Application of Different De-convolution Methods in Well Test Analysis of One Iranian Naturally Fractured Reservoir

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Abstract

De-convolution is a method of converting a variable rate distorted pressure profile into the pressure profile for an equivalent constant rate production sequence. There are two methods used for de-convolving distorted pressure data: Beta De-convolution and material balance de-convolution methods. The application of both methods was tested in well test analysis of a naturally fractured reservoir. The end of well bore storage was estimated by both methods, and then the reservoir data were analyzed by well testing software. The calculated permeability, interaction coefficient and storativity ratio are different in both approaches. The comparison of data shows that the material balance method predicts the pressure response better and is suggested for applying in field cases.

Keywords: Well Bore Storage, Convolution, De-Convolution, Well test Analysis

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1- Introduction

De-convolution is a method to distinguish the distorted data and take apart these data from real reservoir data. Material balance de-convolution technique is restricted when the lack of measurement exists. Van Everdingen [1] and Hurst [2] demonstrated empirically that the sand face rate profile can be modeled approximately using an exponential relation for the duration of wellbore storage distortion during a pressure transient test. The van Everdingen/Hurst exponential rate model is given in dimensionless form as:

$$q_D(t_D) = 1 - e^{-\beta t_D} \quad (1)$$

Joseph and Koederitz [3] and Kuchuk [4] applied "β de-convolution" for the analysis of wellbore storage distorted pressure transient data. In Appendix B, we provide a detailed derivation of the "β de-convolution" relations that we use in our work. The β de-convolution formula, which computes the undistorted pressure drop function directly from the wellbore storage affected data, is given as:

$$p_{sD}(t_D) = p_{wD}(t_D) + \frac{1}{\beta}\frac{dp_{wD}(t_D)}{dt_D} \quad (2)$$

In this study β de-convolution and material balance de-convolution approaches have been applied in a field case to estimate the end of well bore storage and the effect of these methods in well test analysis of a naturally fractured reservoir.

2- Results and Discussion

Convolution is a mathematical operator which, using two functions f and g, produces a third function commonly noted as f*g representing the amount of overlap between f and a reversed and shifted version of g. The convolution operation is defined as:

$$(f * g)(t) = \int_0^t f(\tau)g(t-\tau)d\tau \quad (3)$$

The principle of superposition (or convolution) states that, for a linear system, a linear combination of solutions for a system is also a solution to the same linear system. The superposition (or convolution) principle applies to linear systems of algebraic equations, and for our field of study — linear partial differential equations (i.e., the diffusivity equation for flow in porous media).

The early work by Duhamel [5] on heat transfer has since then been used in numerous engineering domains. Adapted to our domain, petroleum engineering, Duhamel's principle states that the observed pressure drop [6,7] is the convolution of the input rate function and the derivative of the constant-rate pressure response — at t=0 the system is assumed to be in equilibrium (i.e., p(r, t=0) = pi).

De-convolution is a method of converting a variable rate distorted pressure profile into the pressure profile for an equivalent constant rate production sequence.

The general form this method for pressure drawdown or buildup cases are given by following formulas1, 2.

$$\Delta P_s = \Delta P_w + \frac{\Delta P_{wd}}{(\Delta P_{w-\Delta P_{wd}})} \Delta P_{wid} \quad \text{(Constant rate Pressure drop)} \quad (4)$$

Where, for the pressure buildup case, we have:

$$\Delta P_w = \Delta P_w - \Delta P_{wf}(\Delta t = 0) \quad \text{(Pressure drop)} \quad (5)$$

$$\Delta P_{wd} = \Delta t \frac{d\Delta P_w}{d\Delta t} \quad \text{(Pressure drop derivative)} \quad (6)$$

$$\Delta P_w = \frac{1}{\Delta t} \int_0^{\Delta t} \Delta P_w \, d\tau \quad \text{(Pressure drop integral)} \quad (7)$$

$$\Delta P_{wid} = \Delta t \frac{d\Delta P_{wi}}{d\Delta t} \quad \text{(Pressure drop integral-derivative)} \quad (8)$$

The above mentioned pressure drops have been calculated for the well test data in this well.

