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Geological interpretation of channelized heterolithic beds through well test analysis

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ABSTRACT

Well test analysis is a valuable tool to measure the dynamic response of a reservoir through determination of the hydraulic connectivity and effective permeability of the reservoir. Analytical models in well test analysis, are developed based on a simple geological structures, to provide reasonably good approximations for the description and performance of such reservoirs. Nevertheless, most prolific reservoirs such as channelized systems consist of sedimentological features with high degrees of heterogeneity that influence the pressure transient response where using conventional analytical models may result in misleading interpretations. The focus of the current study is on reservoirs which depositional environment corresponds to a main channel feature incising into heterolithic beds in lateral continuity. Analysis of the pressure response demonstrated that it can be used as a tool to predict the equivalent isotropic horizontal permeability of the channel. We explored that the ratio of well test permeabilities between the radial flows can lead to the identification of a secondary geological body next to channel. Thus, it can be used to find the distance of the interface between channel and heterolithic. The results of this study showed that particular features of pressure and its derivative curves from a channel-heterolithic system are useful well testing signatures for reservoir characterization. Therefore, we proposed an algorithm for the recognition of pressure trends and the development of relationships to be used for well test interpretation of heterogeneous oil and gas reservoirs.

1. Introduction

Well test provides a tool to describe the well and reservoir through dynamic conditions. From pressure transient analysis, well parameters such as skin factor, wellbore storage and well geometry, and reservoir properties such as pore pressure and permeability can be estimated. Furthermore, interpretation of well test data can lead to characterization of the changes in facies, natural fractures, layering, and identification of their corresponding boundaries (Bourdet, 2002).

Commercially available well test interpretation tools are based on a series of known models and their analytical solutions. Therefore, geological interpretations in these software packages are carried out based on the predetermined behaviours. Interdependence between geology (static) and well test (dynamic) interpretation is well recognized (Massonnat and Bandiziol, 1991). Well test provides geologists with an improved knowledge of the reservoir system from a dynamic model such as confirming flow boundaries, and composite behaviours. In a similar manner, a good understanding of the geological setting allows us to make an appropriate selection of the possible analytical models from a wide range of possible solutions in well test tools.

These interpretations include the integration of geophysical, geological and petrophysical information (Toro-Rivera et al., 1994). The models provide a concept of the behaviour of a reservoir, as it can be for instance homogeneous, heterogeneous, bounded or infinite reservoir. The behaviour of a reservoir is a product of averaging its properties; thus, they are sometimes different from the geological or well logging models (Bourdet, 2002).

Analytical solutions can generate pressure responses whose parameters are adjusted until the response from the model is almost identical to the reservoir. Nevertheless, this can be a kind of pitfall since for reservoirs with several heterogeneities, different models may be used and tuned to describe the pressure behaviour. This uncertainty might be reduced using additional geological, petrophysical or geophysical data (Corbett et al., 1998).

The study of heterogeneous reservoirs most of the times is simplified by using composite models. The general case for composite reservoir

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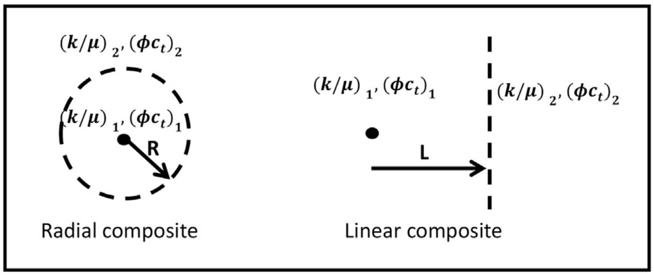

Fig. 1. Conceptualized model for radial and linear composite reservoirs (After Bourdet, 2002).

models consists of two distinct media in the reservoir, each one is characterized by a different porosity and permeability. No type-curves are commercially available for these types of configurations, and the procurement of one will be discussed in the current study. Therefore, the evaluation of non-continuous reservoir units is critical for the resolution of lateral continuity and channel connectivity (Massonnat and Norris, 1993). There are many reservoirs located in channelized settings; hence, it is necessary to understand how accurate well test analyses can describe the heterogeneity due to lateral continuity and channel connectivity in this type of reservoirs (Bourgeois et al., 1996; Massonnat and Norris, 1993; Azzarone et al., 2014).

Radial composite systems have been studied in the past (Hurst, 1960; Carter, 1966), and in these models it is assumed the first zone is near wellbore, and the second zone belongs to the reservoir, where they have different effects on pressure response. The purpose of such models is to describe a radial change in properties from the vicinity of the well toward the reservoir (e.g., acidification treatment, damage, among others). The numerical models for radial composite, as in dual porosity formations, are tested and validated by several studies (Guo et al., 2012).

