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Minifrac Analysis:
A Comprehensive Overview

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0.1 Table of Contents

0.2 Minifrac Definition

- Minifrac tests consist of injecting a small volume of fluid into a target formation at a defined rate to create fracture(s).
- The fracture(s) are allowed to close, while the pressure is monitored and recorded.
- **Objective:** To obtain distinct and useful information from analyses of the various test intervals, while minimizing cost, time, and formation damage.

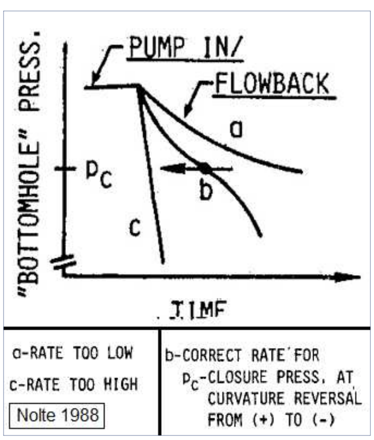
0.3 Minifrac vs. DFIT

- Minifrac (MF) Tests have various other names:
  - Fracture Diagnostic Tests (FDT)
  - Fracture Calibration Tests (FCT)
  - Diagnostic Fracture Injection Tests (DFIT®) (trademark of Halliburton)
- Proposed Distinction
  - Minifrac for Conventional sandstone reservoirs (that flow without frac)
    Rate same as the Mainifrac. X-linked fluid (usually same as Mainfrac).
  - DFIT for Unconventional shale reservoirs (that do not flow without frac)
    Rate much lower than Mainfrac. Newtonian or Linear fluid (may be different for Mainfrac).

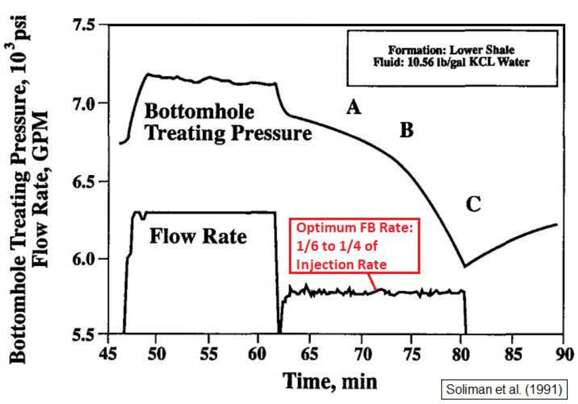
0.4 Intro: Types of Minifrac Tests

- Pump-in / Flow-back
  - Not performed very often (usually no flow-back meter rigged-up)
- Equilibrium Test
  - Not performed very often.
- Pump-in / Shut-in
  - Performed routinely (is being discussed extensively).
- Leak-Off Test (LOT) and Extended Leak-off Test (ELOT)
  - Both are performed during drilling (Not covered)

0.5 Pump-in Flowback



Nolte 1988



Soliman et al. (1991)

Pump-in/Flowback Test - BH Pressure vs. Time

Difficult to determine the correct flowback rate

0.6 Equilibrium Test

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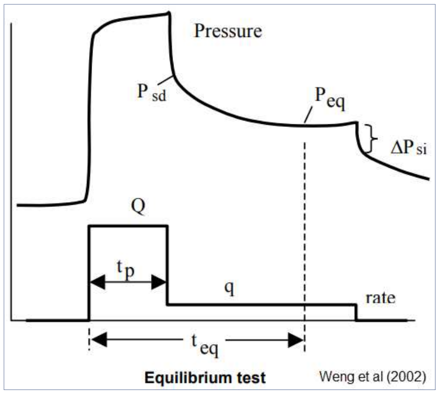

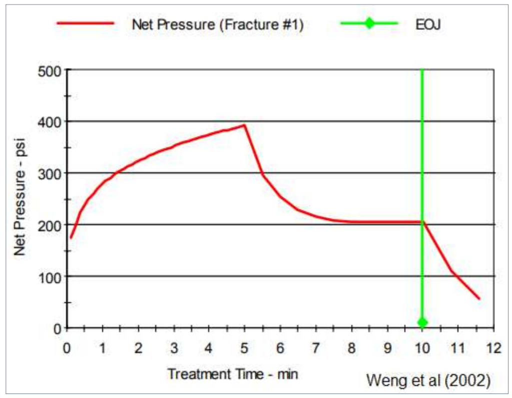

Normal injection rate (Q) is followed by very low rate (q) until a stabilized equilibrium pressure is reached, and the pressure starts to increase.

Peq is an upper bound for Pc

Poulsen (1996)
Weng et al. (2002)

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0.7 Microfrac vs. Minifrac

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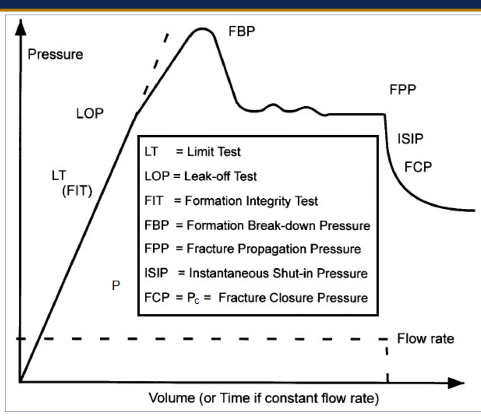

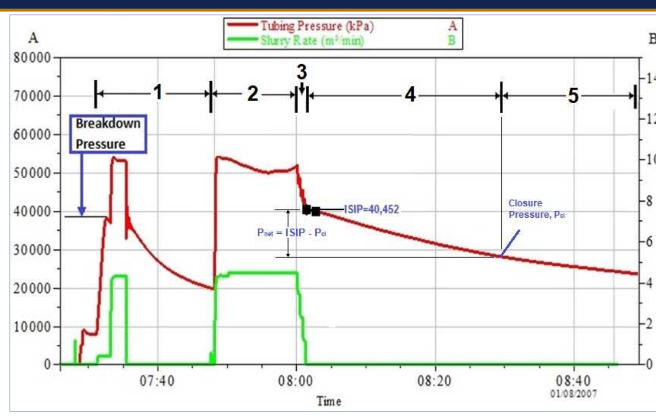

Microfrac (Gals/min)

Minifrac (Bbls/min or m³/min)

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Formation break happens at very low injection rate

