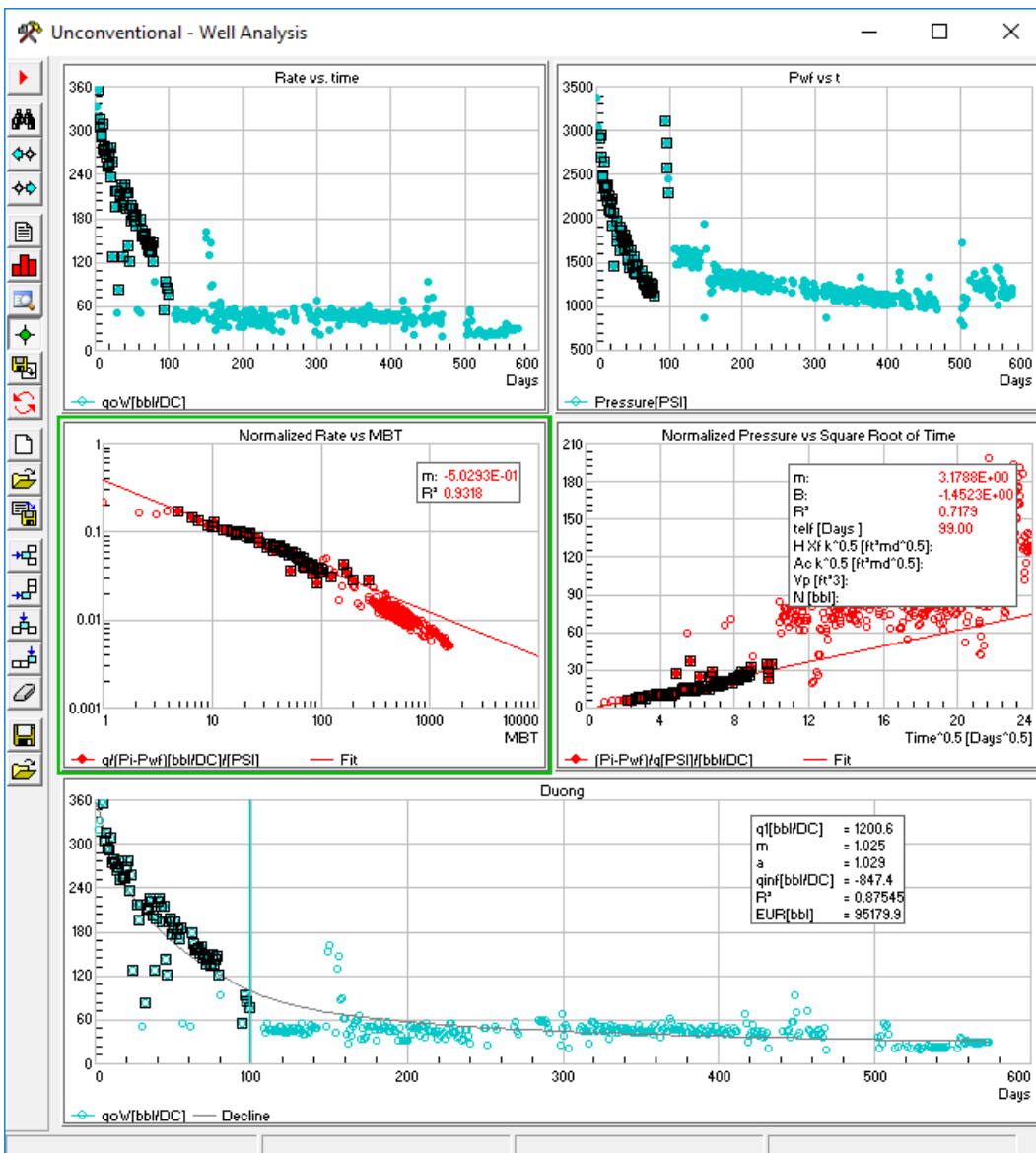


COMBINE RTA AND DCA TO IMPROVE PRODUCTION FORECAST IN SAHARA UNCONVENTIONAL

Sahara Unconventional is a complete suite of tools and methodologies specifically designed to analyze unconventional resources data. It allows making a thorough well by well analysis, defining different workflows to standardize the job. In order to do this, there are different production data visualization and diagnostic plots, specialized Rate Transient Analysis and Decline Curve Analysis available for unconventional wells.

This brochure explains how to obtain a quick and accurate production forecast combining RTA with DCA using Sahara Unconventional.



