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Probabilistic Decline Curve Analysis of Barnett, Fayetteville, Haynesville, and Woodford Gas Shales

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ABSTRACT

This paper presents a probabilistic decline curve workflow to model shale gas production from the Barnett, Fayetteville, Haynesville, and Woodford shales. Ranges of model input parameters for four gas shales are provided to guide the preparation of uniform and triangle probability distributions. The input parameter ranges represent realistic distributions of model parameters for specific gas shales.

1. Introduction

Many people have developed techniques that were designed to forecast production from unconventional resources, such as Brown et al. (2009), Valkó and Lee (2010), Duong (2011), Anderson et al. (2012), and Esmaili et al. (2012). Our ability to forecast shale gas production is complicated by our inability to correctly account for all of the mechanisms that affect production. We present a probabilistic workflow that is a modification of reservoir simulation workflows and is designed for use with rate–time decline curve models.

Different workflows exist for performing reservoir simulation projects. For example, Fanchi has presented workflows for green fields (Fanchi, 2010, 2011a) and brown fields (Fanchi, 2010, 2011b) that use reservoir flow models to generate a distribution of recovery forecasts. The workflows are able to integrate uncertainty in the development of recovery forecasts. The workflow presented here uses the probabilistic decline curve analysis (DCA) workflow to develop model input parameter ranges for the Barnett, Fayetteville, Haynesville, and Woodford shales. The methodology is automated in the form of a software program that calculates the distribution of Estimated Ultimate Recovery (EUR) for production of gas from unconventional gas shale. Using well data from different shale gas plays, we determined realistic minimum and maximum values for the uniform distribution of a parameter and triangular distribution of a parameter. The realistic ranges of model input parameters can be used to guide the preparation of uniform and triangle probability distributions.

2. Decline curve models for unconventional resources

Decline curve models used here must have finite, bounded values of EUR. Not all decline curve models satisfy this criterion. For example, Arps (1945) presented the following empirical decline curve model for flow rate q as a function of time t and parameters a, b:

$$\frac{dq}{dt} = -aq^{b+1} \tag{1}$$

The Arps models are harmonic decline ($b=1$), exponential decline ($b=0$), and hyperbolic decline with other positive values of b. The hyperbolic model typically has $b<1$ for conventional reservoir production. The Arps harmonic model ($b=1$) and hyperbolic model with $b>1$ are not always applicable to unconventional reservoir production forecasts because extrapolation of the decline curve can lead to unbounded values of EUR and corresponding overestimates of EUR.

The Arps exponential model does not always adequately model the decline rate of unconventional reservoir production. Valkó and Lee (2010) introduced the Stretched Exponential Decline Model (SEDM) as a generalization of the Arps exponential model. The SEDM is based on the idea that several decaying systems comprise a single decaying system (Phillips, 1996; Johnston, 2006). If we think of production from a reservoir as a collection of decaying systems in a single decaying system, then SEDM can be viewed as a model of the decline in flow rate. The SEDM has three

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parameters q_i, n and τ (or a, b, and c):

$$q = q_i \exp[-(t/\tau)^n] = a \exp[-(t/b)^c] \quad (2)$$

Parameter q_i is the flow rate at initial time t. The Arps exponential decline model is the special case of SEDM with $n=1$.

A second decline curve model is based on the logarithmic relationship between pressure and time in a radial flow system. We can use productivity index to link rate and pressure to obtain the logarithmic decline curve model

$$q = a \ln t + b \quad (3)$$

with parameters a and b. This logarithm model is referred to as the LNDM model.

The third decline curve model used here is the Arps hyperbolic decline curve model with the restriction that $0<b<1$. The hyperbolic model

$$q = a(1+bct)^{(-1/b)} \quad (4)$$

is referred to as the HYDM model.

Model input parameters for each decline curve model are summarized in Table 1. Cumulative gas production Q is given by the integral

$$Q = \int_{T_0}^{T} q \, dt \quad (5)$$

The lower limit T_0 is the initial time and the upper limit T is the time when the economic limit is reached.

Table 1
Decline Model Parameters.

