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Analytical models & type-curve matching techniques for reservoir characterization using wellbore storage dominated flow regime

Salam Al-Rbeawi

METU-Northern Cyprus Campus, Cyprus

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ABSTRACT

The applicability of early time data in reservoir characterization is not always considered worthy. Early time data is usually controlled by wellbore storage effect. This effect may last for pseudo-radial flow or even boundary dominated flow. Eliminating this effect is an option for restoring real data. Using the data with this effect is another option that could be used successfully for reservoir characterization.

This paper introduces new techniques for restoring disrupted data by wellbore storage at early time production. The proposed techniques are applicable for reservoirs depleted by horizontal wells and hydraulic fractures. Several analytical models describe early time data, controlled by wellbore storage effect, have been generated for both horizontal wells and horizontal wells intersecting multiple hydraulic fractures. The relationships of the peak points (humps) with the pressure, pressure derivative and production time have been mathematically formulated in this study for different wellbore storage coefficients. For horizontal wells, a complete set of type curves has been included for different wellbore lengths, skin factors and wellbore storage coefficients. Another complete set of type curves has been established for fractured formations based on the number of hydraulic fractures, spacing between fractures, and wellbore storage coefficient.

The study has shown that early radial flow for short to moderate horizontal wells is the most affected by wellbore storage while for long horizontal wells; early linear flow is the most affected flow regime by wellbore storage effect. The study has also emphasized the applicability of early time data for characterizing the formations even though they could be controlled by wellbore storage effect. As a matter of fact, this paper has found out that wellbore storage dominated flow could have remarkable relationships with the other flow regimes might be developed during the entire production times. These relationships can be used to properly describe the formations and quantify some of their characteristics.

1. Introduction

Since early days of petroleum industry, well test analysis has been used in reservoirs characterization wherein many formation parameters can be determined. This technique is done by measuring well pressures either, at the wellhead or downhole, at a certain time interval and a certain flow rate. Basically well test analysis is used for permeability, skin factor, and wellbore storage coefficient calculations. It is used also for initial or average reservoir pressure determination, anisotropy identification (permeabilities in the three directions) and distance to fault or reservoir boundaries. As the hydraulic fracturing process has been commercially applied in oil and gas fields as a great enhancement technique, well test analysis has found extra applications such as the estimation of hydraulic fracture length and fracture deviation and inclination. Currently, different types of well tests (drawdown, build up, interference, pulse and drill steam) are used with different models for analyzing and characterizing the formation.

Well testing requires long time monitoring (sometimes several months) to get a complete set of time-pressure measurements. The reason for that is to allow for the test pulse to moves as far as it could in the porous media so that the responses of transient flow

E-mail address: salam@metu.edu.tr.

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conditions and steady state or pseudo-steady state are obtained. However, the longer the test is, the higher the cost is. To reduce the test time and reduce the cost, several attempts have been focused on using early time data for reservoir characterization. Unfortunately, early time data is normally affected by wellbore storage effect. The problem might be more complicated because of the noisy conditions resulted from the measuring devices. Therefore, very few models have been presented in the literature for interpreting early time data.

Wellbore storage effect represents a phenomenon of fluid compression and fluid momentum inside the wellbore in addition to the phase redistribution for the case of multi-phase flow. The effect of this phenomenon may last to late production time when pseudo-steady state develops. Several factors have direct impacts on the duration of wellbore storage effect such as permeability, flow rate, homogeneity and heterogeneity. Agarwal et al. [1] and Ramey [12] were the first who considered the problem of the wellbore storage in the well test analysis. They presented methodologies and analytical models for interpreting early or short time data. Earlougher et al. [4] introduced the concept of the wellbore storage to the injectivity or pressure falloff tests. They showed in their study that test interpretation for formation characterization practically is impossible under certain circumstances of wellbore storage effects. Raghavan [11] explained that significant errors in estimating reservoir parameters can result when the effect of the wellbore storage is not taken into consideration. Kamal [6] investigated the effect of wellbore storage and skin factor on vertical permeability. He developed a set of type curves takes into consideration these two effects. Soliman [13] introduced a log-log graph especially designed for a pressure buildup test with short production time when the wellbore storage controls pressure behavior.

