

Diagnostic Fracture Injection Tests (DFIT™) in Ultra Low Permeability Formations

Pressure transient testing has been the standard method over the years to obtain important well information such as reservoir pressure, permeability, and skin in conventional reservoirs (permeability >1 md). However, with the shift towards unconventional, ultra low permeability reservoirs, the only type of test that is economically practical for operators to determine reservoir and frac properties is the Diagnostic Fracture Injection Test (DFIT™).

The purpose of the DFIT™ test is to obtain essential reservoir properties in a relatively short period of time. The DFIT™ test is the primary empirical method that helps determine fracture design parameters (i.e. closure time, closure stress, net pressure, fluid efficiency, dominant leak-off mechanisms, etc.). These variables are necessary to define the discrete fracture network model. If pseudo-radial flow has been achieved, the reservoir pressure and reservoir flow capacity can be determined via after-closure analysis (ACA).

The DFIT™ is performed prior to the stimulation treatment of a formation. The procedure involves pumping a relatively small volume (5-30 bbls for shale reservoirs and 50-100 bbls for unconventional low permeability sands) of fluid (typically 2-4% KCl or similar) into the formation at rates of 1 - 6 bpm in order to create a small fracture that will bypass any near wellbore damage. There must be a clear indication of breakdown during the pump-in and the injected volume and rate should be measured and recorded for subsequent analysis. The well is then shut-in for an extended period of time and the pressure decline is recorded as shown in Figure 1. DFITs™ tests are typically performed once per well, usually in the toe stage of the lateral through perforations or a sleeve. The DFIT™ testing service is performed after the well has been cased/cemented and prior to the scheduled stimulation date. This “dead” time is optimal to perform a DFIT™ service given that the fall-off can run from several days to several weeks, depending on a variety of factors. The DFIT™ test is ideal because it is performed before the well is brought online, thus the well can be tested without losing production, which is always a reason cited by operators not to test.

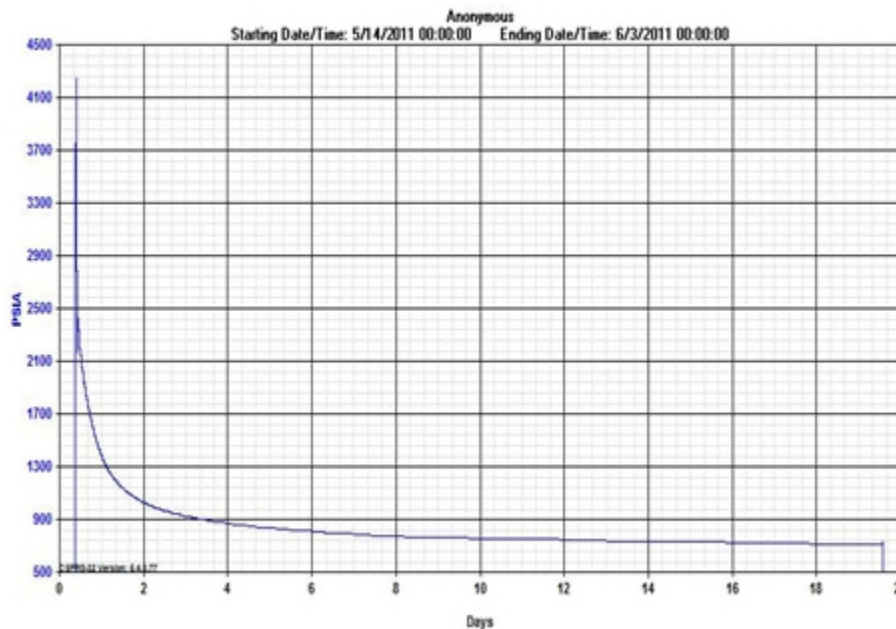


Figure 1 - Pre-frac Injection Fall-off Test

Halliburton has performed hundreds of DFIT™ testing services for many operators domestically and around the world, therefore Halliburton is frequently consulted for recommended DFIT™ testing procedures. Experience has shown that it is important to minimize the amount of total fluid pumped in order to see closure pressure / pseudo-radial flow in a reasonable time frame and to allow after-closure analysis. A typical injected volume recommendation in shale reservoirs ranges from 5-30 bbls. Fall-off time directly correlates with the permeability of the formation and the volume injected, thus fall-off time in shale plays can vary anywhere from 3-14 days. It is important to observe surface pressure readings during the test in order to understand the progression of the fall-off (if closure has been reached, into pseudo-radial flow, etc.). By using the SPIDR® gauge, downloads of the data can be taken periodically and sent to Halliburton for review, which aids in determining when the SPIDR® gauge should be removed so the test doesn't end prematurely or extend unnecessarily.

