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Use and Misuse of Radial Composite Reservoir Models in Well Test Analysis: A Field Example

Walid Othman Ben Saleh*
Petroleum Engineering Department, Misurata University, Misurata, Libya
*Corresponding Author: w.bensaleh@eng.misuratau.edu.ly

Abstract

Radial composite reservoir models are helpful and suitable in well test analysis in all reservoir situations, where two regions with different properties concentrically centered on the well are present. Due to its flexibility, radial composite model hardly fails to match well test data. However, obtaining a match with such model does not necessarily mean the reservoir is behaving like a radial composite. This flexibility sometimes causes uncertainty in test interpretation. The decision to select composite models over other models should be geologically justified and/or should at least come from the knowledge of the real conditions where composite reservoirs responses are expected, not that the data cannot be matched using other available models. This paper presents a field example of how and why many of well test models get mistaken for the radial composite model. Recommendations to avoid such mistakes will also be presented.

Keywords: Well test; radial composite model; pressure test analysis; mobility.

1. Introduction

Well testing of oil and gas wells is carried out by changing production rate before shutting in the well while recording pressure throughout the entire time of test. The two main objectives of testing an oil or gas well are; first to estimate reservoir parameters, such as permeability, skin factor and reservoir pressure as well as to analyze reservoir behavior and define reservoir boundary limits.
Today, in a computerized oil industry, well test analysts relay heavily on available state of the art technology to diagnose which reservoir model can represent a given pressure test data. Although available tools offer satisfactory solutions, caution should be exercised. Well test analyst should consult with a geologist/geophysics to validate model selected for interpretation, and therefore avoid a model that acts like the actual reservoir when in reality the physical assumptions are invalid.
Many analytical and numerical models have been developed over the years and integrated into well testing software packages. Most of the available software classify models into; wellbore models (Constant and changing wellbore storage), well models (vertical, horizontal, fractured and multilateral wells), Reservoir models (homogeneous, double porosity, double permeability, multi-layer and composite), and finally boundary models (infinite, no flow, constant pressure and leaky boundaries).
Radial composite reservoir model, as it is the focus of this paper, falls under reservoir models and will be discussed in a more detailed manner.
In this paper, pressure test data of well X6 are plotted against appropriate time functions using Excel sheet. These plots will be analyzed and discussed. Also the pressure m test analysis software, Saphir, will be used to support our analysis and interpretation.

2. Diagnostic plots for common reservoirs

Figures from 2.1 to 2.4 are simulated curves generated using built-in analytical models in Kappa's

PTA software, Saphir. These are typical log-log diagnostic and Horner plots expected in some frequently encountered reservoirs. These curves were first published in 1988 by C. Ehlig-Economides.

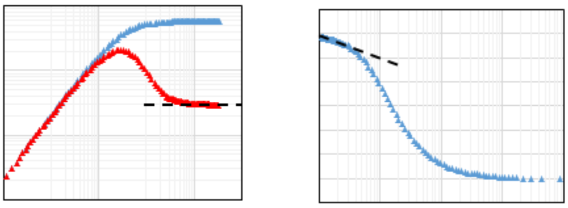

Figure 2.1: Log-log diagnostic plot (left) and Horner plot (right) of a well in a homogeneous reservoir

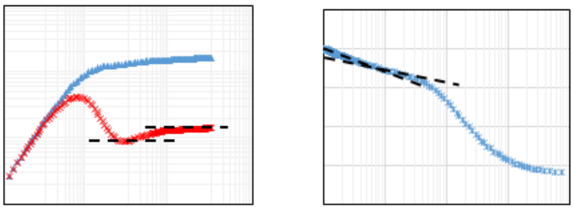

Figure 2.2: Log-log diagnostic plot (left) and Horner plot (right) of a well in a homogeneous reservoir with one sealing fault

For each log-log plot, the blue curve (upper) is the pressure change , ΔP, versus shuti-in time Δt, and the red curve (lower) is the pressure change derivative curve, (ΔP‘×Δt). Patterns characteristic for reservoir and boundary models in the pressure derivative and Horner plots are shown using a dashed black line.

