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EVALUATION OF WELL TESTS USING RADIAL COMPOSITE MODEL AND DIETZ SHAPE FACTOR FOR IRREGULAR DRAINAGE AREA

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Key words: radial composite model, dietz shape factor, irregular drainage

Abstract: Well test can be interpreted in analytical approach and via numerical simulations. In analytical methods pressure data are plotted against the appropriate time function. From buildups hydraulic properties are estimated. From drawdowns deliverability is inferred. Results from both parts must be consistent. However, this becomes very difficult with noisy data or a complicated reservoir.

Numerical tools can verify the results. Through History Match pressure response to specified rates and reservoir conditions is generated. This helps us to verify the current model. Since well testing is an inverse problem, geology should be studied to avoid a model that acts like the actual reservoir, even though the physical assumptions are invalid.

1. Introduction

Interpretation of a pressure transient analysis has always been a difficult complex task. The PanSystem software v3.1.1 (Petroleum Services (EPS) Ltd. Edinburgh) is an easy-to-use yet very powerful software tool with an efficient workflow that offers a wide range of wellbore, reservoir, and boundary models. For most of gas well tests, analysis based on classic wellbore storage model and radial homogeneous flow model is satisfactory. Usually, when dealing with an uncomplicated isochronal well test, from build-ups, firstly, the wellbore storage coefficient is obtained from the early data in a log-log plot and, secondly, permeability and total skin are derived from the infinite acting portion of data using the Horner approximation and type curves. As a next step, the non-Darcy skin analysis is performed on drawdown data to give us the skin factor, rate-dependent skin coefficient and non-Darcy flow coefficient. Subsequently, deliverability is computed to get the sandface absolute open potentials, both for values inferred from buildups and drawdowns. If the values for absolute open flow potentials are similar, it can be deduced that the results from the build-ups and drawdowns are coherent and that the interpretation is most probably correct

In this study we focused on two isochronal well tests where special options were needed in order to interpret the data properly. First, a test from a well that has been stimulated by acidizing that resulted in a permeability discontinuity. Second, we investigated a low-permeability well where deliverability results were not coherent and where material balance on a closed system had to be carried out. The analyses were performed using the PanSystem software v3.1.1 (Petroleum Services (EPS) Ltd. Edinburgh). The differences in the analyses are described.

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2. Radial-composite flow model

One option how to stimulate a producing gas well is acidizing which can result in a permeability discontinuity. As a consequence the area of the wellbore can not be modeled as homogeneous. In such cases the flow model should be changed from radial homogeneous to radial composite [1]. Radial composite flow model consists of an inner cylindrical homogeneous region surrounded by an outer region of different properties (Fig. 1). An infinitesimally thin radial discontinuity is assumed to separate the two reservoir regions [2]. The flow in both regions is radial and horizontal.

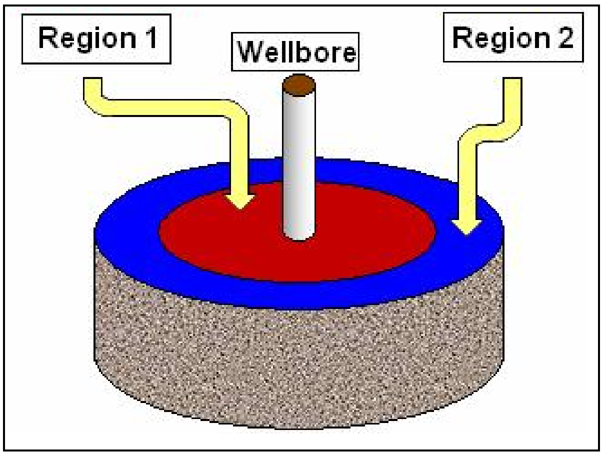

Fig. 1 *Scheme of a radial composite model [3].*

Compared to the radial homogeneous flow, there are some essential new model parameters describing the radial composite model: mobility ratio, storativity ratio and radial distance to the discontinuity [4]. Mobility ratio (*M*) is the ratio of the outer region mobility $(k/\mu)_{outer}$ to the inner region mobility $(k/\mu)_{inner}$.

$M = \left(\frac{k}{\mu}\right)_{outer} \Big/ \left(\frac{k}{\mu}\right)_{inner}$, where *k* denotes permeability and *μ* viscosity.

