The evaluative methods on shale gas productivity using the DFIT

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Abstracts : This paper is focused on the evaluative method on shale gas reservoir productivity. Conventional well testing is useless due to low permeability at shale gas reservoir. But, the needs for the information of productivity are constantly required for the economic investigation for the targeted wells. Nolte had developed the G-function methods from 1970's to evaluate the productivity for low permeability reservoir. Because the effective permeability of shale reservoir (matrix permeability is from nano-darcy to micro-darcy level) render conventional tests impractical before simulation. DFIT(diagonal fracture injection test) were used to evaluate by making small fracture to shale reservoir from injection of some fluid in a high pressure. Nolte and Soliman proposed the after closure analysis which is performed on fall-off collected after fracture closure.

In this study, Flow region of shale gas reservoir were classified and analyzed by log-log plot from DFIT. Injection schedule and fracture geometry dictate how long it takes radial flow to develop but do not influence permeability estimation once radial flow has developed. Subtle difference can be attributed by constant pressure or constant rate, time function, shut-in point, observation time etc.

Introduction

Shale formation differs from conventional reservoir in several aspects. Shale formations are usually naturally fractured with the matrix permeability in the nano-darcy. In addition the matrix usually has some organic contents that may have some adsorbed gas. These differences indicate that a conventional test would have to be un-realistically long to accommodate the ultra-tight nature of the shale formation.[1]

Since 1979 Nolte has published numerous papers on fracture pressure decline analysis and improvements to the original work.[4-8] Castillo introduced the G-function plot and a pressure dependent leak-off coefficient in 1987.[9] And then, Meyer presented a technique to satisfy the mass and momentum equations for 2-D type fractures.[10] The effects of flow-back, inference closure, a time dependent leak-off coefficient during pumping and closure, and fluid rheology were introduced. Nolte refined the original works and developed an after closure analysis for determining formation permeability and reservoir pressure after injection test.[11]

In order to evaluate the productivity of shale gas reservoir, it is important to know the accurate reservoir properties. This paper focused on the DFIT analysis for Kiwigana field where located in northeast British Columbia in the Horn River basin in Canada. Gas is produced from several zones, but commercial production requires horizontal drilling and fracturing due to low permeability. We conducted several analytical methods to gain appropriate shale reservoir properties and described the results.

Pre-closure analysis

Closure pressure, closure time, ISIP(instantaneous shut-in pressure) can be determined by G function time vs. Gdp/dG and square root time graphical analysis. Leak-off behavior evaluation from G-function analysis represents the type of reservoir characteristics. Fracture closure time and pressure are identified by the departure of the straight line that goes through the origin. It could be possible to analyze the p_w vs. square root time. The measured fracture closure pressure is 5,854psi and fracture closure time is 32.705hr.

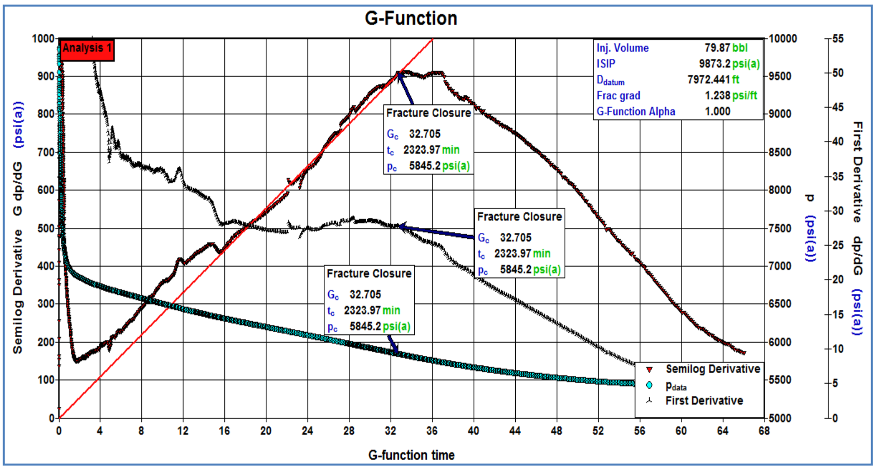

Fig. 1. G-function plot for Well A.

In this G-plot, pressure dependent leak-off (PDL) behavior is observed in initial stage. Pressure dependent leak-off occurs when fluid loss rate changes with effective pressure or stress. In this case, PDL behavior was observed by exhibition of concave upward shape of G-curve at the beginning of the straight line. The pressure dependence referred to here is a charge in the transmissibility of the reservoir fissure or fracture system that dominates the fluid loss rate. Usually, PDL behavior was often apparent when there is substantial stress dependent permeability in a dual permeability reservoir or natural fracture.[2,12]