0.8 Test Events and Analyses

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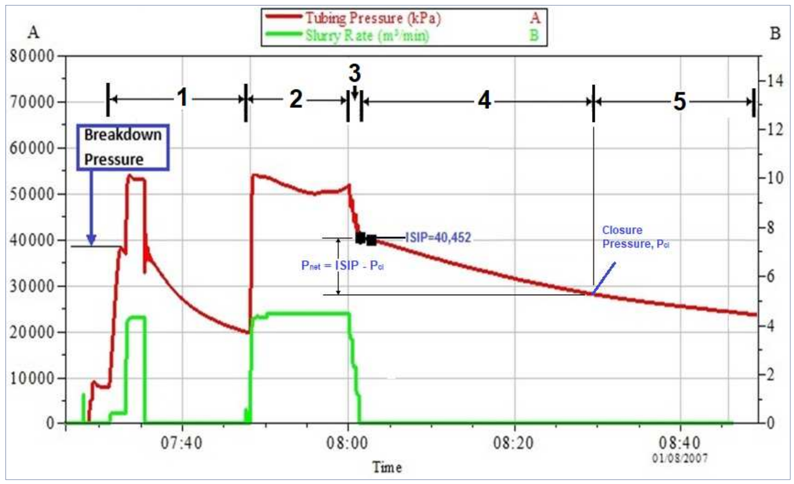
1 Formation Breakdown (FBD)
2 Minifrac Injection
3 Rate Step-down Test (RST)
4 Before Closure Analysis (BCA)
5 After Closure Analysis (ACA)



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1.0 Formation Breakdown (FBD)

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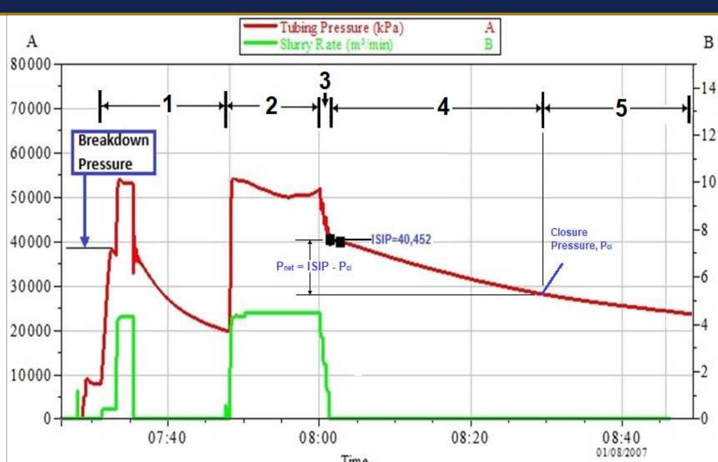

- Formation Breakdown (FBD) consists of two intervals:
  - Injection
  - Shut-in
- Theory:
  - Injection volume should be small and with clean linear (Newtonian) fluids in order to observe the baseline behavior of the formation.

Note that the rate required to initiate fracturing is very low

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1.1 FBD Procedure

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- **Procedure:**
  1. **Fill well and start Injecting WB fluid at very low rate (0.15-0.25 bpm).**
  2. **Continue by increasing injection rate by small increments(0.15-0.25 bpm) until an abrupt pressure reduction is noted. The highest pressure reached is the formation breakdown pressure.**
  3. **Divide by TVD to obtain the frac gradient.**
  4. **Increase injection rate to that of the main treatment rate and inject the remaining fluid volume that has been scheduled for the FBD. Volume depends on the type of formation and the permeability.**
  5. **Shut-in for 15-30 min.**
  6. **Monitor and record pressure.**

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1.2 Formation Break not Clear

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Loc.: Arabian Peninsula

Depth: 4600 m

K: 0.05 mD

ϕ: 0.07 %

Temp: 280 °C

H: 15 m

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If not clear break noted, Use stabilized pressure as formation break pressure or ISIP

1.3 Formation Break: Toe & Sliding Sleeves

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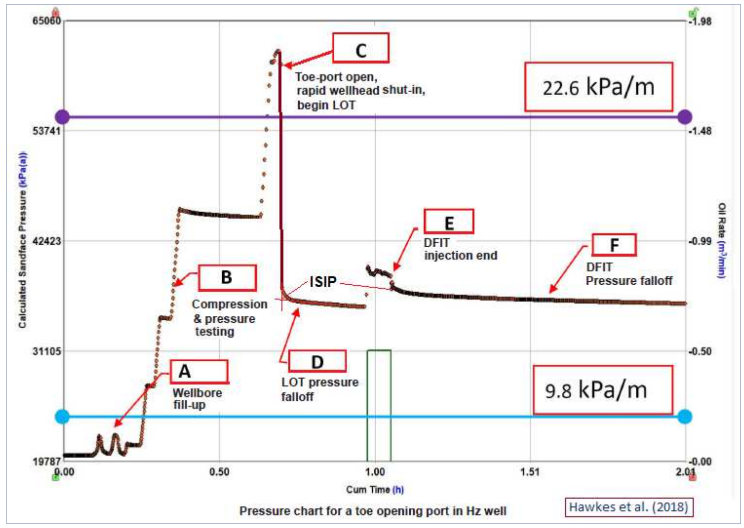
When pressuring up to open a Toe sleeve or a Sliding sleeve, the correct formation break pressure isn't recorded.

In such cases, use the ISIP to calculate the Fracture Gradient.

FG = ISIP / TVD



2.0 Minifrac

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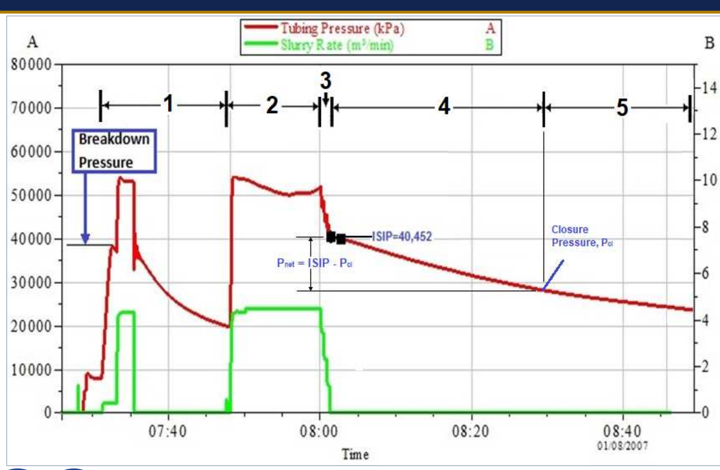

1. Inject X-linked gel fluid. Rate must be equal to that of mainfrac.
2. Overdisplace with linear fluid (Slickwater - visc-10 cp).
3. Perform RST at end of Minifrac.