Storativity ratio (*ω*) is defined as:

$\omega = (\phi C_t)_{outer} / (\phi C_t)_{inner}$, where ϕ is porosity and C_t is total compressibility.

The radial distance from the wellbore to the interface between the inner region and the outer distance (L_{rad}) is derived from the radial composite derivative type-curve [T_D/R_D^2] time match

$$L_{rad} = \sqrt{\frac{0.0002637\, k\, \Delta t_{match}}{\phi \mu_0 C_t \left[\frac{T_D}{R_D^2}\right]_{match}}},$$

where ϕ is porosity, μ_0 is viscosity of the fluid and C_t is total compressibility.

When plotting test data from such a well test in a radial flow plot (Fig. 2) there is a major difference compared to the radial homogeneous flow. The results feature a short duration wellbore storage effect followed by two infinite acting periods, divided by a transition period. The first and second semi-log straight lines reflect the parameters of regions behind and ahead of the permeability discontinuity. The length of the transition period is dependent on the mobility ratio, storativity ratio and the discontinuity radius (Fig. 2). According to [5] the inner region may behave like a closed reservoir for large mobility and storativity ratios for short time during the transition period.

The composite reservoir model has a wide application other than just reservoirs with variations in permeability: reservoirs with a fluid bank, reservoirs with a steam front, a and determination of swept volume during in-situ combustion or steam injection in thermal oil recovery, reservoirs with a CO_2 miscible flooding front and other recovery processes [6], [7], [8] and [9].

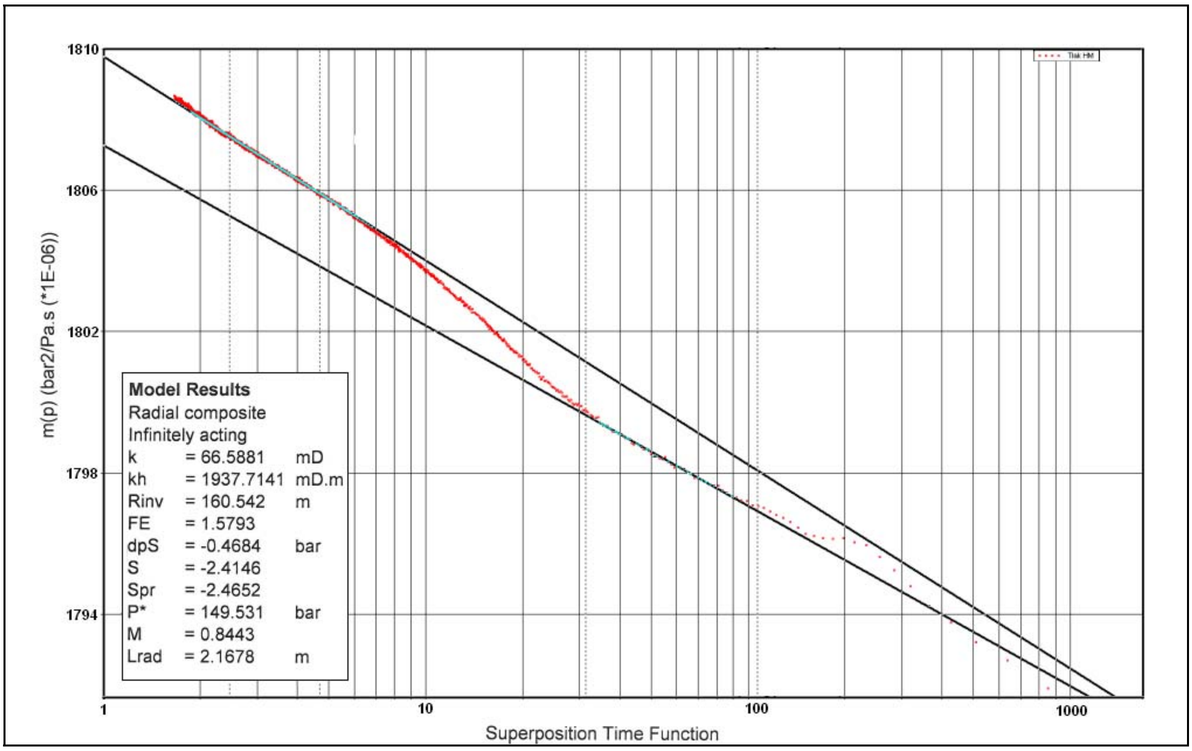

Fig. 2 *Radial flow plot for a radial composite flow.*

3. Deliverability – Absolute open flow

In PanSystem the sandface absolute open flow (AOF) describing the maximum deliverability potential of a gas well can be computed in two ways. First, it is the Laminar-inertial-turbulent AOF (LIT AOF) based on drawdown data, derived from actual flowing test measurements by fitting. Second, it is the theory-based AOF using the semi-steady-state inflow equation (Eq. 1) [10].

