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Pressure transient measurement statistics and gauge metrology

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ABSTRACT

Downhole pressure transient measurements are usually affected by random noise caused by the intrinsic noise of the measuring device (the pressure gauge), environmental noise, and/or wellbore pressure fluctuations. The interpretation of pressure transients depends on the characterization of the noise signal and the obtaining of an accurate reservoir pressure response. This article presents a new procedure to characterize acquired formation pressure measurements, their statistical properties, and standard deviation by assuming independent and identically distributed random measurement noise. *Apparent accuracy* and *apparent resolution* of measurements are introduced. An automated methodology is developed to obtain and characterize the probability density function of the random noise. This new methodology will replace the conventional manual technique of selectively zooming on pressure curves and measuring their variations.

Pressure data from a drillstem test (DST) were used to illustrate the automatic calculation of the apparent resolution. The noise affecting the DST data was then fully characterized and its density function computed. The dataset was also used to introduce and illustrate a new methodology for the analysis of pressure gauge drift using the distribution of slopes extracted from the local linearization of the pressure data. This methodology was able to identify gauges suspected of slight pressure drift that was not detectable visually.

1. Introduction

Downhole pressure gauges are commonly used in drillstem test (DST) wireline formation testers (WFT) to acquire pressure transient measurements. These measurements are used to determine the initial or average reservoir pressure, identify the reservoir permeability and barriers, and estimate the well productivity. The achievement of these objectives depends on the quality of the acquired signal. In fact, the measured pressures are constantly affected by a seemingly random component caused by the intrinsic gauge noise, environmental noise, and/or wellbore pressure fluctuations. The data noise is directly related to the level of scattering observed on the acquired pressure. Fig. 1 shows an example of a sequence of a DST pressure dataset, and Fig. 2 an arbitrary zoom on a stable section of the dataset exhibiting the scattering.

The quality control of the pressure transient data before the start of the interpretation workflow is a mandatory step (refer to Joseph et al. (Joseph et al., 2802) for a detailed description of the general methodology for reservoir test interpretation). Wellbore and environmental pressure components recorded by downhole gauges are then identified, to prevent their misinterpretation as reservoir pressure response. Mattar (1996) enumerated potential downhole phenomena that affect pressure transients, including multiphase, geotidal, microseismic, changing liquid levels, recorder plugging, etc but did not suggest any automated workflow for anomalies data detection or data noise filtering … In practice, this preprocessing step has been so far limited to the simple visual inspection of the data and the comparison of gauges acquiring pressure in the same DST string.

With the introduction of the Bourdet pressure derivative by Bourdet et al. (1989) and the widespread use of reservoir characterization by type-curve pressure derivative techniques (refer to Raghavan (1993), Gringarten (2008), Kuchuk et al. (Kuchuk and Habashy, 1997) and Kuchuk (Kuchuk, 2802)), the problem of noise affecting the acquired downhole pressure data gained importance as the derivative acts as an amplifier for noise. However, the focus in the literature was mostly on adapting the differentiation algorithms to obtain a smooth derivative and reduce the level of scattering on the derivative curve instead of attempting to identify and characterize the noise. Bourdet et al. (1989) and Clark et al. (Clark and Golf-Racht, 1985) made recommendations on optimal choices for their discrete differentiation algorithms. Lane et al. (1991) suggested to match the data using the spline technique and

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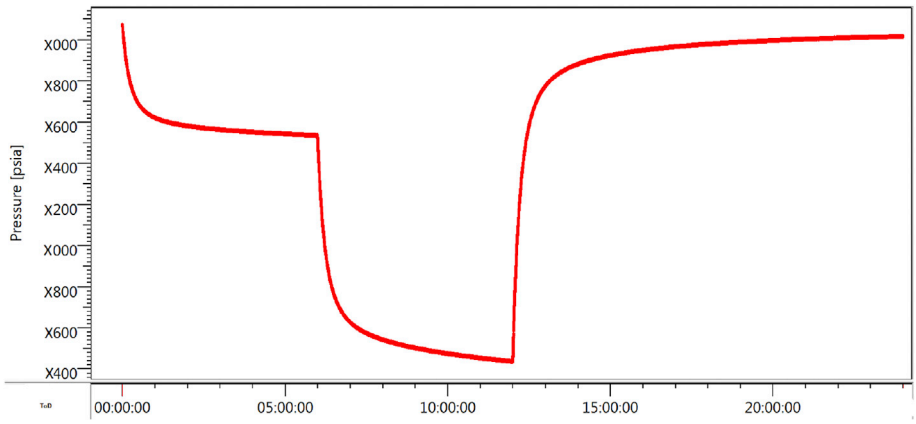

Fig. 1. Example of a DST pressure transient dataset showing two drawdown periods followed by a shut-in.