Considerations:

- Wellbore volume
- Friction in: Wellbore, Perforations and Near-wellbore.
- Formation Permeability
- Formation Thickness

2.1 Diagnostic Fracture Injection Test (DFIT)

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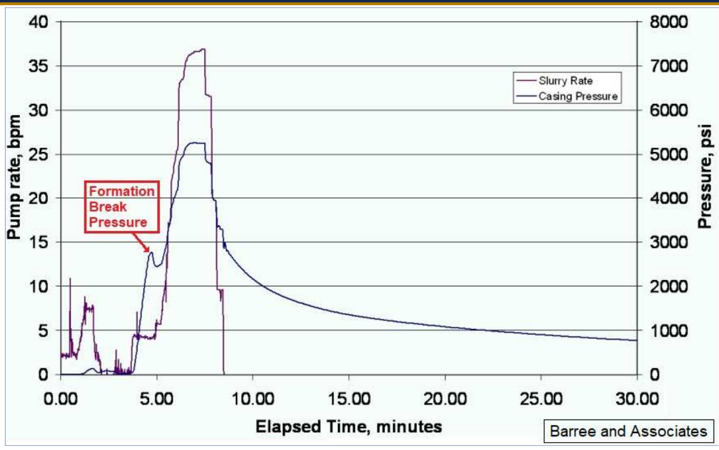

1. Inject clear Newtonian fluid **(Usually WB Fluid).**
   Rate may be lower than mainfrac.
   Low rate to Formation break.
2. Perform RST at end of DFIT.
3. No need to displace.

Considerations:

- Formation Permeability
- Formation Thickness
- Friction in: Wellbore, Perforation, Near-wellbore.

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2.2 General DFIT Design Rules for Unconventional formations

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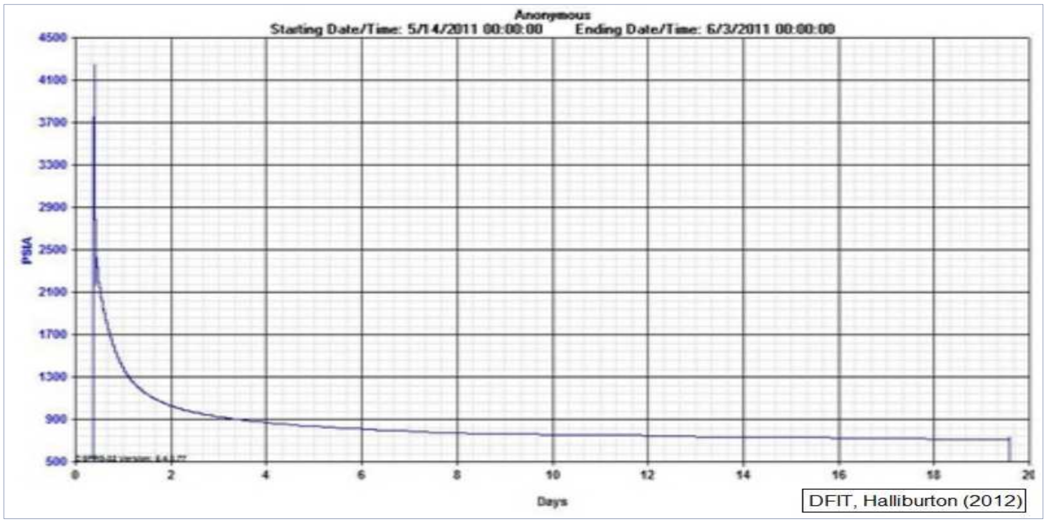
- Injection Volume (typical): 1 to 60 bbls
- Injection Rate (Typical): 0.1 to 15 bbls/min.
- Type of fluid: Clear Newtonian (2-3 % KCl water)

Injection Period (min)	Permeability (md)	Time to Closure Pressure
5	0.1	0.2 hr (12 min)
20	0.1	10 hr
5	0.01	2-3 days
5	0.0001	10 days

JPT, Sept 2014

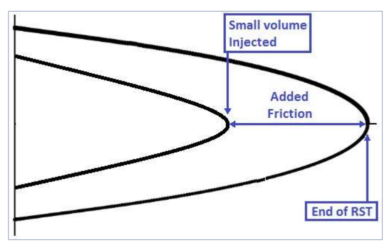
SPE International

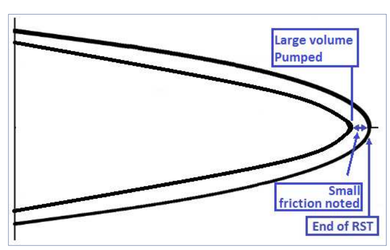
2.3 DFIT Example



2.4 Minifrac Design Volume for RST

- **Fluid Volume:**
  - **Theory:**
    In order to prepare for the RST at the end of the Minifrac, The fluid volume injected should be fairly large, such that during the very small interval of the RST (30-45 sec), the increase in fracture size isn't very large. (See fracture profiles).
  - **Reason:**
    The friction in the fracture will not change during the extremely short interval of the RST.





2.5 Minifrac Design for RST

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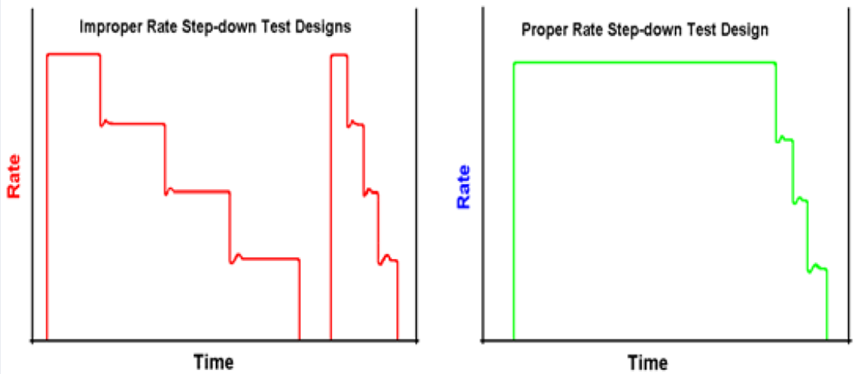

Improperly and properly designed Rate Step-down Tests.

Proper and Improper designs of RST are shown.

Substantial amount of fluid must be injected prior to performing the RST.

The steps must be very short (10-15 sec) and rapid.

Massaras et al. 2007

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2.6 Rate to Initiate Fracturing Equation

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$$q_{i,\max} = \frac{4.917X10^{-6}kh[(FG*D)-\Delta p_{safe}-p]}{\mu\beta(\ln\frac{r_e}{r_w}+s)}$$

Where,

$q_{i,max}$	=	injection rate in bbl/min
k	=	permeability of undamaged formation, md
h	=	net thickness, ft
FG	=	fracture gradient, psi/ft
D	=	depth, ft
Δp_{safe}	=	safety margin, psi
p	=	reservoir pressure, psi
μ	=	viscosity of injected fluid, cp
β	=	formation volume factor
r_e	=	drainage radius, ft
r_w	=	wellbore radius, ft
s	=	skin

For low to moderate permeability, an injection rate of 1-2 bpm can initiate and propagate hydraulic fracturing.

For micro- and nano-Darcy the rate is lower. It can be estimated by using the plot of the next slide.

For specific situations, approximate injection rates can be estimated with Darcy's Radial Flow equation (left).

Generally, to propagate a fracture, the injection rate must be high enough so that the treating pressure exceeds the Fracture Extension Pressure (FEP).