The purpose of this workflow is to obtain production forecasting for unconventional wells with large periods of linear flow combining different empiric models according to the underlying flow regime.

Sahara

Unconventional reservoirs require an enormous conductive surface area between the well completion and the reservoir to attain commercial production rates due to the very low permeability of the matrix. This enormous area is commonly achieved creating a system of multiple hydraulic fractures around the well. Initial production is dominated by the high permeability but low storage fracture system, and therefore declines rapidly. The ultra low permeability matrix provides stable long term production. Unconventional wells often present transient behavior that can last for several years, and during this transient period they show linear flow. This flow regime will be followed by boundary dominated flow at later times. In this context, empirical methods such as Duong, Stretched Exponential (SEDM) or Power Law appeared to replace the traditional Arps models originally developed for boundary dominated flow regime.

Even if often transient linear flow regime is the only available for analysis and history matching, extrapolating production in time and EUR estimation based on transient rate decline can be optimistic and mistaken. Besides, each empirical method has a range of applicability based on the assumptions made for its development. In this context, several authors have proposed hybrid decline models: an empirical transient

model for transient linear flow and a combination of Arps models for boundary dominated flow regime. Diagnostic plots and RTA are used to identify the production data flowing under each flow regime. In this way, better forecasts and reserves estimation can be achieved.

In order to implement hybrid declines models in Sahara Unconventional, unconventional declines methods such as Hyperbolic ($b > 1$), Duong, Power Law or SEDM have two options available: *Set Telf* and *Switch to Exponential*. Figure 1 shows the options in red for the Duong model. Telf is the end of linear flow time and is included in the first period of the adjustment. The first set of points is fitted using the selected empirical model until Telf. After that an hyperbolic model is used to fit data. Additionally, it is possible to switch to an exponential decline during forecast.

Sometimes production data is very noisy and this can significantly affect the accuracy of results. Sahara Unconventional allows to obtain an integrated visualization of historical production data, easily detect and remove outliers, identify wells' behavior and evaluate how any point impacts in each chart at a glance.