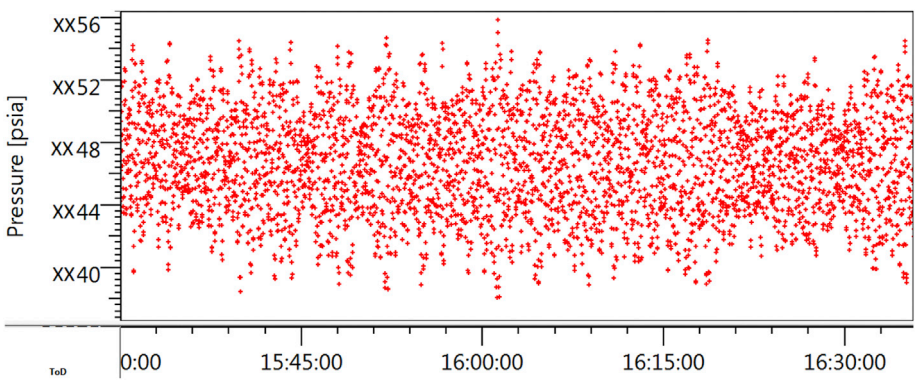

Fig. 2. Pressure scattering observed on a DST pressure transient dataset.

applying the continuous differentiation. It is worthy to note that the scattering observed within a window with fixed number of pressure derivative points sliding over a Bourdet derivative curve has varying time lengths due to the logarithmic timescale nature of the derivative. Hence, the scattering cannot be attributed to a single timescale physical phenomenon. In fact, noise must be studied and filtered on the Cartesian pressure curves.

The attempt to automatically invert well test data to obtain reservoir characteristics was faced with the challenge of uncertain variances (errors) in observed data. Similarly, the focus in the literature was not on the identification of the noise but rather on the choice of the non-linear regression technique that is less affected by the noise in the observed data. For instance, Onur et al. (Onur and Kuchuk, 2802a) applied the weighted least square regression technique to multiprobe wireline formation tester packer and probe pressure transient measurements. Onur et al. (Onur and Kuchuk, 2802b) proved later that maximum likelihood regression is better suited for pressure transient data.

The study of noise affecting pressure data gained importance again as the technology of permanent downhole gauges became reliable and access to large sets of pressure data from permanent monitoring systems became possible. The need to manage and filter large sets of data required automation processes. However, the focus was mostly on data reduction and event detection. Sophisticated spectral analysis techniques such as the wavelets were applied (refer for instance to Kikani et al. (Kikani and He, 2802)). Al-Hashim et al. (Al-Hashim et al., 2802) showed a field example of pressure transient analysis data from permanent downhole gauges applying the wavelet technique.

Wavelet filtering was used as well by Gonzalez-Tamez et al. (Gonzalez-Tamez et al., 2802) to recover the reservoir signal in cases where the latter is smaller than the level of noise. This often happens in highly permeable reservoirs where the maximum pressure variation at the end of the shut-in periods is of the order or smaller than the noise level affecting the data, leading to the loss of information on the reservoir characteristics when interpreting the data. Osman et al. (Osman and Stewart, 2802) used a more classic approach to remove the noise by applying a digital filter in the frequency domain, and then transforming the data back to the time domain.

Noise aspects from the acquisition hardware and transmission protocols standpoint were discussed by Veneruso et al. (Veneruso et al., 2802). They studied the signal bandwidth, the sampling effects, the digital noise, the truncation errors, the filtering and the aliasing. Kuchuk et al. (2010) reviewed in their book the metrology definitions of pressure sensors stressing on the definitions of apparent gauge resolution and gauge manufacturer resolution.

Nonetheless, a basic analysis of the pressure data scattering, shown for instance on Fig. 2 should primarily lead to.

1. The determination of the “true” in-situ pressure
2. The quantification of the level of noise

This requires the proper definition of the concepts of apparent gauge accuracy and resolution.

In practice, the analysis of noise affecting downhole pressure datasets has been limited to the selective zooming on the pressure curve and the use of a hand ruler to measure manually its thickness. This article provides the statistical framework and an automated workflow to analyze the noise affecting downhole pressure measurements. A new workflow to identify pressure gauge drift is introduced as well and exhibited on a DST field dataset.

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