Barree et al. 2014

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2.7 Rate to Initiate Fracturing Plot

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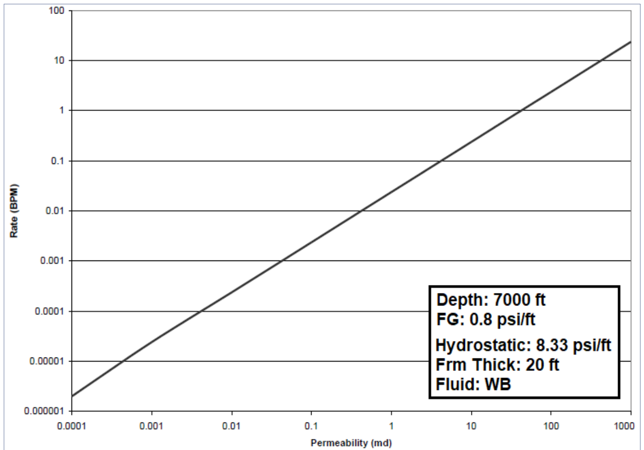

Rate necessary to initiate a fracture at various reservoir permeabilities.

Use equation (previous slide) or the plot to estimate rate to initiate fracturing.

After fracture initiation, a maximum injection rate of 5-6 bpm or 7-8 bpm is adequate.

For injecting 3-5 minutes,
The max volumes would be:
Min: 3 x 6 = 18 bbls
Max: 5 x 8 = 40 bbls

Barree et al. (2014)

2.8 Time to Closure

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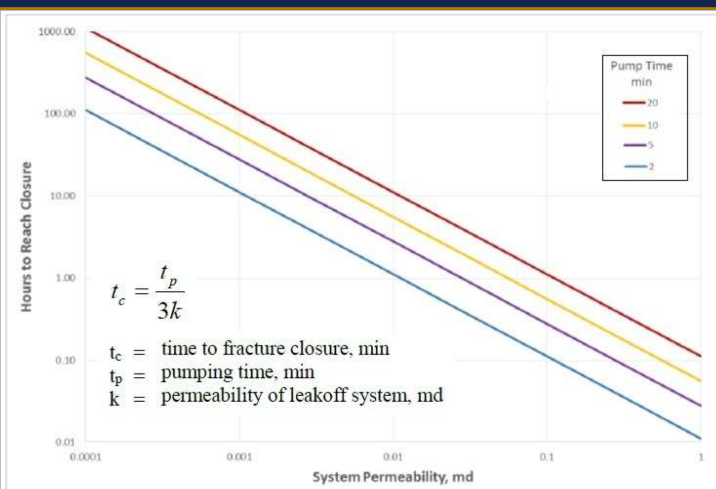


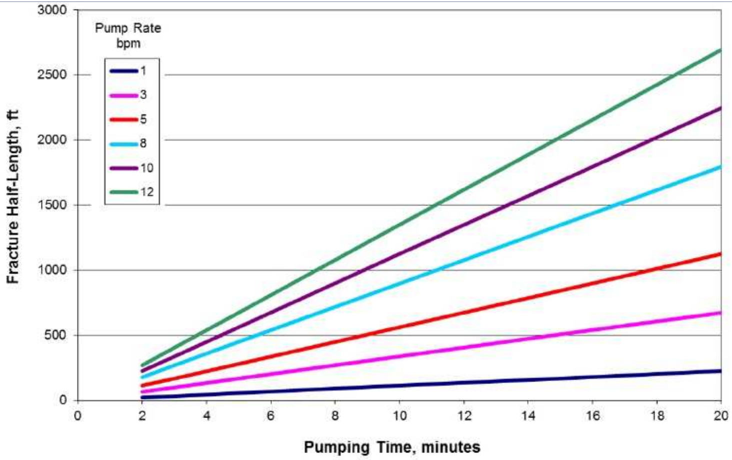
Approximate time to reach fracture closure for various pumping times. 169539

Estimated time to closure for pumping times of 2 to 20 min.

For longer pump times, use the equation.

Barree et al. 2014

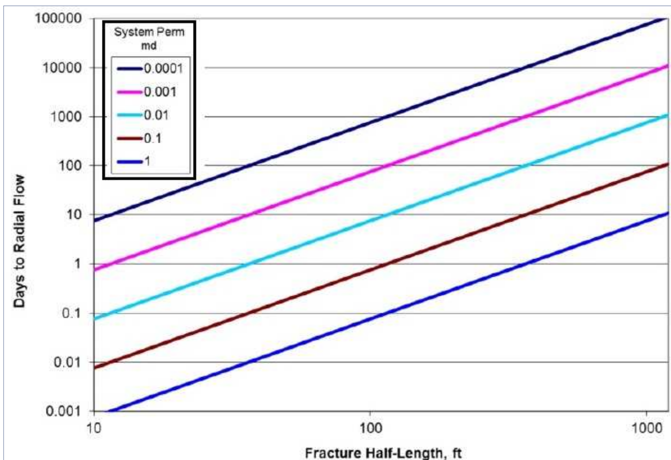
2.9 Frac Length Created



Fracture half-length created as a function of pumping time and rate.

Barree et al. (2014)

2.10 Time to Pseudoradial



$$t_{pr} = \frac{\phi \mu C_t x_f^2 t_{Dxf}}{0.0002637k}$$

t_{pr} = time to reach pseudo-radial flow, hours
φ = porosity, fraction
μ = fluid viscosity, cp
Ct = total reservoir compressibility, 1/psi
xf = fracture half-length, ft
k = permeability of leakoff system, md

t_{Dxf}=1 for a gas reservoir viscosity of 0.02 cp, porosity of 8%. fracture height of 30 feet total reservoir compressibility of 3.0e-5/psi.

Time, in days, to theoretically reach pseudo-radial reservoir transient flow conditions for a gas reservoir for various system permeabilities.

Barree et al., 2014

2.11 Results from Basic Minifrac Analyses

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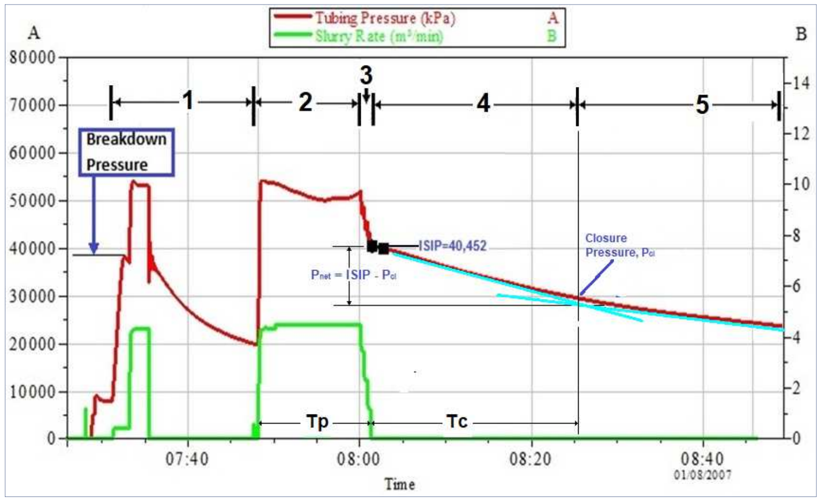
- Breakdown Pressure (P_{br})
- Instantaneous Shut-in Pressure (ISIP)
- Closure Pressure (P_{cl})
- Net-pressure (P_{net}= ISIP-P_{cl})
- Pumping Time (T_p)
- Closure Time (T_c)
- Fluid / Fracture (F.E., E_f)
- Pad Percentage (%)
- Pad Size (Vol)