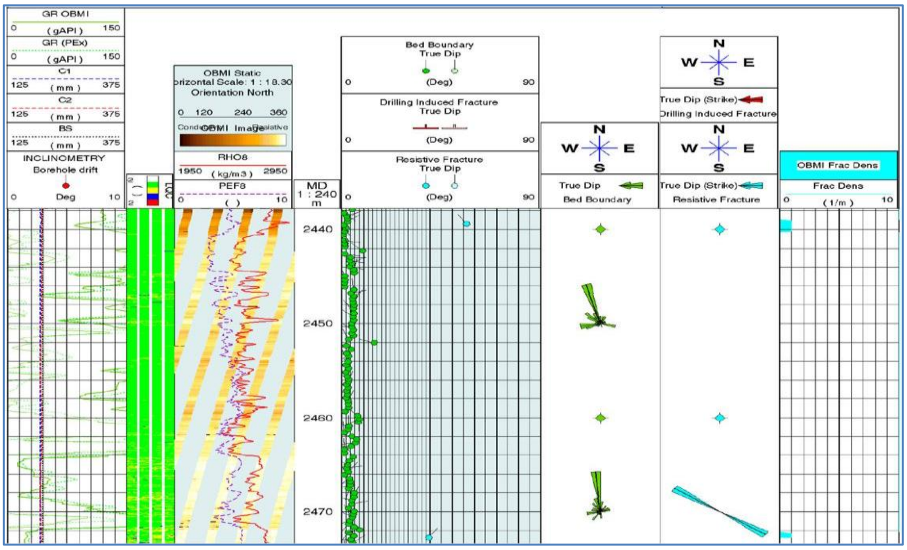

Fig. 2. OBMI data for near well A position.

OBMI(Oil-base micro-imager) data were compared to confirm the existence of natural fracture. At the depth range of 2440-2470MD(measured depth) where the well location is positioned at, natural fracture is detected by OBMI data.

After closure analysis

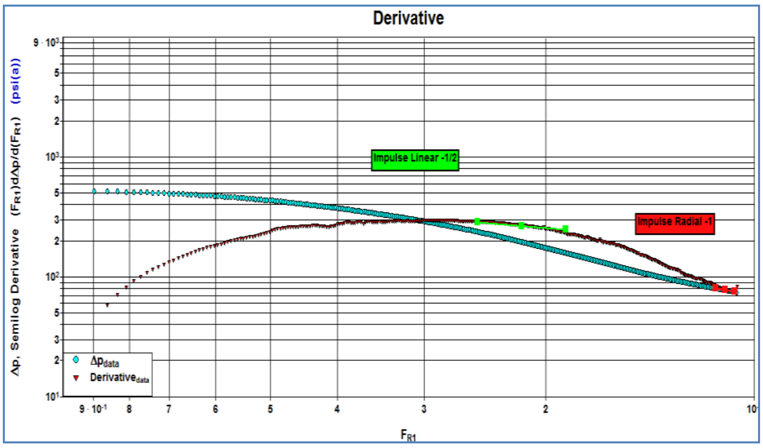

Fig. 3. Nolte derivative log plot for Well A.

Nolte Log plot is made to analyze the permeability of shale reservoir in Fig. 3. But, permeability cannot be measured appropriately due to the lack of shut-in time. At the final stage, it seemed that the radial flow started. So, radial flow plot is used to confirm the flow regime as radial flow as follows in Fig. 4. If a pseudo-radial flow regime is identified, then the Cartesian radial flow plot can be used to determine reservoir conductivity(kh), permeability and initial pressure. For the results of example data are kh=0.7247 md·ft, k=0.0116md and $P^* = 5323$psi.

In order to evaluate the injected fluid efficiency, ΔP_w vs. F_L plot was used. The factor F_L has some relation with C_T and Nolte derived that leak-off coefficient and reservoir pressure could be estimated in initial linear flow regime. Total fluid loss coefficient is estimated as 2.7183 ft/min$^{0.5}$.

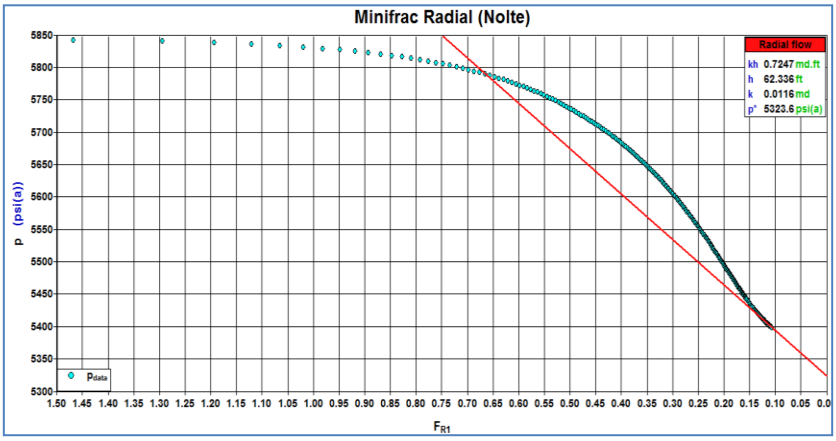

Fig. 4. Nolte radial flow plot for Well A.