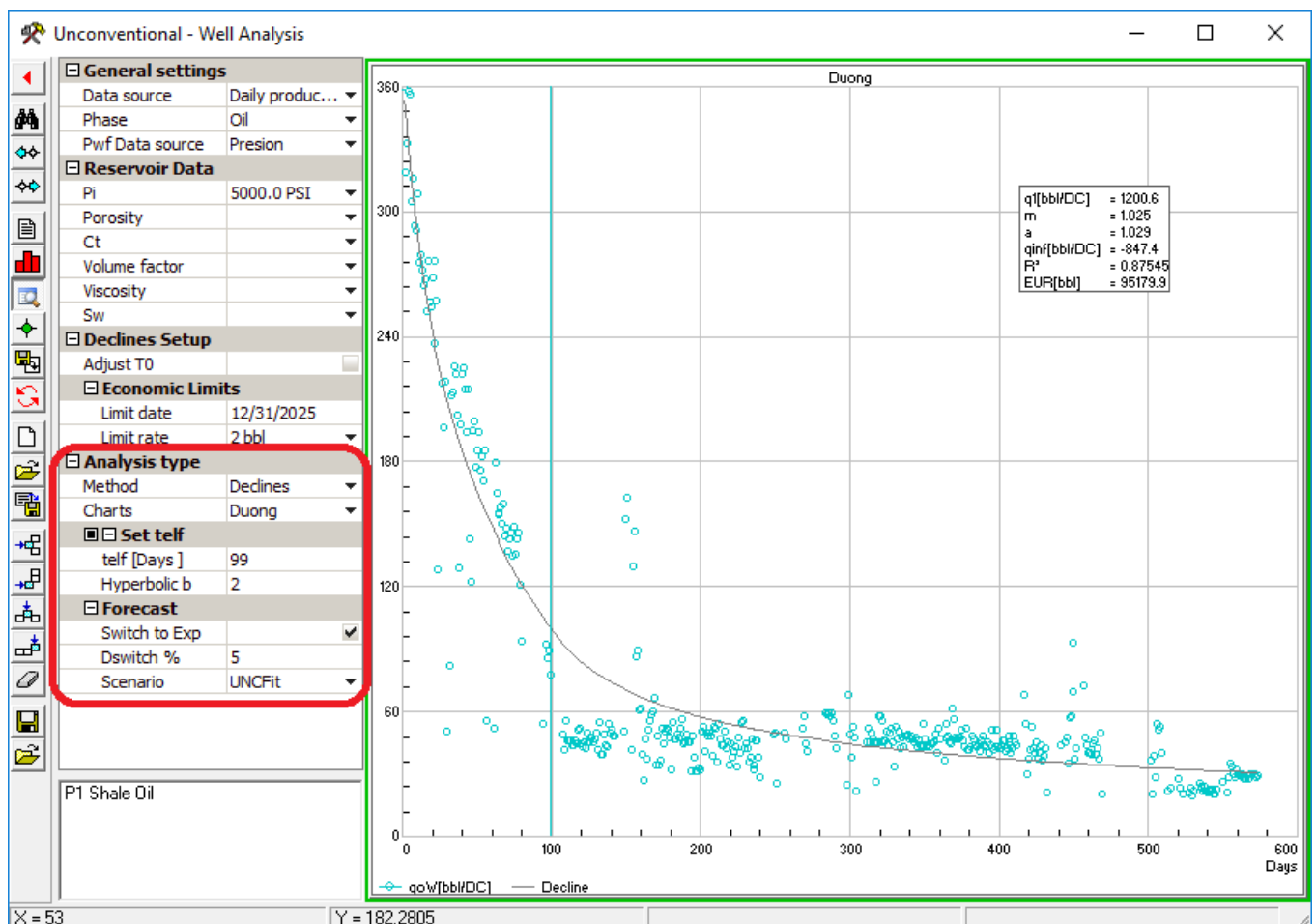


Figure 1. In red: options to perform hybrid declines analysis for available empirical methods in Well Analysis Window (Sahara Unconventional).

COMBINING RATE TRANSIENT ANALYSIS TO IDENTIFY LINEAR FLOW REGIME PERIOD WITH HYBRID DECLINE METHODS

In the following example, Sahara's Unconventional Well Analysis Window has been configured with four plots: Rate and Pwf vs time for visualization of raw data and a Normalized Rate vs Material Balance Time and Normalized Pressure vs Square Root of Time plot in order to identify the points under linear flow. It may be diagnosed by a half slope on a log-log diagnostic plot or by a straight line on a square root of time plot. A half slope straight line help us to identify the points flowing under linear flow in the Normalized Rate diagnostic plot (black line in **Figure 2.a**). Then, the corresponding points can be selected to perform a linear regression using a polygon, a rectangle or editing the points (**Figure 2.b**). It is possible to display the points selected for the half slope straight line in the

Normalized Rate in the Square Root of Time plot to check if they lie on a straight line. In this plot, now we can calculate a regression with the selected points. The Telf is the last point of the regression in this graph and it is displayed in the results box as shown in **Figure 3**. Now, this Telf can be entered in any decline method plot.

Once the different flow regimes are properly identified any available decline method can be added to the template and used as an hybrid decline method using the previously determined Telf. Even comparative analysis using different options and decline models can be performed as shown in **Figure 4**.

If pressure data is not available different log-log diagnostic plots such as Rate vs time, Rate vs MBT, Cumulative vs time or Rate/Cumulative vs time can be used to identify the different flow regimes.

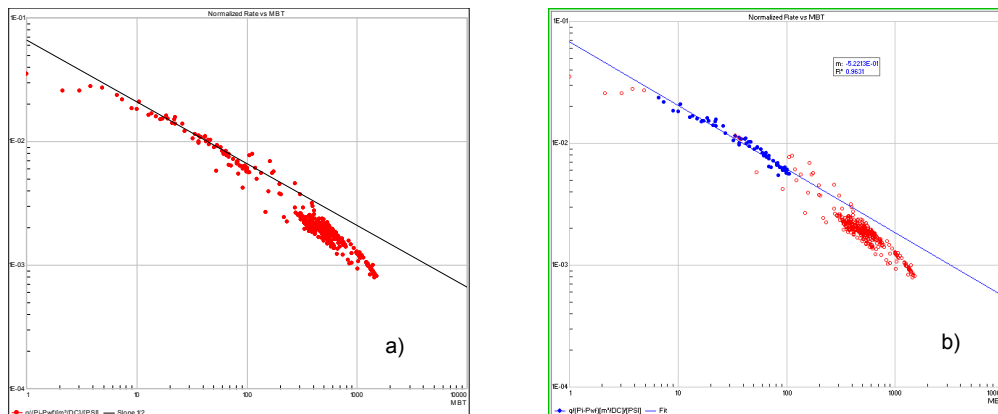


Figure 2. Identification and selection of the points corresponding to linear flow in the Normalized Rate vs MBT diagnostic plot.

