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Research paper

# Individual well flowing rate recovery from PDG transient pressure with either assigned daily rate or total cumulative production of the well or group of wells through wavelet approach

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ABSTRACT

The advent of permanent down-hole gauge (PDG) makes the real-time reservoir monitoring and management possible, where the long term transient data can be processed to distill information about the reservoir through using recently developed wavelet transform algorithm. However, the key in analyzing the PDG data, particularly transient pressure, is to get the flowing rate history right during the pressure draw downs and build ups.

In practice, the most available flowing rate data include assigned daily rate, total cumulative production of the well or group of wells with a measurement error tolerance at about ±10%. While multiphase down home rate data is rather expensive to have, the industry is desperately looking for ways to get the flowing rate history right.

The second big problem in analyzing long term PDG data is that there is a time shift between the flowing rate and the corresponding transient pressure. In other words, when the rate goes up, the pressure also goes up instead of going down as expected. This caused a big problem in reservoir simulation, history matching and numerical well testing.

This paper presents a technique based on the recently developed wavelet approach to recover flowing rate history directly from the measured PDG transient pressure, under the most common practical conditions described above.

In this method, the exact timing of the rate change is identified through wavelet high frequency analysis. Then the rate and pressure are synchronized in every identified time intervals. Since the rate and the frequency amplitude of the transformed transient pressure are proportional, the real rate value in each time interval can be derived under the given common practical conditions.

Both synthetic and field examples were used to demonstrate and further validate the developed technique, which showed very promising results.

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## 1. Introduction

Reservoir engineering is the core of exploitation. One of the main tasks of reservoir engineering is processing and analyzing the pressure and production rate data from the reservoir. Almost every reservoir engineering method has a great relation with pressure and production rate. But, few companies install the down-hole flow meter for saving money. Some oil companies measure the daily production rate on the surface using a separation equipment. This production history cannot represent the down-hole production rate because the data recording frequency is low and the influence of a well is big. So, it's a big problem to get the precise production profile. This is worsened further if production wells are completed following commingled scheme. The wrong production history will increase the uncertainty of reservoir simulation and will result in the mistake of making a decision. Therefore, flow history reconstruction is extremely important for correct well/reservoir parameter calculations.

Several correlation-based and physics-based rate allocation methods have been proposed. The simplest method is to use productivity function (PI for oil wells) or an infinite radial flow mml:model for flow rate reconstruction (Sammy and Eduardo, 2004). Some improvement is reached by using the exact interpretation model to adjust the flow rate to the corresponding pressure value while accounting for effects of superposition in a manner simmilar to that of transient inflow performance (Meng et al., 1982). But this method has a limitation to be applied in unsteady state and some complex reservoir model. Athichanagom and Horne (1999) presented how to reconstruct the unknown parameters and address uncertainties of flow rates through regression on pressure by parameterizing them as unknown parameters constrained to the existing rate measurements and production

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data. The objective function consists on the reduction in error between the real and estimated cumulative production after the rate history has been adjusted. However, this method is based on the reservoir model in addition to the application of optimal method to the model. Another approach is based on the application of soft computing (Fuzzy Logic) to investigate pattern of relationships between production contribution of layers in commingle wells and rock petrophysical data as well as other relevant geological/engineering data (Widarsono and Atmoko, 2005). The Fuzzy Logic is a qualitative method which largely depends on the experiment of reservoir engineering.

During recent few years, PDG pressure data has found a wide range of applications in the oil and gas industry (Ouyang and Kiani, 2002), including: reducing ambiguity and uncertainties in the data interpretation; detecting the changes in reservoir properties; monitoring skin, permeability, pressure drawdown over time; evaluating the performance of well completion, stimulation or workover; identifying reservoir connectivity; assisting reservoir simulation and history matching, etc. Several papers were published to apply the permanent down-hole pressure gauges for production or injection profiling and allocation (Liang and Ramzy, 2003).

Well workover is a common procedure for stimulating a well in order to enhance its performance. Coiled tubing is typically employed as an integrated piece of the tool string for well work-over operation. The introduction of coiled tubing into a wellbore will reduce the cross-section area open to fluid flow, resulting in higher fluid velocity and thus higher frictional pressure drops, which will be sensed and recorded by PDG. Ouyang and Kiani (2002) demonstrated a one-to-one relationship between the in-situ flow rate and the change in the frictional pressure drop. As long as the coiled tubing passes through all the fluid in-fluxing/out-fluxing intervals, in-situ well flow rate can be calculated for all the wellbore locations, leading to a complete production or injection profile. Sun and Konopczynski (2006) proposed a technique of integrating down-hole real-time pressure and temperature data to predict and allocate multiphase production in a multiple zone intelligent well system, which used customized Interval Control Valves (ICV) choke performance models.