$$p_e - p_{wf} = \frac{q\mu}{2\pi kh}\left(ln\frac{r_e}{r_w} - \frac{1}{2} + s\right) \quad (1)$$

where p_e represents pressure at external boundary,
p_{wf} is the bottom hole flowing pressure,
r_e is the external boundary radius,
r_w is the wellbore radius,
S is mechanical skin, h is thickness,
k is permeability.

These two AOF values should be equal (Fig. 3), which indicates that the permeability and skin derived from the build-ups are coherent with the deliverability results from the flow periods. A difference in these results might indicate that the test periods were too short and were still transient, or that some of the model parameters need to be adjusted in the theoretical model. If it is a low-permeability well, a change in layer parameters can be very helpful. The layer parameters that are used in deliverability calculation are layer pressure and Dietz shape factor [11] together with drainage area.

The Dietz shape factor (C_A) is introduced into the inflow equation to account for the drainage area shape and the position of the well (Eq.2) [10].

$$p - p_{wf} = \frac{q\mu}{2\pi kh}\left(\frac{1}{2}ln\frac{4A}{\gamma C_A r_w^2} + s\right) \quad (2)$$

where p is the average pressure, p_{wf} is the bottom hole flowing pressure, γ is the exponential of Euler´s constant, A is the drainage area, r_w is the wellbore radius, S is mechanical skin, h is thickness, and k is permeability. The Dietz shape factor assumes constant rate well tests. Examples of Dietz shape factors for a range of reservoir geometries are illustrated below (Fig. 4). By default the C_A value is 31.62 (centre-positioned well in a circle reservoir) and the drainage area is equal to 259 ha.