The results of a DFIT™ test can be used to optimize a stimulation plan to get the most efficient frac design and to evaluate the effectiveness of a completion. By performing a test before and after a stimulation job, the engineer will be able to evaluate just how effective their fracture was. Furthermore, a DFIT™ test is performed to obtain the initial reservoir properties of the well for reservoir modeling or log calibration. It is therefore critical that the test data not be misinterpreted. Three analysis techniques are used when analyzing and interpreting a DFIT™ analysis: Nolte G-function, G-function log-log, and square-root of shut-in time. Each technique utilizes various diagnostic derivative curves, which help determine closure, leakoff mechanisms, and flow regimes. Figure 2 displays the Nolte G analysis, which is the most commonly used pressure decline analysis technique.

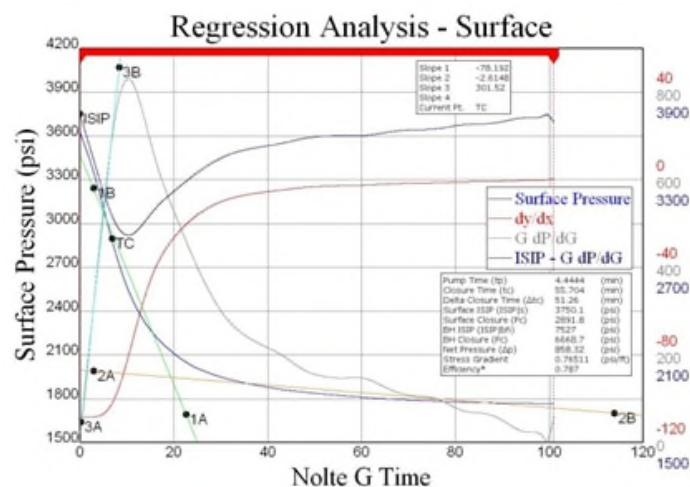


Figure 2 - Nolte G-Function

Figure 3 shows an example of the square-root of shut-in time (Delta Time) analysis method. It is very similar in appearance to the Nolte G-function technique, and a single closure point must be found for both the G-function and square-root shut-in time plots.

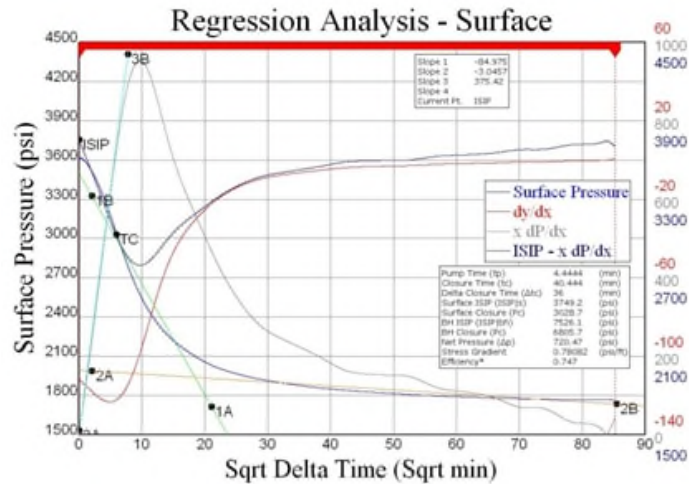


Figure 3 - Square-root of Shut-in Time

Figure 4 displays an example of the G-function log-log analysis method. This method allows for a third confirmation of a closure point, in addition to a flow regime identification during leakoff and after-closure. The log-log plot helps determine whether pseudo-linear, pseudo-radial, or full radial flow was seen, allowing us to properly analyze the after-closure data for reservoir characteristics.