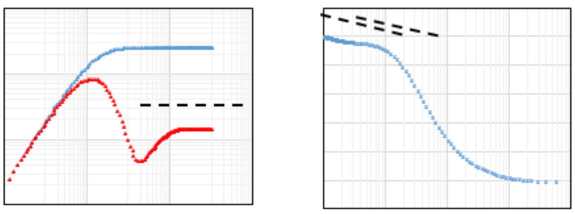

Figure 2.3: Log-log diagnostic plot (left) and Horner plot (right) of a well in a dual porosity system

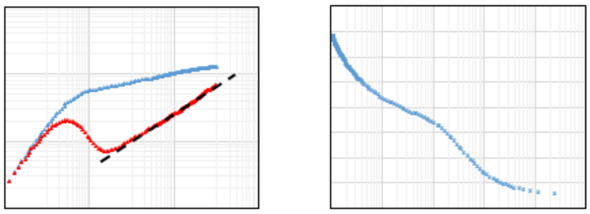

Figure 2.4: Log-log diagnostic plot (left) and Horner plot (right) of a well in a homogeneous reservoir with two parallel faults (channel)

3. Radial Composite Reservoir Model

Radial Composite model assumes two distinct regions with different petrophysical properties as shown in Figure 3.1. This geometry is used to represent radial change of properties which may be as a result of fluid or formation change. Such change can be man-induced as in case of water injection well and stimulated well, or observed due to certain phenomena like, change in saturation due to aquifer or gas cap, producing at pressure below bubble point dew point, reservoir compartmentalization and actual change of porosity and permeability.

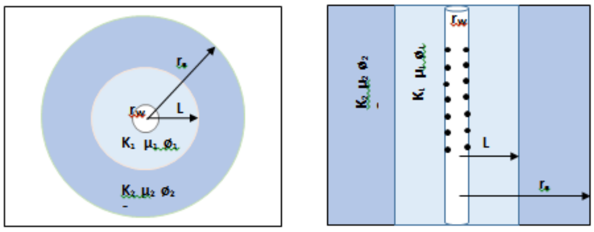

Figure 3.1: Schematic of a Two Region Radial Composite Reservoir

The changes of reservoir mobility ratio (K/μ) is expressed by M in Equation 3.1, and change of reservoir storativity($\emptyset C_t$), is expressed by F in Equation 3.2

$$M = (K/\mu)_1/(K/\mu)_2 \quad (3.1)$$

$$F = (\emptyset C_t)_1/(\emptyset C_t)_2 \quad (3.2)$$

Mobility ratio of radial composite can also be characterized by the ratio of first and the second line slopes M= (m_1/m_2) observed on a semi-log graph. A mobility ratio greater than 1 indicates a decrease in mobility form region 1 to region 2 while a decrease in mobility is indicated by a mobility ratio less than 1.

Figure 3.2 was generated for a two region radial composite reservoir with varying mobility ratio (M). As we can see here, a radial composite with (M>1) can be wronged for a bounded reservoir. For instance, when M is equal to 2, the model becomes very similar to a homogeneous reservoir with a single fault. On the other hand, a radial composite with increasing mobility (M<1) will have the fingerprint of a reservoir with constant pressure boundary. This is where the flexibility of this model stems from. However, It should be mentioned that the effect of storativity (F) is no as significant.

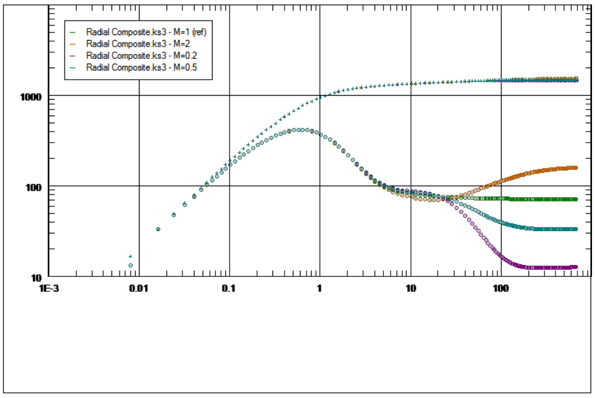

Figure 3.2: Log-log plot of a well in Two Region Radial Composite Reservoir with varying Mobility Ratio (M=0.2, 0.5, 1, and 2)

4. Field Example

A single rate pressure build-up test was run in a vertical oil well (X6) which is perforated in two layers; Upper and Lower Sarir Sandstone formations, separated by a thin shale formation. Well is producing single phase fluid only from the upper sandstone layer. Information concerning to well, fluid and reservoir parameters are provided in Table 4.1. Pressure test data of the tested well X6 are not presented in a table-form, for the sake of space, instead it is shown as a history plot in Figure 4.1 imported from Saphir software.