2.12 Nolte Fluid Efficiency-Pad Equations

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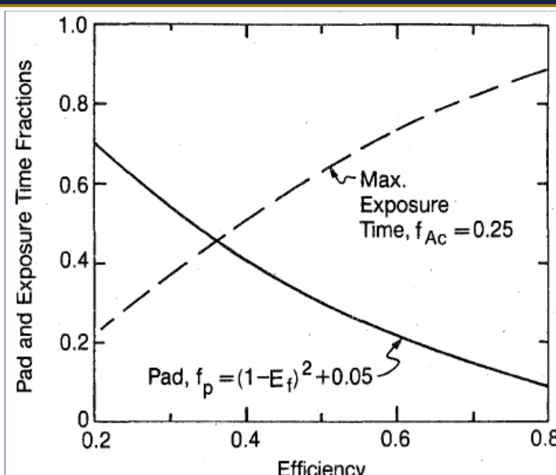


Pad and exposure relations with efficiency.

$$F.E. - E_f = \frac{\left(1+\frac{T_c}{T_p}\right)^{1.5} - \left(\frac{T_c}{T_p}\right)^{1.5} - 1}{\left(1+\frac{T_c}{T_p}\right)^{1.5} - \left(\frac{T_c}{T_p}\right)^{1.5}}$$

Nolte Method:

% Pad Volume = $(1- F.E.)^2 + 0.05$

Kane Method (HAL):

% Pad Volume = $(1-F.E.)^2$

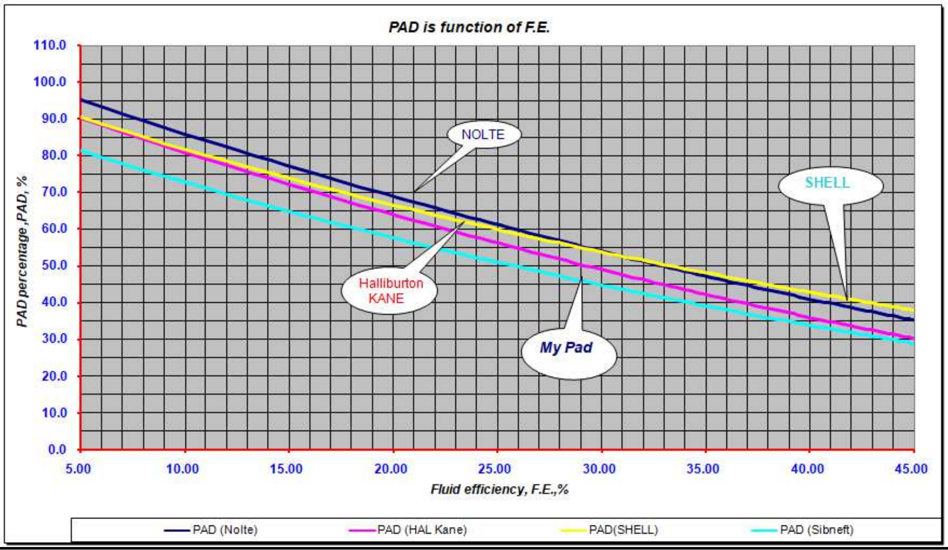
Shell Method % (Pad + Prepad):

% (Pad + Prepad) = (1 - F.E.)/(1 + F.E.)

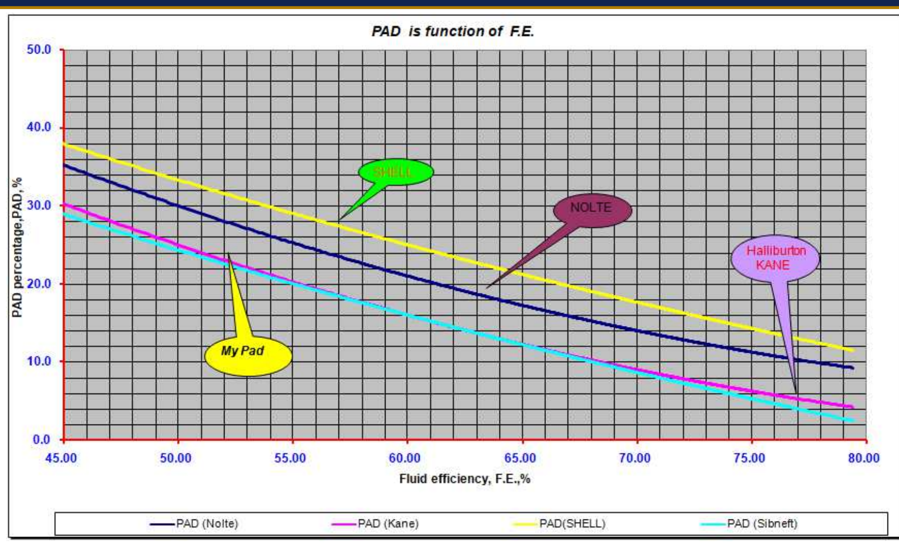
Pad Volume = (SLF Volume*%Pad)/(1-%Pad)

Nolte (1986)

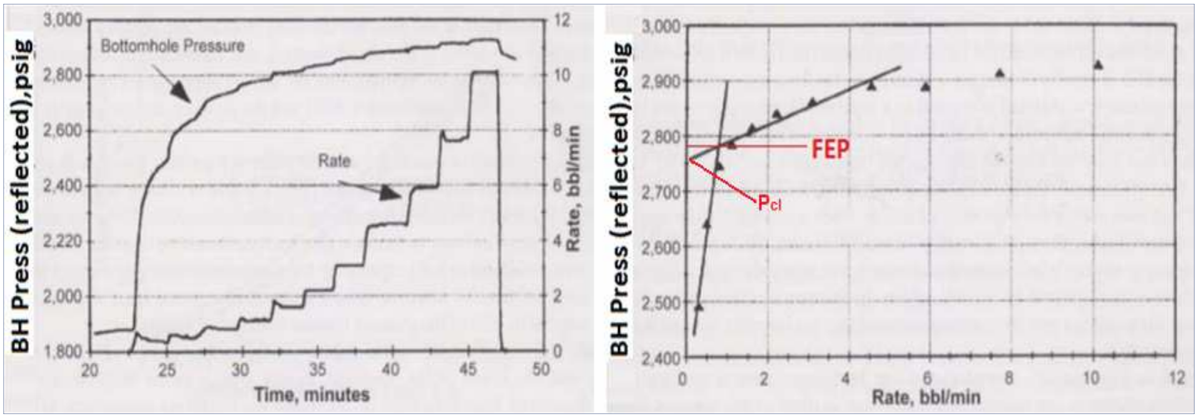
2.13 Pad vs. Fluid Efficiency (5-45%)



2.14 Pad vs. Fluid Efficiency (45-80%)



3.1.1 Step-up Rate Test (SRT)



FEP = Fracture Extension Pressure (upper bound for Pcl) Tinker et al.(1997)

3.1.2 Step-up Rate Test

The SRT consists of two intervals: Injection (in steps up) and Shut-in.