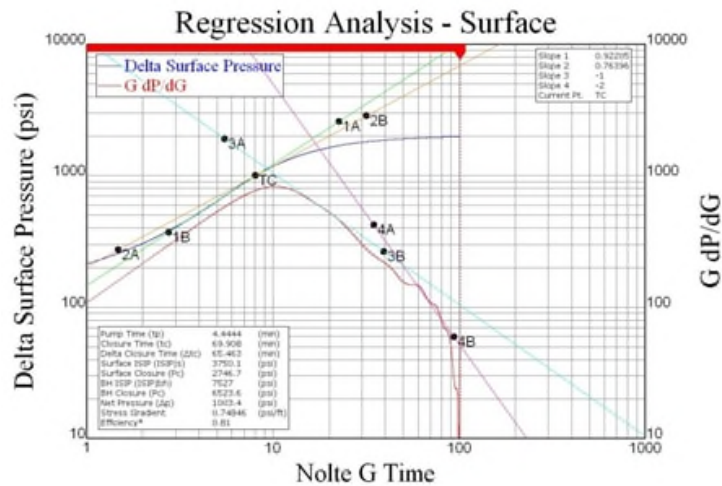


Figure 4 - G-Function Log-Log

Figure 5 and 6 are examples of after-closure analysis on data that exhibited a pseudo-radial flow regime. Figure 5 is plotted on a Cartesian scale and Figure 6 is on a logarithmic scale.

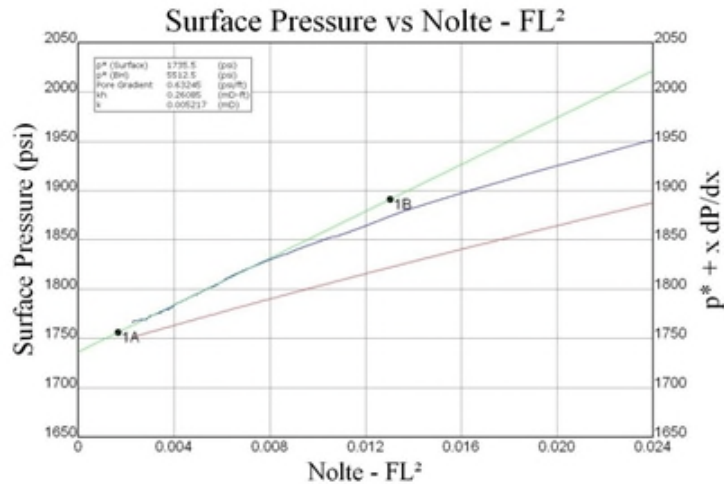


Figure 5 - After-Closure Analysis

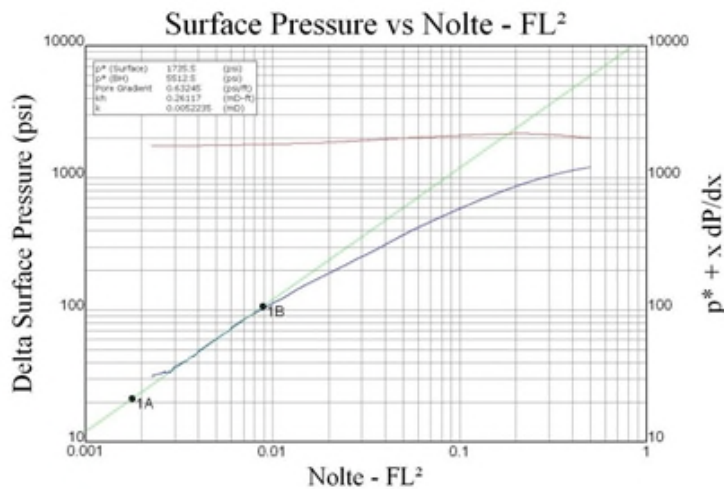


Figure 6 - After-Closure Analysis Log-Log

The analysis of the DFIT™ data can be conducted by Halliburton's in-house well testing engineers.

When performing a DFIT™ test, it is critical to utilize a surface gauge with the ability to record high frequency (1 sample per second), high resolution (0.01 PSI), temperature compensated data. Detection of subtle pressure changes over a short period of time is essential in analyzing the fall-off data accurately. Additionally, because the analysis uses derivative curves to determine closure, flow regime, leak-off mechanisms, etc., quality of the data is extremely important. Noise in the pressure data is amplified in the derivative curves, so it is crucial to have as little noise as possible. The DFIT™ test not only requires accurate pressure data, but also a precisely recorded injection schedule. Recording quality rate data during the injection period is important for achieving the desired test results. The SPIDR® surface pressure gauge system is ideally suited for DFIT™ testing due to its high frequency, high resolution, and thermally compensated data while having the capability to simultaneously record accurate injection rates. It can interface directly with any size turbine flowmeter when using a magnetic “pickup” supplied by Halliburton. The SPIDR® gauge will record the pulses output by the turbine meter and convert the data to injection rate using the coefficient of the meter. Our FLOWCOM software is then used to plot the injection rates, cumulative injected volume, and pressure as a function of time, which are all key components for the DFIT™ analysis. Figure 7 displays the injection period of a DFIT™ test utilizing the SPIDR® gauge with a turbine meter pickup. The blue line represents the wellhead pressure, the red line is the instantaneous rate, and the green line is the cumulative volume pumped.