Kuchuk and Kirwan [7] presented new skin and wellbore storage effect type curves for partially penetrated formation by vertical wells. They developed an analytical model describes the effects of both skin factor and wellbore storage on pressure behavior at the wellbore for a well working with an infinite conductivity condition. Daviau et al. [3] presented several analytical solutions for pressure transient analysis of horizontal wells acting in different reservoirs. They considered the cases of wellbore storage only and the compound effect of wellbore storage and skin factor. They stated that early vertical radial flow may not be observed because of the wellbore storage effect. This fact was confirmed by Ozkan et al. [9] who also examined the influence of wellbore storage and skin factor on the transient-pressure response of a finite-conductivity horizontal well. Vasquez-Cruz and Comacho-Velazquez [16] introduced a method of analysis for well tests with insufficient duration to reach radial-flow condition. This method was developed based on two classical models related to well test affected by changing wellbore storage.

Spivey et al. [14] developed an algorithm for computing pressure responses for a well with constant wellbore storage coefficient and non-Darcy skin factor across the completion. The algorithm has been used to generate type-curves for drawdown and buildup tests. Cheng et al. [2] used fast Fourier-transformation-based deconvolution for interpretation of pressure transient test data dominated by wellbore storage. They stated that this technique can deconvolve noisy pressure and flow rate data from drawdown and buildup tests when early time behavior is dominated by the wellbore storage effect. In their study, they used variable wellbore storage coefficients. Ilk et al. [5] suggested using B-Spline deconvolution of pressure transient data distorted by wellbore storage. They indicated that the most straightforward application of deconvolution is to deconvolve pressure build up data to eliminate the effect of the wellbore storage.

2. Mathematical models

It is well known for those interested in well test analysis that early time period is controlled by the effect of wellbore storage. Compression of reservoir fluid inside wellbores or phase redistribution may lead to distort the recorded data at this period. Not only early time, sometimes the distortion may last to late test time when pseudo-steady state is expected to be developed. In both cases, the effect of wellbore storage may cause significant errors in the data interpretation and formation characterization if it is not treated very well. Considering wellbore storage effect and skin factor, real time pressure behavior at the wellbore can be calculated from pressure behavior in Laplace domain using the following model:

$$\overline{P_{wD}} = \frac{S\overline{P_D} + s}{S + C_D S^2\left(S\overline{P_D} + s\right)} \tag{1}$$

In this model, C_D is the dimensionless wellbore storage coefficient. It can be calculated as follows:

$$C_D = \frac{0.894C}{h\O c_t L_w^2} \quad \text{for horizontal well} \tag{2}$$

$$C_D = \frac{0.894C}{h\O c_t x_f^2} \quad \text{for hydraulic fractures} \tag{3}$$

while $(\overline{P_D})$ and $(\overline{P_{wD}})$ are the dimensionless wellbore pressure in

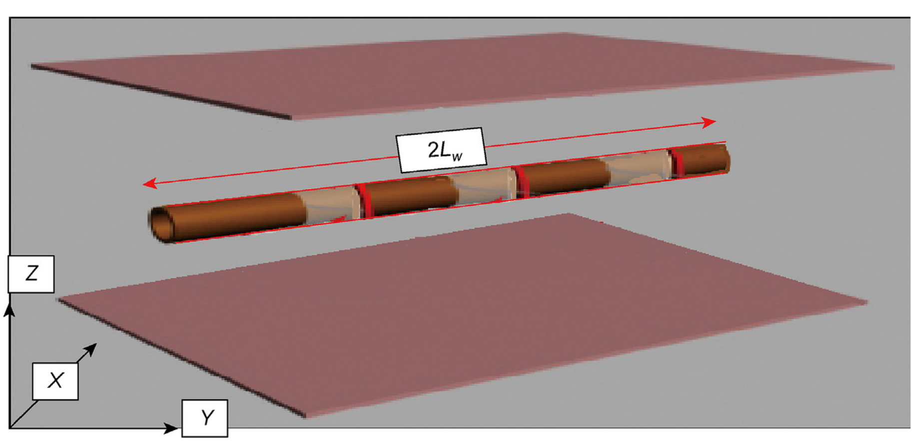

Fig. 1. Horizontal well.