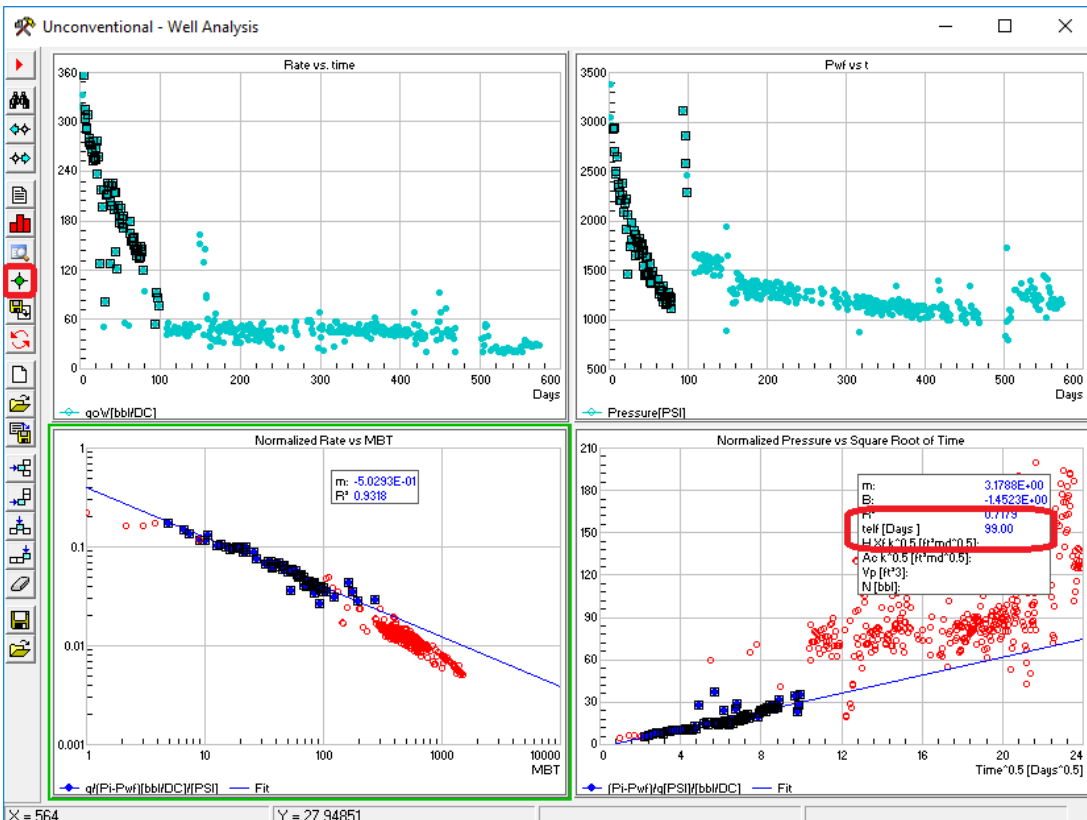


Figure 3. Combining a Normalized Rate vs MBT and a Normalized Pressure vs Square Root of time plot to identify linear flow regime points and determine Telf.