In linear composite systems, on the other hand, it is assumed a vertical plane at the interface between two reservoir media exist (Ambastha et al., 1989; Idorenyin and Shirif, 2015). This configuration can reflect two different sedimentological elements such as a channel and heterolithic, as we use it in this study. Schematic representations of both radial and linear composite reservoirs are shown in Fig. 1.

As shown in Fig. 1, each zone has a specific mobility ratio which is the ratio of rock permeability to viscosity of the host fluid (Ambastha, 1995). The composite model assumes that the thickness of the reservoir is constant, the change of properties is abrupt, and flow across the interface of regions is without any resistance.

Analysis of the pressure response of the linear composite systems, gives a first radial flow that describes the main reservoir body next to the well, and a second radial flow describes an equivalent of the total system i.e., main reservoir body and next lithology (Bourdet, 2002). However, in the radial composite model only the external region influences the second radial flow. Furthermore, if the system is followed by a sealing boundary, pressure response will be a linear function of the square root of time. Linear flow can be identified from the derivative pressure on a logarithmic plot through a straight line with slope of one-half. This type of flow is a common characteristic for channels and it is observed at late time response of the pressure transient tests (Lee et al., 2003).

Different models are developed to characterize reservoir heterogeneities through pressure transient analysis. Chen et al. (2012) developed a workflow for stratigraphic well test analysis in turbidite reservoirs; Ezulike and Igbokoyi (2012) obtained a three-dimensional semi--analytical solution for horizontal wellbore drawdown response in composite clastic reservoirs; and Mijinyawa et al. (2010) presented a multi-disciplinary method linking history matching of well test data to seismic and geological evidence using a simple numerical simulator. Recently Walsh and Gringarten (2016) investigated the well test responses to different geological settings for a fluvial reservoir system.

A high percentage of productive reservoirs are highly heterogeneous as turbidites, braided fluvials, and meandering channels among other laterally channelized complexes (Kuchuk and Habashy, 1997). Therefore, permeability contrast, between different facies, influences the pressure transient responses. Investigators (Toro-Rivera et al., 1994; Chandra et al., 2011) concluded the presence of a secondary body next to the main sand directly influences the obtained effective permeability through well test analysis. On the contrary, heterogeneities in porosity can slightly impact on the pressure response (Savioli et al., 1995).

To analyse the well test response of complex geological features, investigations have broadly made with the use of reservoir numerical modelling to emulate pressure transient analysis. Many investigations have been conducted on understanding well test signatures associated with different heterogeneities such as lateral and vertical connectivity of facies, channelized environments, geochok, geoskin, ramp effect, interaction between fluid and geological heterogeneities among others, and found that such heterogeneities should be given a careful attention in reservoir characterization process through well test analysis (Corbett et al., 1996, 2005, 2012; Hamdi, 2012, 2014; Hamdi et al., 2012). Bourgeois et al. (1996) studied the influence of levees in a channel. They used a three-zone composite model, and their qualitative analysis of the pressure response showed the effect of changing the mobility ratio between facies, distance to the levees, and the width of the channel. They found that for limit cases such as a perpendicular fault to a channel, or a parallel fault at a very far distances from the channel, responses have similarities with a closed or infinite acting system respectively.

Similarly, Massonnat and Norris (1993) conducted two stochastic models with varying the frequency of facies, a case of 20% channel and 20% levees, and then another case of 50% channel and 20% levees. They were able to contrast their results with a real drill stem test from a field to

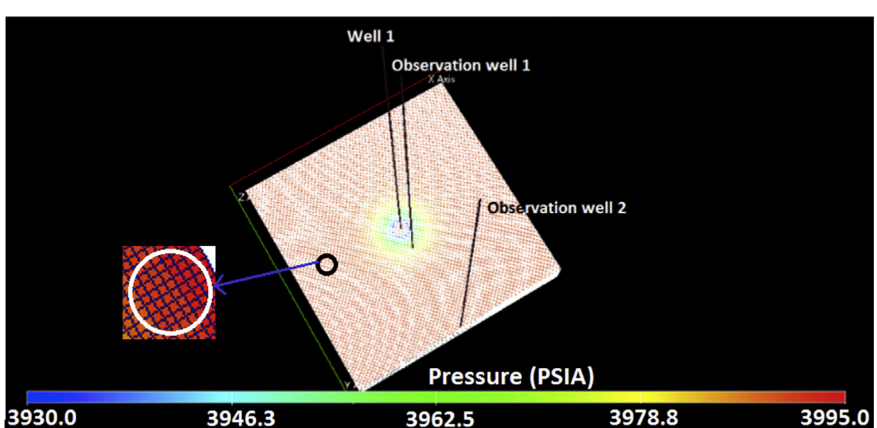

Fig. 2. Pressure distribution in 3D homogeneous grid block size model.