Table 4.1: Well and Reservoir Data

Parameter	Value
Perforated Interval	Upper 12142-12518ft Lower 12682-12770ft
Reservoir Bubble Point (Pb)	4750psi
Reservoir Pressure (Pi)	4871psi
Porosity (ø)	10.8 %
Oil Form. Volume Factor (B_o)	1.7 bbl/stb
Oil Viscosity (μ_o)	0.35cp
Total Compressibility ct	1.5×10^{-5}psi^{-1}
Reservoir Temperature (T_r)	279F
Wellbore Radius (r_w)	0.354ft
Net Pay (h)	40ft
Prod. Time before Shut-in (tp)	32.5hrs
Bottom-hole Pres. @shut-in (P_{wf})	1638psi
Oil Flow Rate (q_o)	786 stb/day

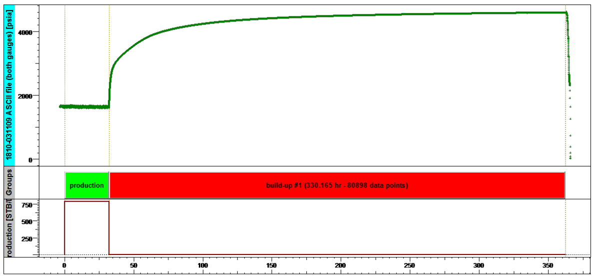

Figure 4.1: Single Rate Pressure Build-up Test Data for Well X6

4.1. Semi-log Analysis

A plot of Horner time ((tp+dt)/dt) versus shut-in pressure (Pws) is shown below in Figure 4.2. From the plot, two straight lines with different slopes (m_1 and m_2) can be identified. This behavior is likely to occur in three cases; well near a single sealing fault, well between two parallel faults and in radial composite reservoirs. In the case of sealing fault, second slope must always be as twice as the first slope which is not true in this plot.

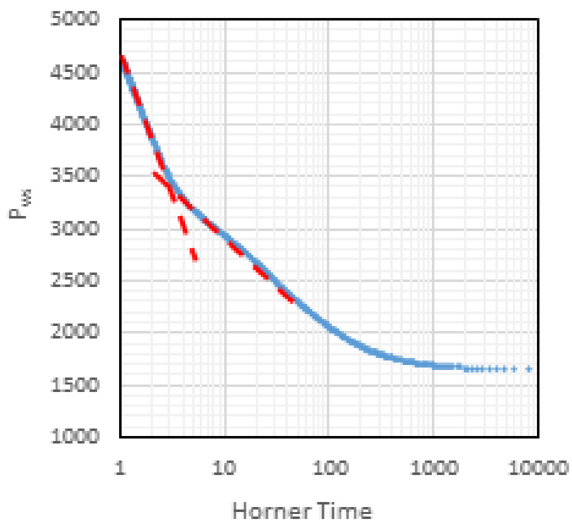

Figure 4.2: Semi-log Plot of build-up test (Shut-in pressure versus Horner time)

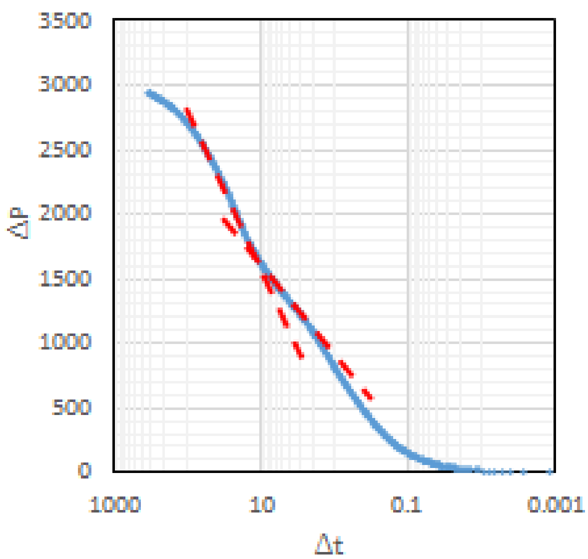

Figure 4.3: Semi-log Plot of build-up test (Pressure change vs shut-in time)

Figure 4.3 is a plot of pressure change versus shut-in time. Two straight lines with different slopes are present. Similarly in radial composite reservoir models, an MDH will exhibit two straight lines, the first line corresponds to the mobility in the inner zone and the second line corresponds to the mobility in the second zone. The ratio of the slopes (m_1/m_2) will give M, the mobility ratio.