- **Theory:**

The only useful data obtained from the SRT is the Fracture Extension Pressure (FEP), and Closure Pressure Pcl. FEP isn't very useful for Conventional and Unconventional Propped Hydraulic Fracturing. FEP only serves as upper bound for Pcl. Pcl can be determined by other methods.

- **Procedure:**

1. Start the SRT by injecting at very low rate. Reason: Pressure increases dramatically at test initiation. Continue rate increase in slightly larger steps.
2. At about halfway through the test make the rate increases larger.
   Reason: Small pressure increases are noted.
1. The last 3-4 rate increases should be very large.
   Reason: Very small pressure increases are noted.

3.2.1 Well Friction Analogous to Venturi FM

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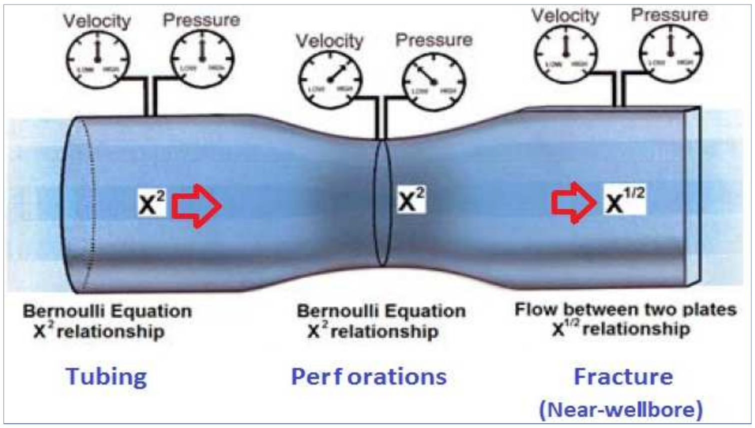

Modified Venturi flow Meter (FM) represents well system.

- Upstream represents the Tubing
- Throat represents the Perforations

The flow rate for both is a X^2 relationship.

- Downstream represents the near wellbore area of the fracture.

(parallel plate configuration)

The flow rate is a $X^{½}$ relationship.

Cleary et al. 1993
Massaras et al. 2007

3.2.2 Stagnation Pressure

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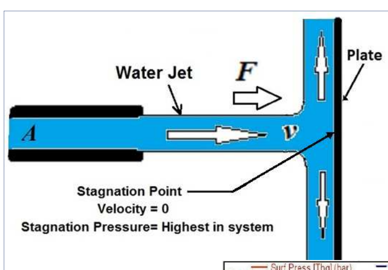
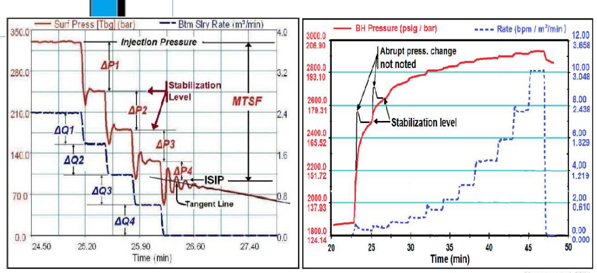


Only the Rate Step-down Test can be used fro Friction Analysis.
RST cannot detect **abrupt** pressure changes



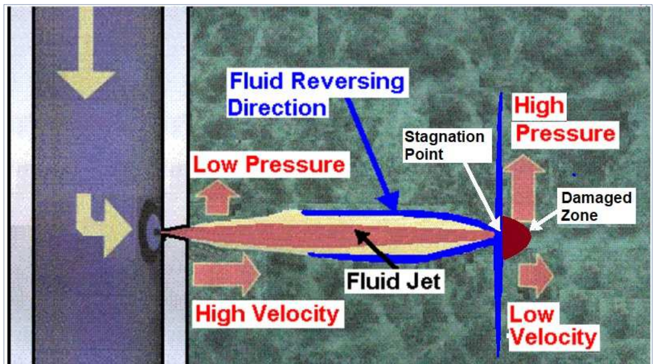
Massaras et al. 2011

Jet impinging on a plate is analogous to jet flow via a perforation impinging at end of the perforation tunnel:

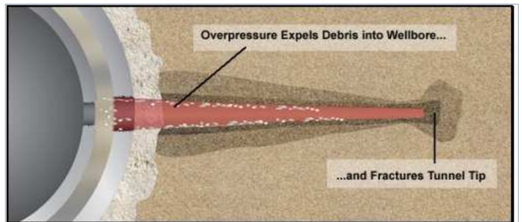
Because stagnation pressure is (at stagnation point) is very high, **abrupt** rate reductions during the RST result in instantaneous pressure reductions.

The opposite isn't true for the SRT.

3.2.3 Perforation Friction



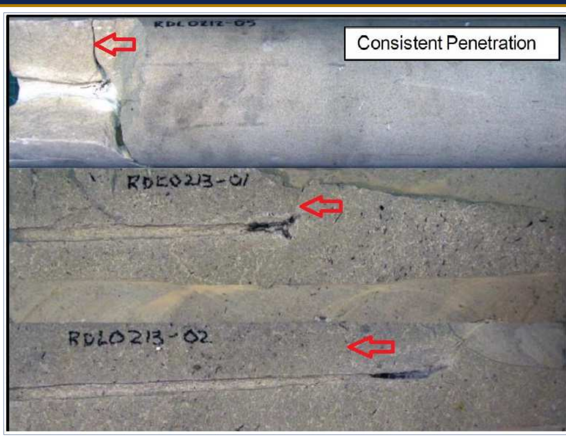
Perforation and fracture, showing the velocity and pressure relationships, a combination of which causes high stagnation pressure. Massaras et al. (2007)



Over-pressure Expels Debris and Fractures Tip

New Debris-Free Tunnel with Fractured Tip

3.2.4 Perf Tip Damage



Comparison of consistent penetration charge against various similar conventional charges

Cuthill et al. (2017)

Flow is impinged similar to a bent garden hose, which if bent enough stops flow completely.