Material balance de-convolution is an extension of the rate normalization method. Johnston21 defines a new x-axis plotting function (material balance time) which provides an approximate de-convolution of the variable-rate pressure transient problem. There are numerous assumptions associated with the "material balance de-convolution" methods — one of the most widely accepted assumptions is that the rate profile must change smoothly and monotonically. In practical terms, this condition should be met for the wellbore storage problem.

The general form of material balance de-convolution is provided for the pressure drawdown case in terms of the material balance time function and the rate-normalized pressure drop function. The material balance time function is given as:

$$t_{mb} = \frac{N_p}{q} \quad (9)$$

The wellbore storage rate function for the pressure Build up case, qwbs,BU, is given as:

$$q_{wbs,BU} = \frac{1}{m_{bs}}\frac{d}{d\,\Delta t}\Delta p_{ws} \quad (10)$$

Where the wellbore storage "slope" is defined as:

$$m_{wbs} = \frac{qB}{24C_s} \quad (11)$$

And the pressure drop terms are defined as:

$$\Delta p_{ws} = p_{ws} - p_{wf}(\Delta t = 0) \quad (12)$$

The wellbore storage cumulative production for the pressure buildup case, Np,wbs,BU, is given as:

$$N_{p,wbs,BU} = \Delta t - \frac{1}{m_{wbs}}\Delta p_{ws} \quad (13)$$

The wellbore storage-based, material balance time function and rate normalized pressure for the pressure buildup case is given as:

$$\Delta t_{wbs,BU} = \frac{\Delta t - \frac{1}{m_{wbs}}\Delta p_{ws}}{1 - \frac{1}{m_{wbs}}\frac{d}{d\,\Delta t}\Delta p_{ws}} \quad (14)$$

$$\Delta p_{s,BU} = \frac{1}{1 - \frac{1}{m_{wbs}}\frac{d}{d\,\Delta t}\Delta p_{ws}}\Delta p_{ws} \quad (15)$$

The rate normalized pressure function should be plotted versus the material balance time function (tmb).

The de-convolution results by both approaches are shown in figure1 and figure 2 for this well on semi-log and log-log papers. Where the constant rate pressure drop (Δps) equals to pressure drop (Δpws), the well bore storage effect is finished.