The current method for rate allocation using Permanent Downhole Pressures is proposed by McCracken and Chorneyko (2006) ExxonMobil Upstream Research. This approach gives four steps method to allocate rate by using the permanent down-hole pressure. The first step in this process is to determine an initial guess which is given by applying allocation factors based on infrequent surface well tests to the total measured production for the rates. Secondly, the measured down-hole pressure is analyzed using a pressure transient analysis method and the initial rates. A simple reservoir model is developed using the pressure transient analysis results and down-hole pressures as history-matching criteria. Thirdly, this model is then used to predict rates using the down-hole pressure measurements as an input. The result is rates that are consistent with the down-hole pressure and are related to the drawdown, since these rates are predicted using high frequency pressure data. However, these predicted rates do not necessarily match the cumulative production. Finally, an algorithm was developed to provide a mechanism for comparing predicted production rates to the measured cumulative rate and to reallocate the production so that the measured cumulative production is honored. However, there are two points in their approach which I cannot agree. First, the difference between the predicted production rate and the real measured cumulative rate may be caused by using the wrong and simple model. But the authors just tried to eliminate the difference by reallocating the rate without considering changing the model. The s. point is that the relation between pressure and rate cannot just use a simple model to express it without any hypothesis. And they did not give the detailed information about this simple model.

Recovering rate from PDG pressure and accumulated rate are based on the correctly measured data. The key of back allocating the rate is to know the relationship between the rate and real-time pressure. This relationship is complex and nonlinear, which cannot be described by the current available formula. The new approach presented in this paper will recover the rate from a different angle. First of all, the locations where the flow rate changes can be detected from PDG pressure with current wavelet transform approach (Chui, 1992; Jitendra and Meiqing, 1998; Athichanagom and Horne, 1999). After the wavelet transform is used to process the PDG pressure, people pay more attention to processing data. But nobody pays attention to the relation between the amplitude of high frequency signal and rate. This is a linear relationship, which can be used to recover the rate with the restriction of accumulated production in a linear reservoir system as assumed. In the next section, the theory of this relationship will be described. Then two case studies will show the result of recovering rate in a single well. Finally, this approach will be extended to allocate the production rate in a situation of production from commingled wells.

## 2. Method description

### 2.1. Signal and system

The reservoir is considered as a system and the rate is considered as the input signal, while the pressure is output signal resulted from the rate and reservoir system. Every rate changes in short time like an impulse signal to the reservoir system. For a linear system, the response of a step signal is constant. This relationship can be used to approximately calculate the rate from PDG pressure with the restriction of accumulated rate. There is no real linear system in real world. But, the nonlinear system can be treated as a linear system in a short time. In addition, this theory is applied to the field data with the help of wavelet transform.

The key of applying this theory is to find the impulse signal and Linear Time-Invariant (LTI) system (Oppenheim et al., 1997). In fact, there is no impulse signal and LTI system in the real world. Any real physical system has some inertia associated with it and thus does not respond instantaneously to inputs. Consequently, if a pulse of sufficiently short duration is applied to such a system, the system response will not be noticeably influenced by the pulse's duration or by the details of the shape of the pulse. Instead, the primary characteristic of the pulse that does matter is the net, integrated effect of the pulse, its area. For a short duration before the details of the impulse shape or its duration no longer matter. Nevertheless, for any physical system, we can always find an impulse that is 'short enough'. In our reservoir system, any change of production rates in instantaneous time can be considered as an approximate impulse signal. On the other side, there is no real LTI system in the real world because the parameters of the system are all changing with time. But the nonlinear system can be considered as a linear system in a short time. The next part of the paper will discuss the relationship between rate and pressure in a single phase oil reservoir system.

### 2.2. Impulse signal and its reservoir response

Let's begin with a simple reservoir model. The differential equation for fluid flow in a porous medium, the diffusivity equation, obeys the law of mass conservation, an equation of state, and Darcy's law, i.e. considering a one dimension equation:

$$\frac{\partial^2 P}{\partial r^2} + \frac{1}{r}\frac{\partial P}{\partial r} = \frac{1}{0.0002637}\frac{\phi\mu c_t}{k}\frac{\partial P}{\partial t} \tag{1}$$

This equation assumes horizontal flow, negligible gravity effects, a homogeneous and isotropic porous medium, a single phase fluid of small and constant compressibility, and applicability of Darcy's law, also the parameters such as $\phi$, $\mu$, $C_t$, $k$ are independent of pressure.

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