Apparently semi-log plots do not show a clear fingerprint of the reservoir behavior, and should be used for interpretation. Log-log plots should be generated instead, and late, slopes corresponding to flow regimes present on semi-log plots would be easy to interpret.

4.2. Log-Log Diagnostic Plots

Using available pressure data, Bourdet pressure cha -nge derivative was calculated and plotted along with pressure change against shut-in time, Figure 4.4 .For build-up and unlike drawdown, Bourdet in his paper published in 1988 stated that pressure derivative is calculated in respect to Horner time instead of the shut-in time. In case of type curve matching, equivalent shut in time ((tp×Δt)/(tp+Δt)) is used sine all type-curves are generated for a flowing reservoirs. In our example, equivalent shut-in time is used to calculate pressure derivative.
A close examination of the diagnostic log-log plot shown in Figure 4.4, four different solution are possible:

1. Radial composite with decreasing mobility
2. Double porosity with a no flow boundary (s)
3. Two layer with a no flow boundary (s)
4. Homogeneous with a no flow boundary (s)

The pressure derivative response is very comparable with a radial composite model with a decreasing mobility (M>1), refer to Figure 3.2 at (M=2). However, a review of the well file, the well was not stimulated nor used for water injection before pressure build-up test. In addition, the well is producing at a pressure well-above the bubble point pressure. Therefore a radial composite model might be an incorrect model to use here.
The fingerprint of a homogeneous reservoir with a single fault is a double slope on the semi-log plot and a double pressure derivative which is not the case in this example. However to examine the validity of the other two models, a more sophisticated tool than just visual examination should be used, and here will be the Saphir software.

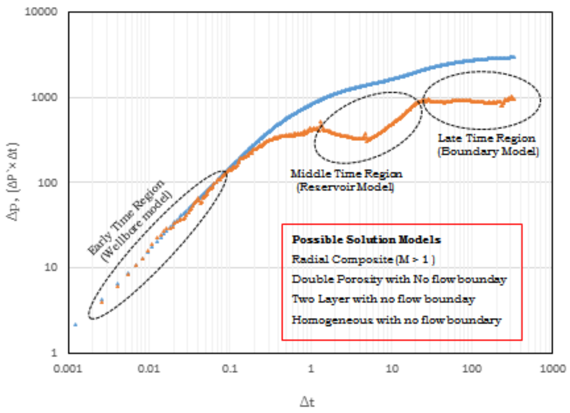

Figure 4.4: Log-Log plot of ΔP and (ΔP‘× Δt) versus Δt (ΔP‘ is calculated in respect to Δte

4.3. Analysis and Interpretation using Saphir Software

Using Saphir software, lower gauge pressure data were uploaded. After several match attempts, a good match was obtained with two models; first is a double porosity reservoir model with two parallel faults, and second is a two layer model with two parallel faults. Below are graphs with matched model and tabulated results.

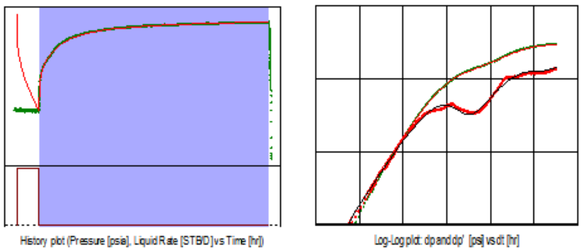

Figure 4.5: Pressure history plot (Left) and Log-log plot (right) for well X6 with a matched model using Saphir Software.

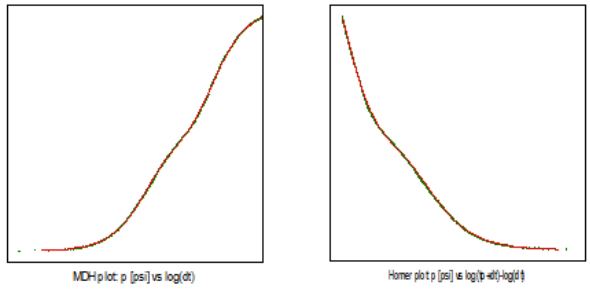

Figure 4.6: MDH plot (Left) and Horner plot (right) for well X6 with a matched model using Saphir Software.