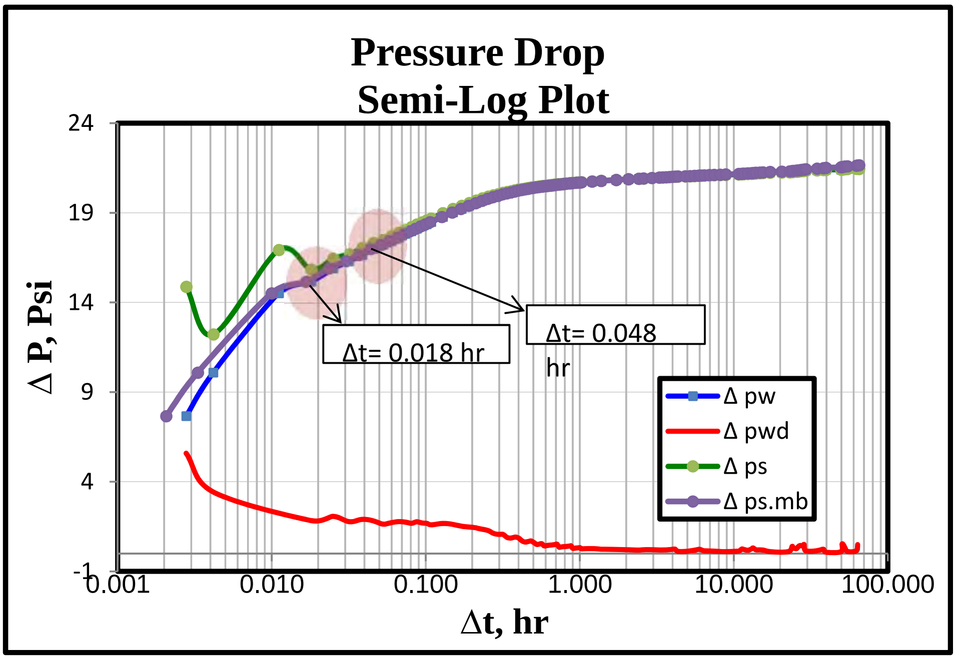

Figure 1: Semi- log plot of pressure drop

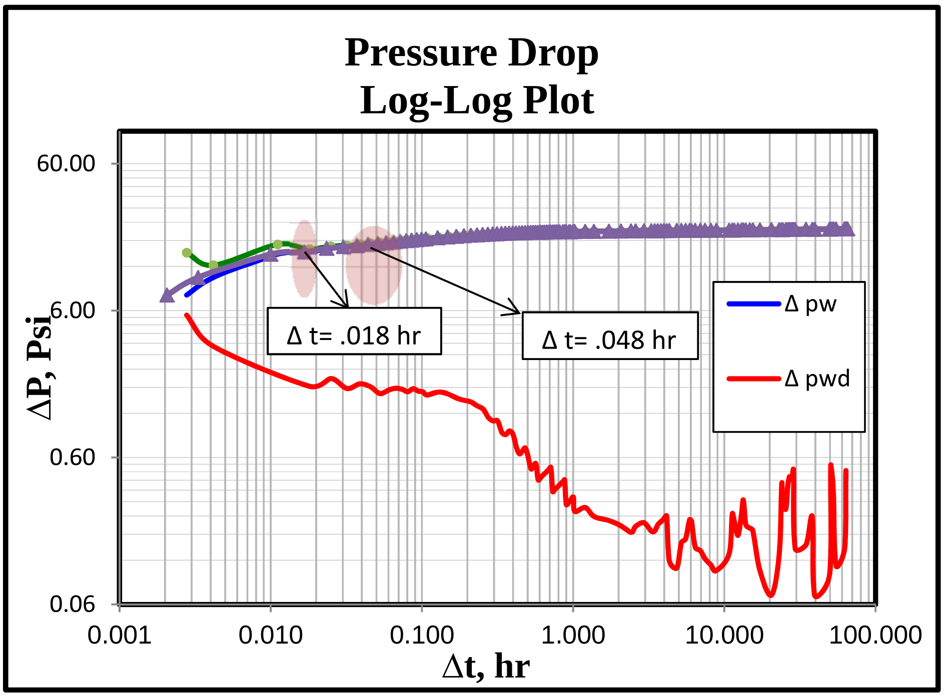

Figure 2: Log- log plot of pressure

The most positive aspect of the application of the explicit de-convolution methods in this example is that we gain approximately the reservoir data and recognizing the pressure distorted data by wellbore storage. The data in the range of $0<\Delta t<0.048$ hr in this well are effectively de-convolved and can be analyzed using "traditional" semi-log or log-log analysis/interpretation methods for well test data by β de-convolution method. This range would be $0<\Delta t<0.018$ hr for the material balance de-convolution method. Figure 3 and figure 4 show the reservoir data used for matching the best model for both approaches.