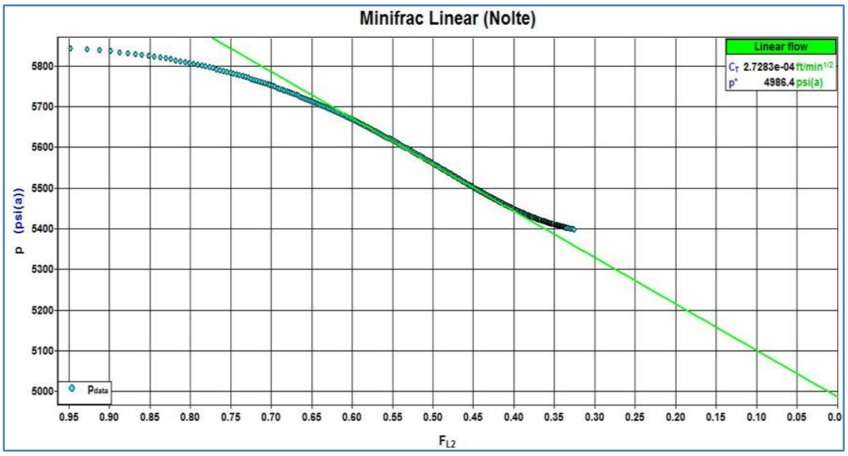

Fig. 5. Nolte linear flow plot for Well A.

Soliman's short term tests are useful in the analysis of DFET.[13] At the Fig. 6, linear and radial regimes are identified. Using the Soliman-craig linear flow plot, fracture half length could be calculated as 36.75ft.

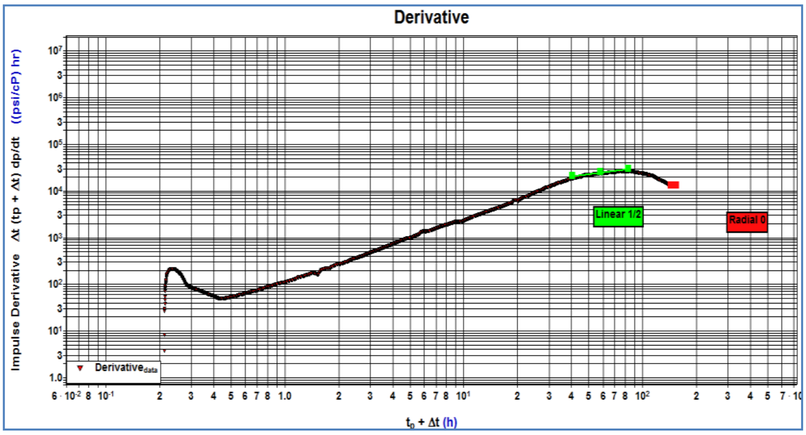

Fig. 6. Soliman-Craig derivative plot for Well A.

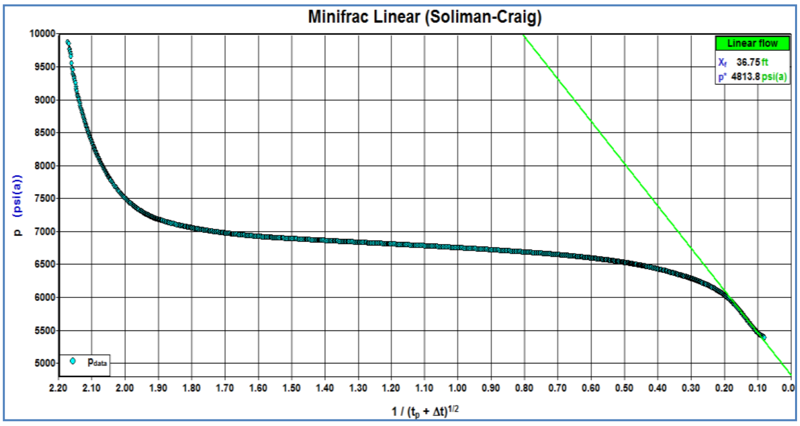

Fig. 7. Soliman-craig linear flow plot for Well A.

G-function permeability estimation

An empirical function to approximation for formation permeability has been derived from numerous numerical simulations for fracture closure. The correlation is based on the observed G-function time at fracture closure.[2]

$$k = \frac{0.0086\mu_f\sqrt{0.01P_z}}{\emptyset C_t\left[\frac{G_c E\, r_p}{0.038}\right]} \qquad \text{(Eqn. 1)}$$

Where, P_z = PISIP – Pc

r_p = storage ratio (1, PDL)

E = elastic modulus

In order to have rough estimation, properties were assumed to ν=1cp, ISIP=9873psi, E=3.35Mpsi, ⌀=0.04, total compressibility=$5.09\text{X}10^{-5}\text{psi}^{-1}$, t_c=32.05hr. Permeability calculated by the eqn. 1 is 4.4351μd. The result is seemed to adaptable and similar to the results of graphical analytical method.

Conclusion

1. DFIT results of injection/fall-off testing in the Kiwigana shale formation were presented. The results represented that G-function, Nolte-FR, Nolte-FL, Soliman-Craig analysis are reliable and repeatable methodologies for determining closure stress, closure time, permeability, pore pressure.
2. The results have good consistency between other analytical methods and will be used for hydraulic fracturing job effectively.
3. The need for the prolonged shut-in time is realized to analyze the radial flow regime in DFIT.

Acknowledgments

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