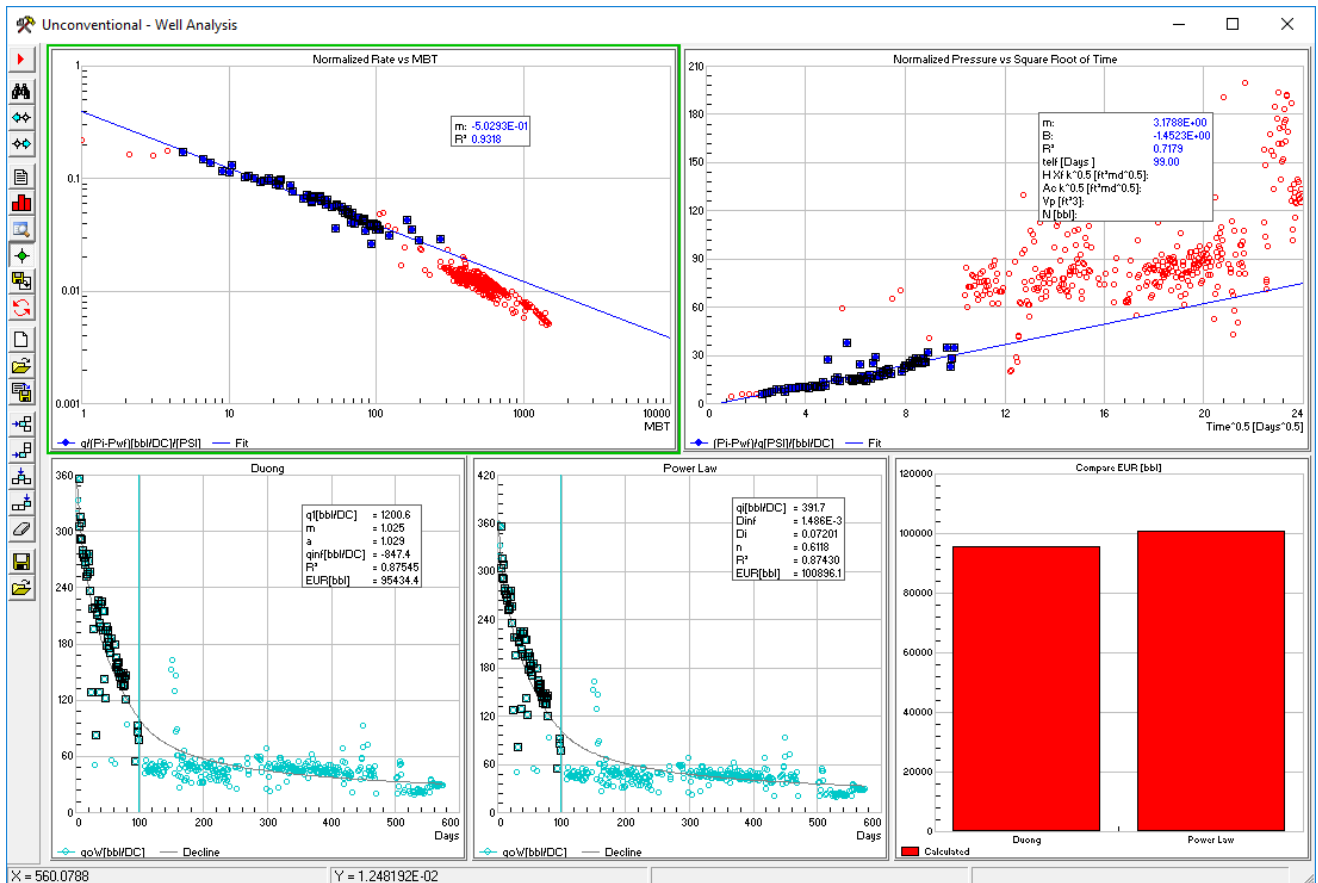


Figure 4. Comparative analysis for EUR using hybrid Duong and Power Law models.

SET TELF OPTION - HOW IS THE TRANSITION BETWEEN THE TWO METHODS?

TELF IS LESS THAN THE LAST DAY OF HISTORY

In this case, the points are adjusted with the original method (Duong in Figure 1) until the Telf. Then, a hyperbolic is used for the remaining history points with the following parameters:

$$Q_i = Q @ Telf \quad D_i = D @ Telf \quad b: \text{user defined}$$

where Q_i is calculated as q at Telf using the parameters obtained for the original decline method (Duong in Figure 1) and D_i is D at Telf where D is the nominal decline rate (in fraction) calculated as:

$$D = -\frac{dq/dt}{q}$$

Under these circumstances the forecast is calculated using the hyperbolic decline method until economic limit is reached.

TELF IS EQUAL TO THE LAST DAY OF HISTORY

Adjustment is made using all production history data with the original decline method. For the forecast a hyperbolic decline with parameters calculated as in the previous option until economic limit is reached is used.

TELF IS GREATER THAN THE LAST DAY OF HISTORY

The adjustment is made using all production history with the original decline model. The forecast calculation begins with the original decline model until the Telf. Then, it is switched to a hyperbolic, whose parameters are calculated in the same way.

FORECAST OPTION - SWITCH TO EXPONENTIAL AT DSWITCH

If this option is checked, the forecast period is allowed to change to an exponential decline at a Dswitch. By default a Dswitch = 5% is used. This is the annual effective decline rate (in percent). The equivalence between D (daily nominal decline in fraction) and D_e (annual effective decline in percent):

$$D = -\ln\left(1 - \frac{D_e}{100}\right) / 365.2425$$

$$D_e = \left(1 - e^{-12D}\right) * 100$$



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