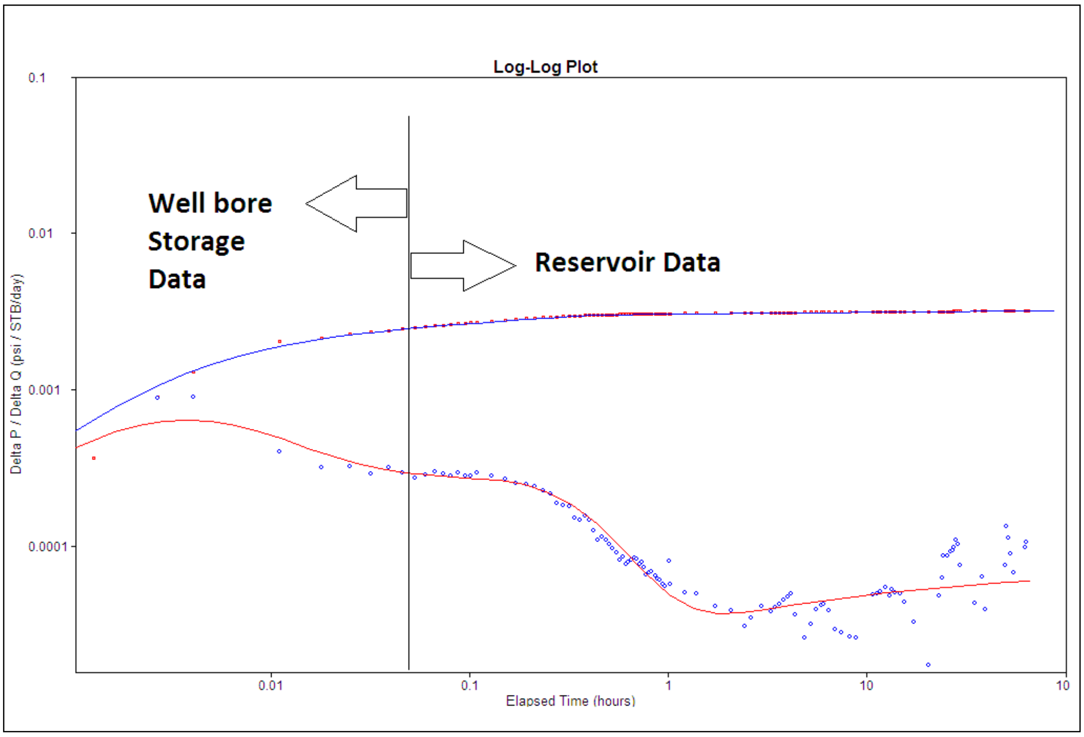

Figure 3: The reservoir and distorted data in well testing software (β de-convolution)

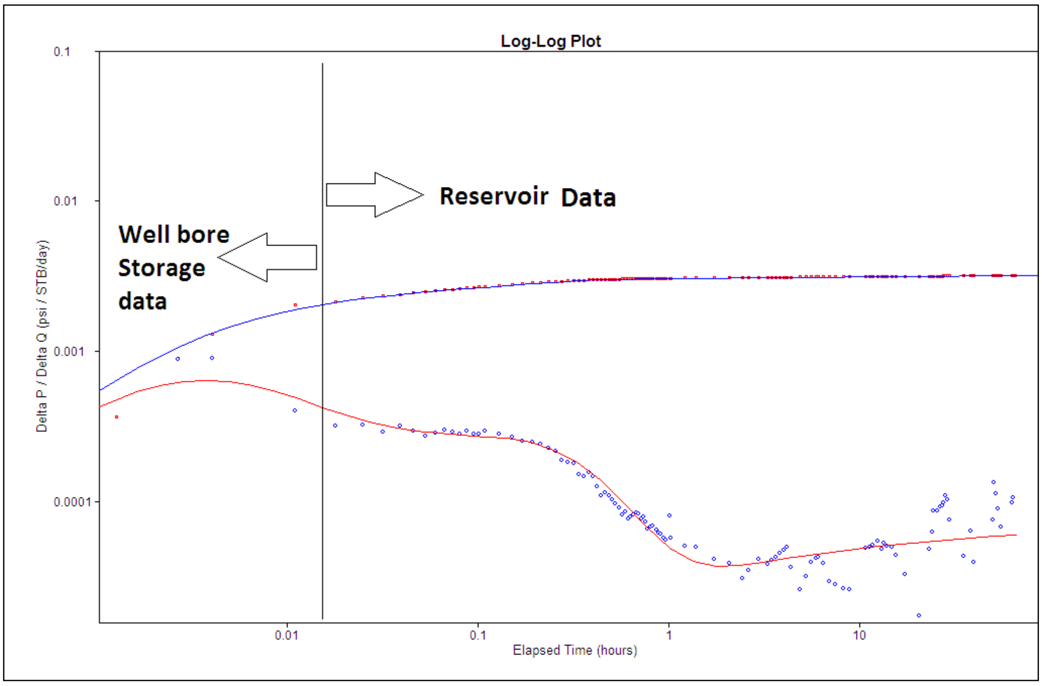

Figure 4: The reservoir and distorted data in well testing software (Material Balance method)

The pressure data were analyzed by well testing software in both approaches and the reservoir parameters were bets matched over the real reservoir pressure data. Figure 5 and figure 6 show the result of matching pressure data with dual porosity model in log-log plot. Table 1 compares the calculated parameters.