4.4. Specialized plots

To confirm the boundary model (Two parallel faults) linear flow regime plot is used. A plot of pressure versus tandem time ($\sqrt{tp + \Delta t}$ -$\sqrt{\Delta t}$) should yield a straight line of slope m at the late time region (Corresponding to half-slope channel effect). The slope of the line is then used to calculate channel width given the permeability estimated from the radial flow regime. From Figure 4.7, slope of the straight line is equal to (300 psi/hr$^{0.5}$) and channel width is 470ft which is in a good agreement with the findings using software.

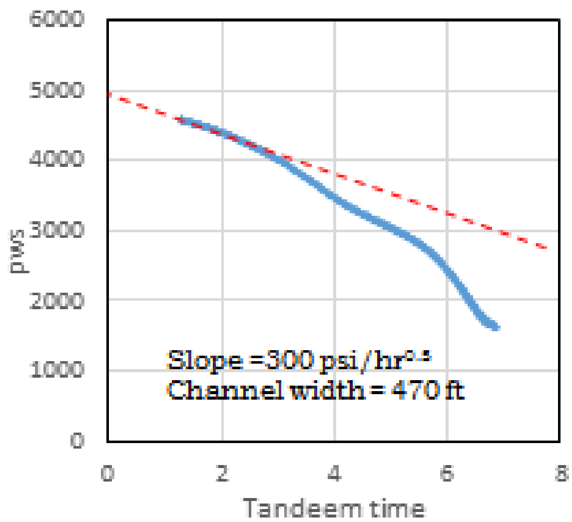

Figure 4.7: Linear flow plot, Pws vs Tandem time function

A plot of ‘Pws versus shut-in time should yield a three distinct straight lines, Tiab et.al 1980. As shown in Figure 4.8 ‘Pws versus shut-in time did

Table 4.2: Well X6 Match Results

Model	Vertical Well; Constant wellbore storage; Double Porosity; Two parallel Faults	Vertical Well; Constant wellbore storage; Two Layers; Two parallel Faults
Skin Factor	-5.07	-5.03
Pi	4863psia	4874psia
K	0.88 md	0.83
C	0.0266 bbl/psi	0.027 bbl/psi
	ω =0.102	
	λ= 5.5e^{-5}	
Distance to boundaries	68ft 348ft	75ft 358ft

yield a curve with three distinct straight lines, which confirms the presence of a parallel fault.

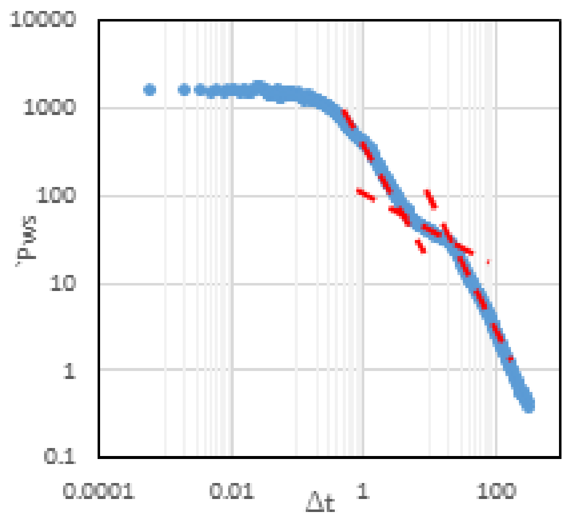

Figure 4.8: log-log plot of 'Pws versus Shut-in time

4.5. Conclusion

1. Well test analysts should not rely solely on pressure test analysis software for analysis and interpratiaon for it is sometimes misleading and can lead to an inaccurate results.

2. Available published log-log diagnostic plots are very useful and a really good to start with for a quick model prediction.

3. Well test analyst should always consult with a geologist/geophysist whether the selected model conforms to the real situation.

4. Having a good explanation of the mobility change around well should be the motive of using radial composite models not because the data cannot be match with other models.

5. Longer buildup tests will ease the interpretation of transient pressure tests as the flow regimes correspond to boundaries can be easily identified.

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