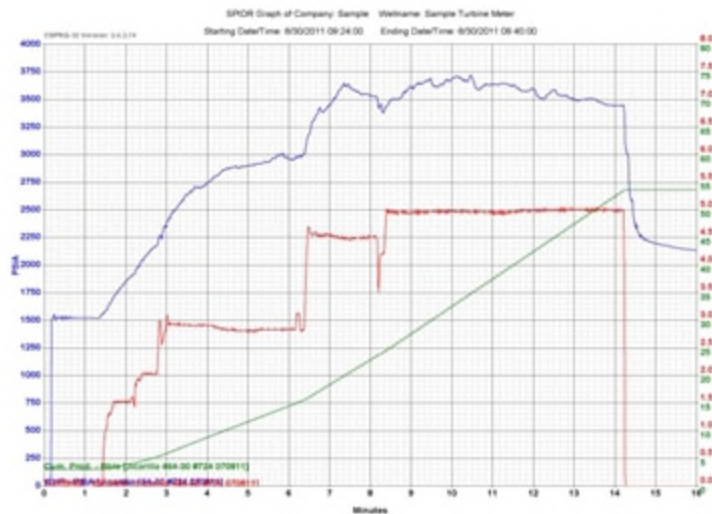


Figure 7 - Recorded Pressure and Injection Rate

A DFIT™ test is an optimal test to perform using surface acquired pressure data. Because the fluid being injected is an incompressible fluid and is continuous from the perforations to the wellhead, the conversion to downhole pressures is straight forward. However, there have been concerns on the analysis comparison between surface and downhole data. As a result, a DFIT™ test was performed where both a downhole gauge and the SPIDR® surface gauge were utilized. Figure 8 shows the SPIDR® surface data (pressure scale on left y-axis) and the downhole pressure data (pressure scale on the right y-axis) overlaid with each other so the shapes of the curves may be compared. It can be seen that at about 35 hours the shape of the surface pressure starts to differ from the shape of the downhole gauge data, and after about 38 hours the well is on vacuum at the surface. Prior to 35 hours, the surface data is a direct representation of the downhole gauge data. The results of this comparison and analysis demonstrated that surface data provides the same results as downhole data provided the well does not go on vacuum.

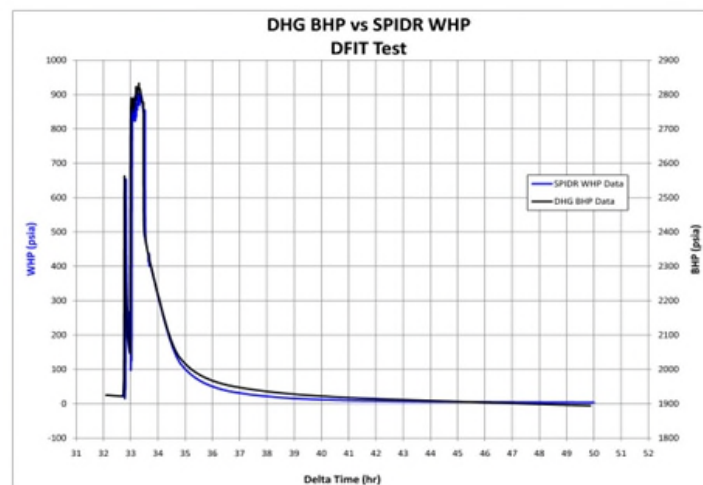


Figure 8 - DHG BHP vs. SPIDR® gauge WHP

Most operators in unconventional shale reservoirs conduct DFIT™ tests due to the excessive time required with traditional Pressure Transient Tests (i.e. build-up and drawdown testing) to reach radial flow. But the DFIT™ test has application in tight conventional sands as well. As an example of the

Halliburton's DFIT™ testing service, a major South Texas operator has utilized this technology for Wilcox wells to specifically determine permeability ahead of the scheduled frac date. The classic problem in the Wilcox is that permeability from drilling logs is often erroneous resulting in stimulation expenditures that don't provide an economic rate of return. The DFIT™ test can provide the operator with empirically derived permeability numbers that will allow him to make the proper frac/no frac decision.

Halliburton offers free consultation and well test planning for all your pressure transient testing need, and we are available 24/7 for assistance. The SPIDR® gauge with our turbine meter pickup is available for rental and can be delivered overnight to any U.S. location and within 5 days to most international locations. Same day hot shot delivery service is available as well.

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