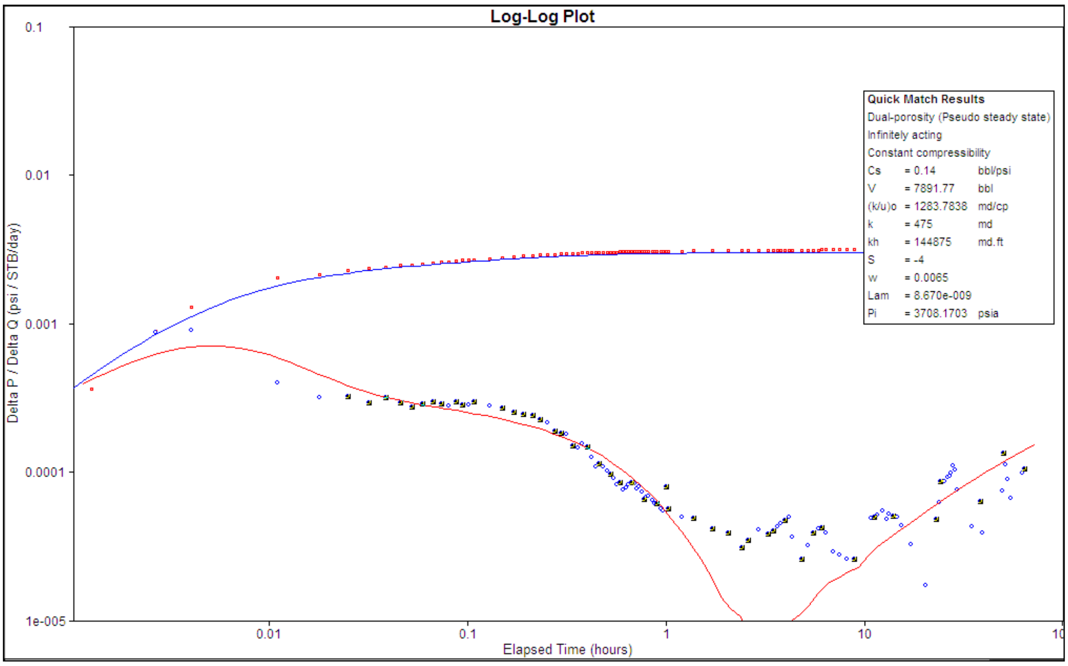

Figure 5: The matched model over the reservoir data log-log plot (β de-convolution)