Parameter	SEDM	LNDM	HYDM
DCMA	a or q_i	a	a or q_i
DCMB	b or τ	b	b
DCMC	c or n	NA	c or D_i

3. Probabilistic DCA workflow

Reserves estimates may be either deterministic or probabilistic (Lee, 2009). A deterministic estimate of reserves is a single best estimate of reserves based on geological, engineering, and economic data. A probabilistic estimate of reserves uses geological, engineering,

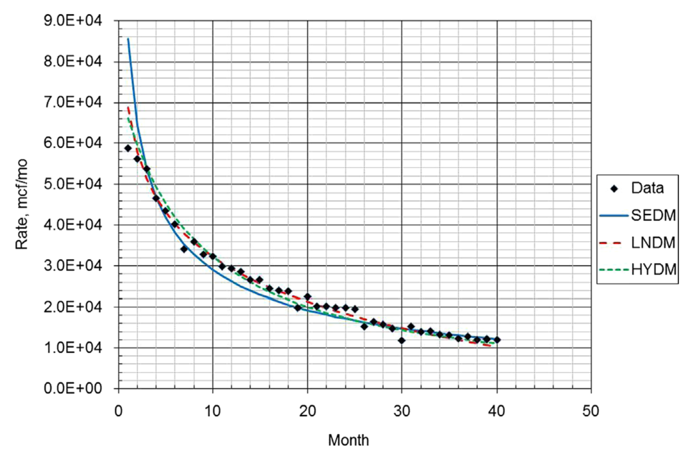

Fig. 2. Barnett shale A – PC50.

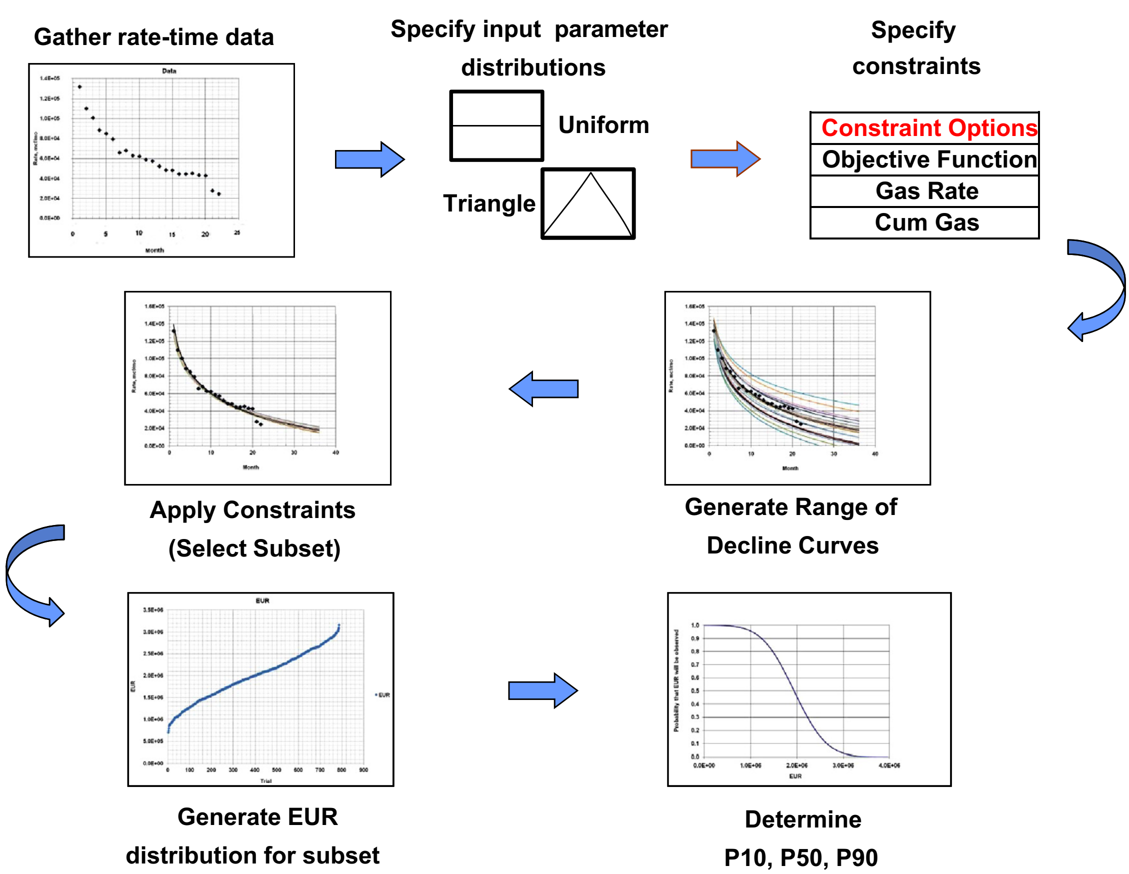

Fig. 1. Probabilistic DCA workflow.