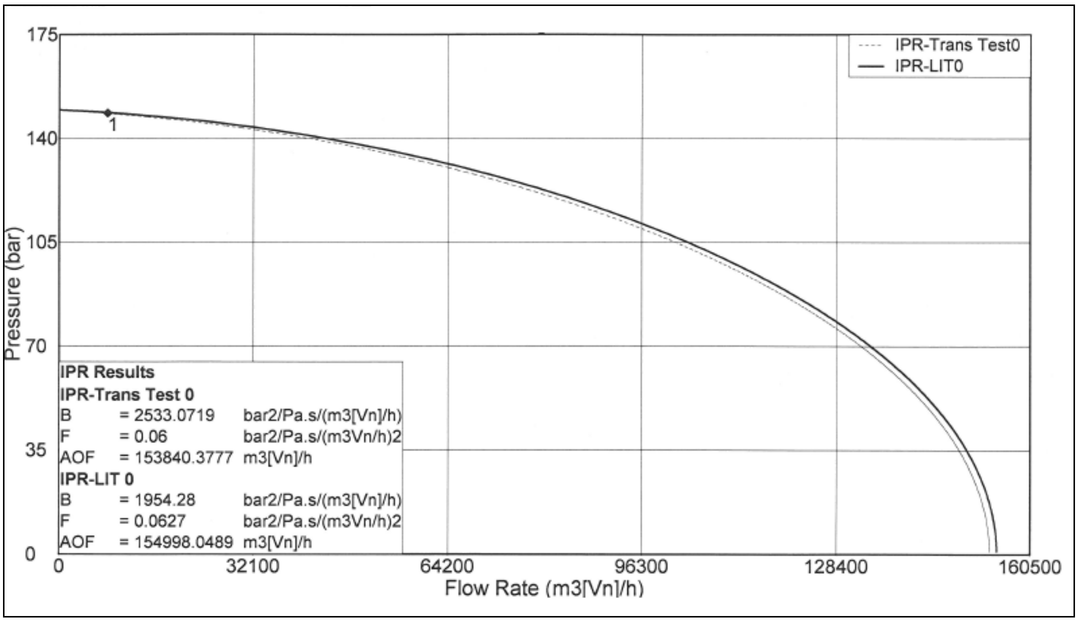

Fig. 3 *Deliverability-IPR plot.*

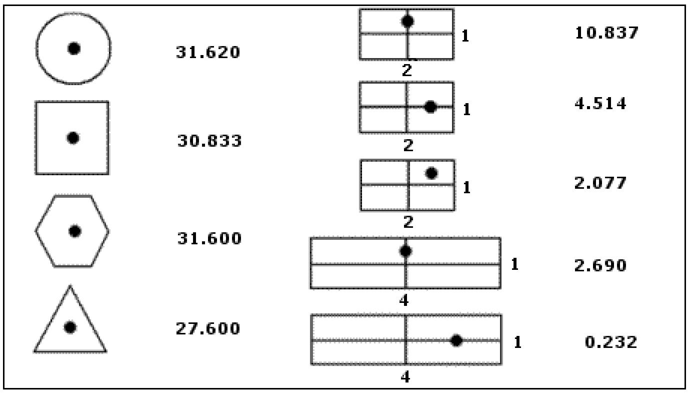

Fig. 4 *Constant rate Dietz shape factors [3].*

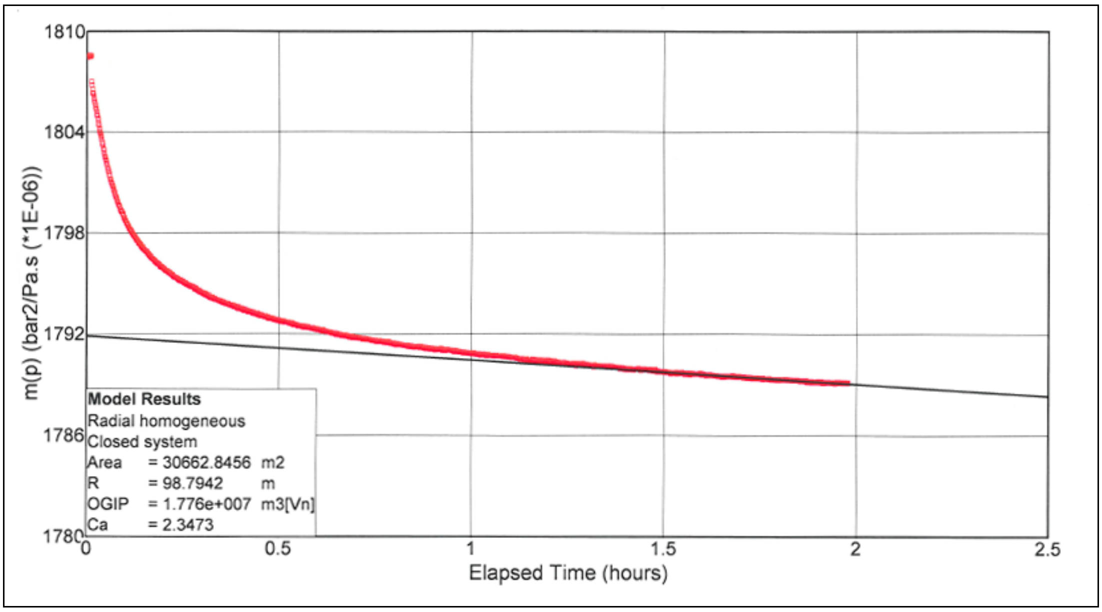

Fig. 5 *Cartesian plot for a closed system.*

The Dietz shape factor (C_A) together with the drainage area and the gas-in-place volume (OGIP) are estimated from the cartesian plot (Fig. 5) by the means of material balance. To model this, the boundary model must be closed system, assuming radial homogeneous flow only. C_A is derived from the last extended flow period using a straight line on the late portion of data. For this well the C_A is equal to 2.347, which suggests a rectangular drainage area (Fig. 4).

4. Conclusions

We have shown examples of two unusual well tests. First, it was an isochronal test from a well after acidizing where the usual radial homogeneous flow model would not be satisfactory. In this case the radial composite flow model had to be chosen due to a permeability discontinuity that resulted from the acid stimulation. In the second part we described an example of a low-permeability well where the deliverability results from the LIT analysis based on flow periods were not coherent with the results provided from the semi-steady state flow. To obtain correct deliverability results it was essential to derive a Dietz shape factor from the material balance in a closed system.

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