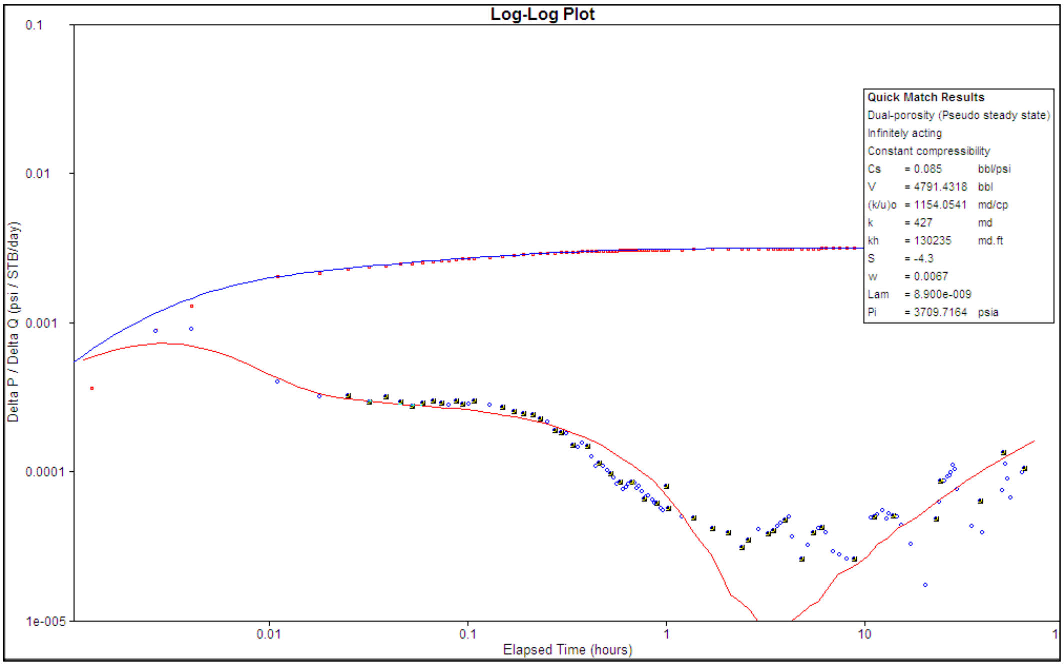

Figure 6: The matched model over the reservoir data log-log (Material Balance method)

Table 1: Calculated reservoir parameters by well testing software in both approaches

Reservoir Parameter	**β De-convolution**	**Material Balance De-convolution**
Well bore storage coefficient (bbl/psi)	0.14	0.085
Permeability (md)	475	427
Interaction coefficient	8.67 E-9	8.9 E-9
Storativity ratio	0.0065	0.0067
Skin	-4	-4.3

The Semi-log and Cartesian plots of best matches in both cases have been shown in figure 7 to 10. It can be seen that the quality of matches for material balance approach is better, so this method is suggested as the de-convolving method to be used in real cases to distinguish the end of well bore storage.

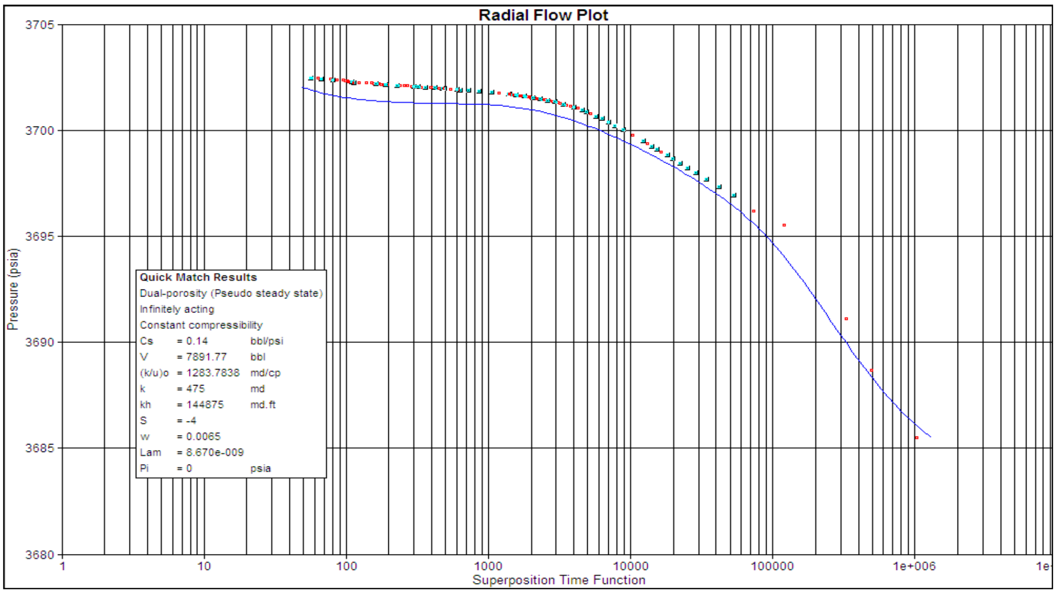

Figure 7: The matched model over the reservoir data Semi-log plot (β de-convolution)

