simple, easily applied and rapid methods of forecasting production and estimating reserves. Therefore, an empirical technique such as Decline Curve Analysis (DCA) is an appealing alternative compared to the other two methods.

Because of its relative simplicity, Decline Curve Analysis (DCA) is the most common method used in the industry. Arps (1945) presented a decline model that has been the basic foundation for DCA. The proposed model is a hyperbolic decline curve, with harmonic and exponential curves as special limiting cases. The Arps hyperbolic decline model is valid assuming boundary dominated flow (BDF), i.e. flow affected by the reservoir boundaries. Many unconventional reservoirs reach BDF

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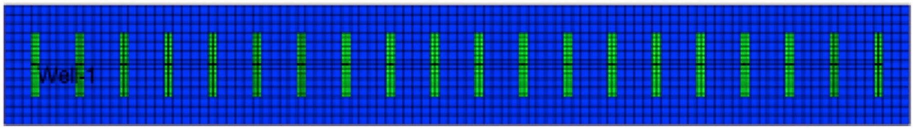

Fig. 1. Reservoir model.

Table 1
Reservoir data for the reservoir model.

Permeability	0.001 md
Porosity	0.06
Reservoir Temperature	250 °F
Initial Reservoir Pressure	5000 psia
Depth to top of formation	10,000 ft
Reservoir Thickness	250 ft
Corey Relative Permeability Exponent	2.5
Critical gas saturation, S_{gc}	0.05
Residual saturation of oil (gas/oil displacement), S_{org}	0.2

Table 2
Fluid compositions.

Components	Fluid 1	Fluid 2	Fluid 3	Fluid 4
	Composition (%)	Composition (%)	Composition (%)	Composition (%)
CH_4	58.07	61.82	53.47	49.43
C_2H_8	7.43	7.91	11.46	7.28
C_3H_8	4.16	4.42	8.79	8.02
I-C_4H_{10}	0.96	1.02	–	2.31
N-C_4H_{10}	1.63	1.74	4.56	3.61
I-C_6H_{12}	0.75	0.80	–	1.80
N-C_6H_{12}	0.80	0.86	2.09	1.79
C_8H_{14}	1.14	1.21	1.51	2.32
C_{7+}	22.59	17.59	16.92	22.41
CO_2	2.32	2.47	0.90	0.16
N_2	0.15	0.16	0.30	0.87

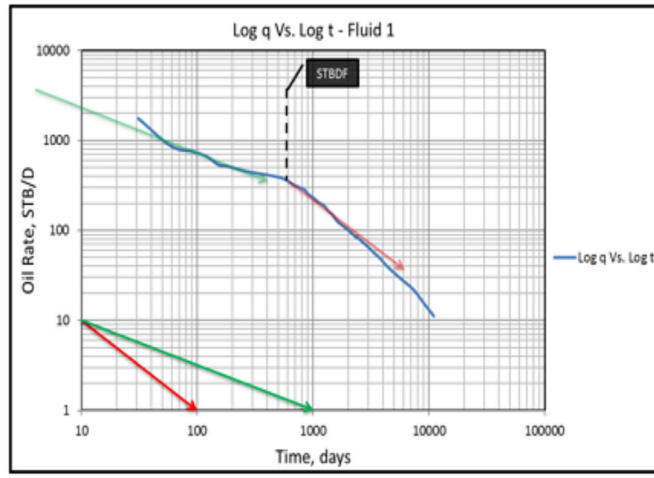

Fig. 2. Log q vs. Log t - Fluid 1.

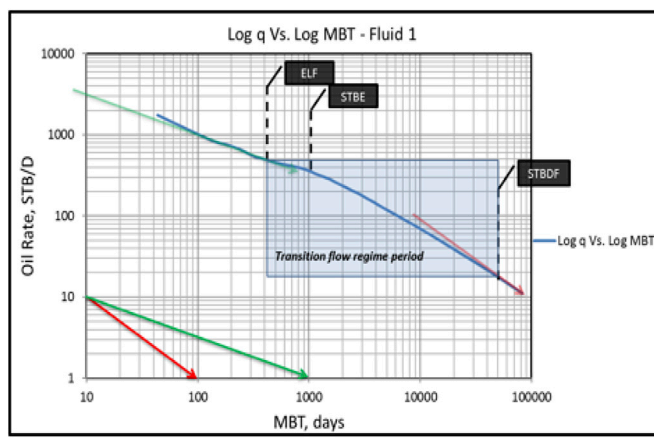

Fig. 3. Log q vs. Log MBT - Fluid 1.

regimes only after many years, thereby making the use of Arps' hyperbolic decline models generally inappropriate for reserves evaluation in these instances. Other DCA models have been suggested such as the Duong model, the Stretched Exponential Production Decline (SEPD) model and the power-law model proposed by Ilk et al. (2008). All these methods have exhibited several limitations in their use. Valko and Lee (2010) introduced the SEPD model, which despite being able to smoothly model changes from transient flow to BDF, can often underestimate reserves, especially with limited production data. The assumption of linear or near-linear flow for the entire well life in the model proposed by Duong (2011) leads to overestimation of reserves in shale plays. Yu and Miocevic (2013) proposed a modified form of SEPD, the YM-SEPD model, which considerably improves forecasts in shale reservoirs. However, short production histories, an uncertain time-zero rate and the nature of production data can hinder the effective application of this model. All these limitations contribute significantly to uncertainty in reserves estimation and production forecasts in shale reservoirs.

Due to the fact that no particular model has been completely suitable for forecasting long-term shale reservoir production performance, coupled with other factors associated with LRS reservoirs such as multiphase flow effects, further research efforts led to the use of combination (hybrid) models. For example, the use of a model like YM-SEPD for transient flow combined with Arps' hyperbolic model for the BDF regime is a hybrid decline model.

This study contributes to the ongoing efforts of trying to find consistent and fast ways of forecasting production in shale reservoirs. It presents results of better approaches to production forecasting in liquid rich shale reservoirs using simple hybrid models. Also, a workflow for predicting the secondary phase (gas) production is proposed in this paper.

1.1. Decline curve analysis models

Some of the available models for production forecasting in shale reservoirs applied in this work are briefly described here.

1.2. Arps' decline model

Production decline characteristics depend on the rate of decline, D and the decline exponent (b value):

$$\mathbf{D} = -\frac{\mathbf{dq}/\mathbf{dt}}{\mathbf{q}} \tag{1}$$

where q is the production rate in barrels per day, month or year and t is time in days, months or years. Equation (1) defines the instantaneous