3.2.5 Effective Perforations

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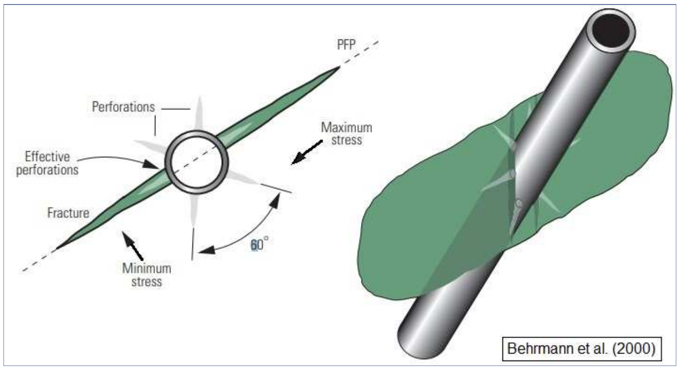

- Only 5% of wells are vertical at the perforated interval.
- 95% are inclined 1-5 deg.
- As such not all perforations are in contact with the fracture.
- Most wells are perforated with 6 SPF and 60 Φ.
- In a perforated interval of say 20 ft (120 perfs), probably only 5 ft are in contact the fracture.
- Only 1/3 (2 perfs/ft) are (effective) accepting fluid.
- So max 5 ft x 2 perfs/ft = 10 perfs.
- Confirmed by solving for number of open perforations with the equations in next slide.

3.2.6 Very Few Perfs Open

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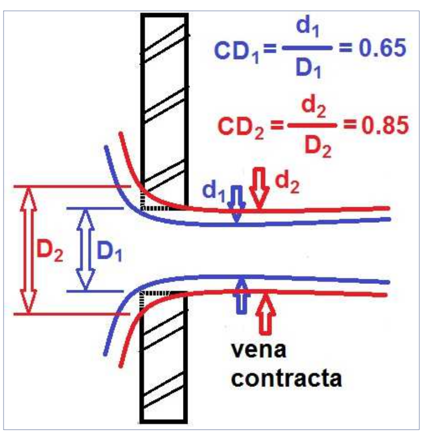

Number of perforations accepting fluid can be calculated:

$$Q = \frac{D^2 C \sqrt{\frac{P}{\rho}}}{0.4967}$$

$$\text{Number of Perforations Open} = \frac{\text{TotalRate}}{Q}$$

D = Perforation diameter, in.
C = Coefficient
(0.65 before proppant, 0.95 after proppant)
(0.85 default in all simulators)
P = Pressure, psi
ρ = Density, lb/gal

The equations and coefficient (C), for perforation friction were developed with sharp corner perforations (drilled) .

Example:
Perf .Diam. = 0.45 in
C = 0.65
P = 8000 psi
ρ = 8.33 lb/gal
Total Rate = 40 bpm

No. of Perfs Open = 4.9

3.2.7 RST Design Considerations

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Incorporate the Rate Step (down) Test (RST) at end of Minifrac.

- **Make RST in 4 <u>equal</u> steps (or make 1st and 4th steps equal)**
  - **Three steps is too few and five is too many.**
  - **Need enough data to:**
    - **See the plot curvature**
    - **See the expected progressive reduction in pressure trend (see next slide)**
    - **Obtain the Median Ratio (Massaras et al. (2012).**
- **Make steps very short (10-15 sec).**
- **Pump with 4 or 8 pumps all at about equal rate and take out 1 pump or 2 pumps at a time.**

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3.2.8 RST Logic-ISIP Determination

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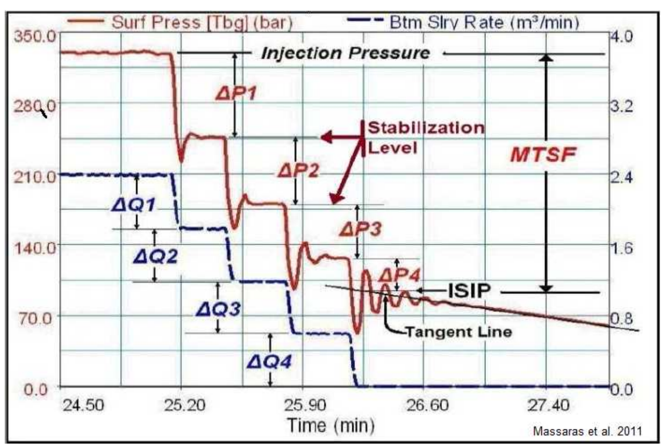
- **Because most well parameters remain constant during short duration (30 -45 sec) of the RST, any deviation from the expected pattern of progressively smaller pressure reduction steps is a strong indication of hindrance to fluid flow.**
- **By the process of elimination, it can only be caused by a restrictive NWB area, and the associated NWB friction.**



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3.2.9 RST Differentiates FEF

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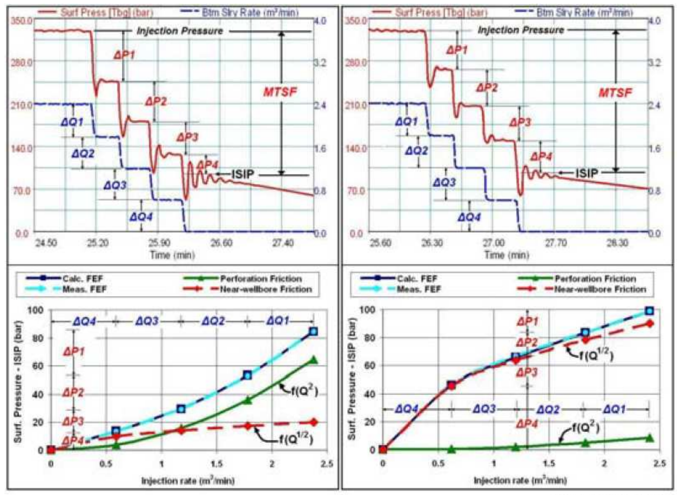
- The RST differentiates Fracture Entry Friction into Perforation friction and near-wellbore friction (Tortuosity).
- If plot is concave upwards, perforation friction dominates (larger). If plot is concave sideways, near-wellbore friction dominates (larger).