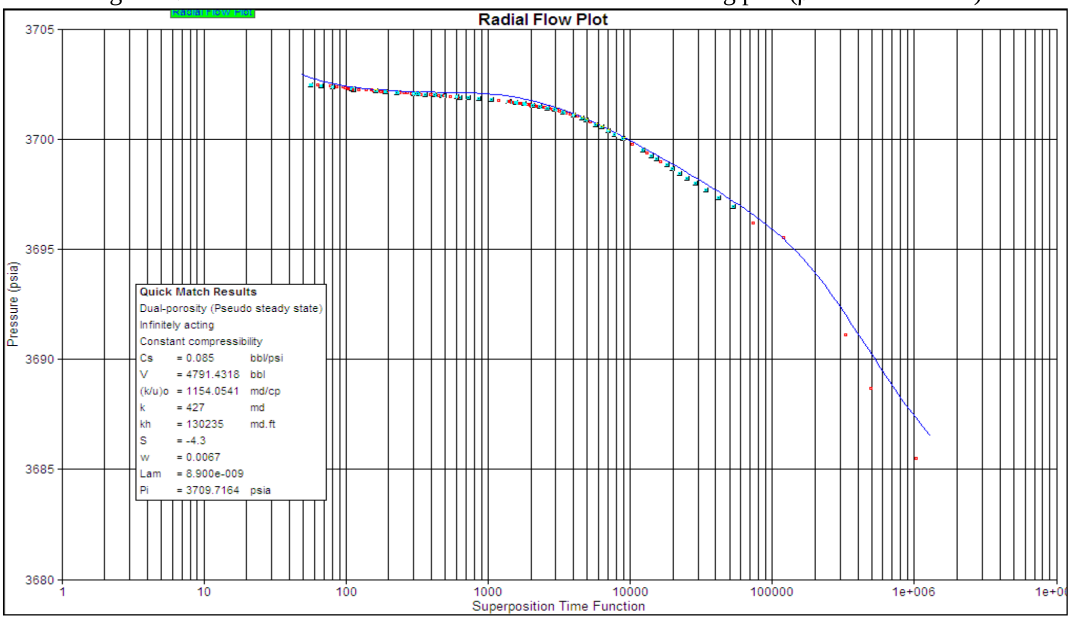

Figure 8: The matched model over the reservoir data Semi-log (Material Balance method)

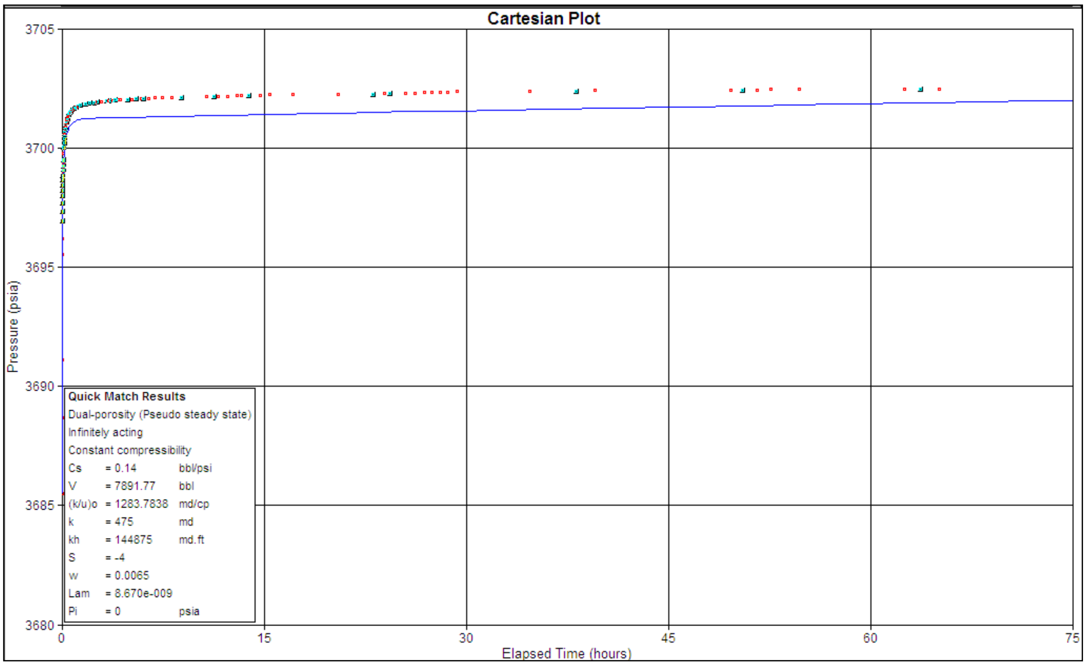

Figure 9: The matched model over the reservoir data Cartesian plot (β de-convolution)

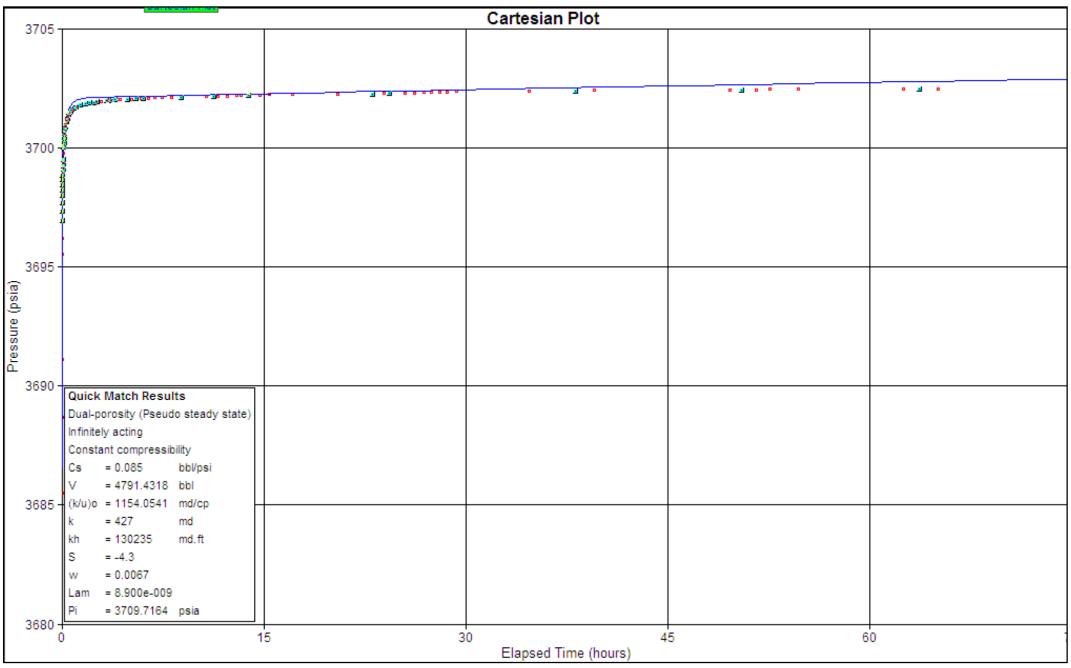

Figure 10: The matched model over the reservoir data Cartesian plot (Material Balance method)

3- Conclusions

1- The β De-convolution method and material balance can be used to predict the end of well bore storage for this field case.

2- The real reservoir data in this case estimated to be started after 0.048 hr by βde-convolution method and 0.018 hr by material balance convolution method, which helps to eliminate the distorted pressure data from analysis.

3- The permeability, storativity coefficient, interaction coefficient and skin factor in case of using β De-convolution method shows about 10%, -11%,-15% and -7% difference with case of using material balance approach in well test analysis.

4- The analyzing of pressure data in well testing software shows that by using the material balance de-convolution method a better match over the real reservoir data can be resulted. So, the material balance de-convolution method is suggested to be used for the real cases.

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