Massaras et al 2007

3.2.10 FEF Guidelines

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- Enhanced FEF Methodology has 45% success rate.
- Using also the Median Ratio increases the success rate to 90%.
- Each methodology is necessary but not sufficient for high rate of success.
- Indicators of high NWB Friction are:
  1. The Media Ratio (MR)= ΔP4/ΔP1 ≥ 0.5 Massaras et al. (2011)
  2. Near-wellbore Friction ≥ 435 psi (30 bar) Massaras et al. (2007)

General Decision Control Guideline Based on Ranges of FEF Component Values

Perforation Friction		Near-wellbore Friction		Remarks
(bar)	(psi)	(bar)	(psi)	
0–15	0- 218	0 – 15	0- 218	Very low probability for screenout
15–30	218 - 435	15 -30	218- 435	Caution required
30-50	435-725	30-50	435-725	Screenout highly probable
> 50	> 725	> 50	> 725	Screenout almost certain

Massaras et al. (2007)

3.2.11 Low NWB Friction

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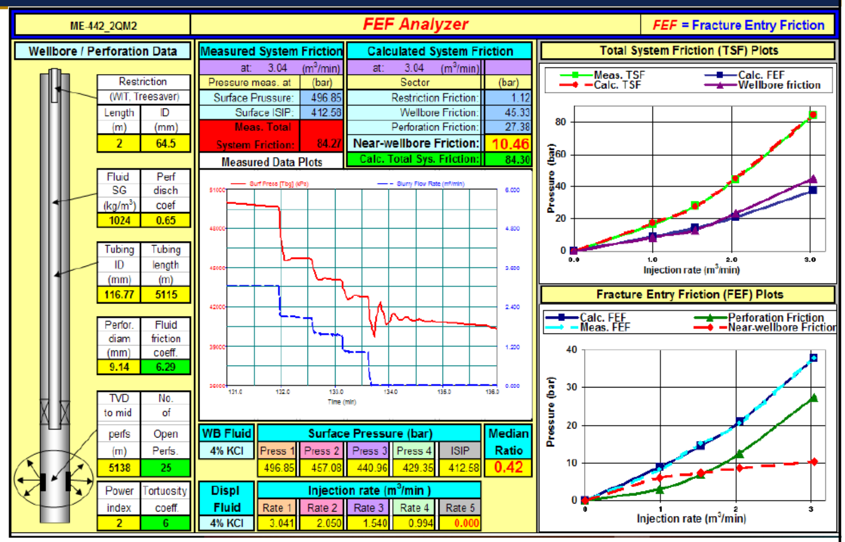
- DP4 small compared to DP1.
- Therefore NWB Friction low.
- NWB Friction

  10.46 bar (< 30 bar)
- MR = 0.42



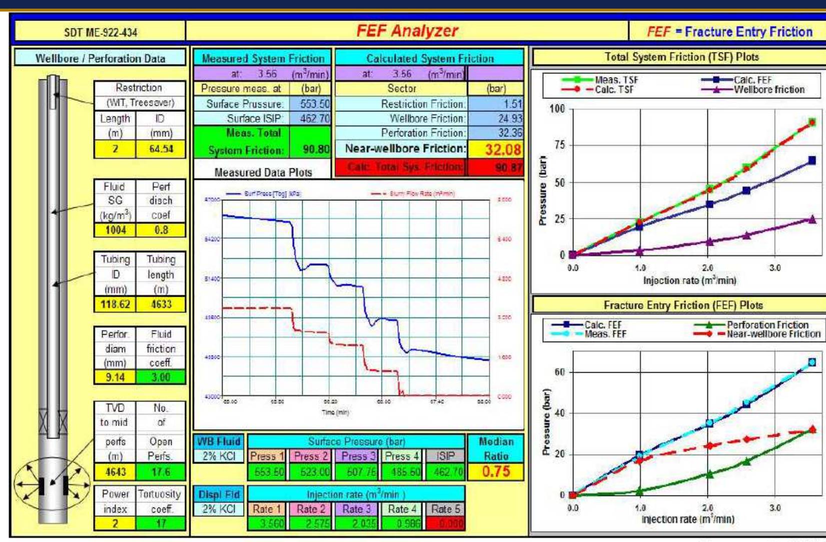
Massaras et al. 2011

3.2.12 High NWB Friction

Webinars

- DP4 large compared to DP1.
- Therefore NWB Friction high.
- NWB Friction

  32.08 bar (> 30 bar)
- MR = 0.75



Massaras et al. 2011

3.2.13 NWB Friction & Commercial Software

Webinars

- Conventional FEF analysis has been implemented by most commercial Fracture Propagation Simulators.
- Matches TSF only at highest rate, this, causes misallocation of the friction into the three components. Cannot output unique solution.
- Enhanced FEF Analysis matches at all rates, thus, produces unique (correct) solution.

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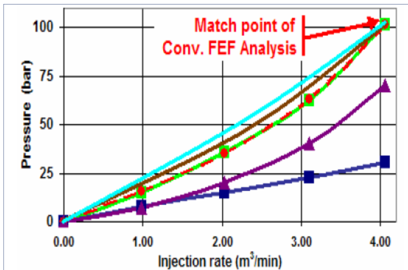

Conventional FEF Analysis showing how the TSF is allocated incorrectly to the various FEF Components.

	Calc. Wellbore Friction (bar)	Calc. Perforation Friction (bar)	Calc. Near-wellbore Friction (bar)	Calc. Total System Friction (bar)
Incorrect Match	50	25	25	100
Incorrect Match	60	20	20	100
Perfect Match	70	18	12	100

SPE 106058 Massaras et al 2007

3.2.14 Frac Design from RST

Webinars

- Data from RST used to design frac parameters:
  - Slope of prop ramp
  - Max prop concentration
  - Prop plateau duration
- Minifrac /DFIT and FEF Analysis are predictive.
- Real-time (RT) Monitoring and Analysis are required
- Monitor in RT: Inverse Slope Method. Massaras et al. (2012)

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4.0 Before Closure Analysis (BCA) Methods

Webinars

- Nolte (1979) and (1988)
- Barree and Mukherjee (1996)
- Barree et al. (2007) and (2009)

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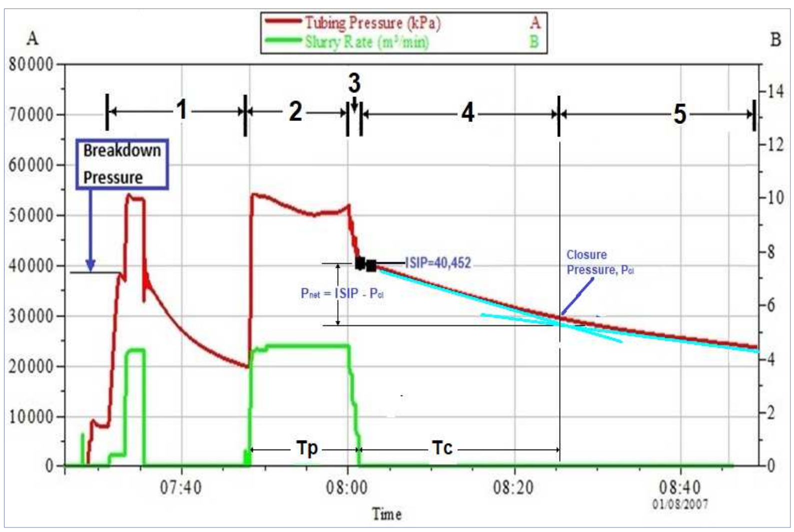
4.1 BCA Application

Webinars

Before Closure Analysis, (BCA) is usually performed:

- On data from ISIP to fracture closure (interval 4).
- In real-time to ensure data is recorded until and past fracture closure.



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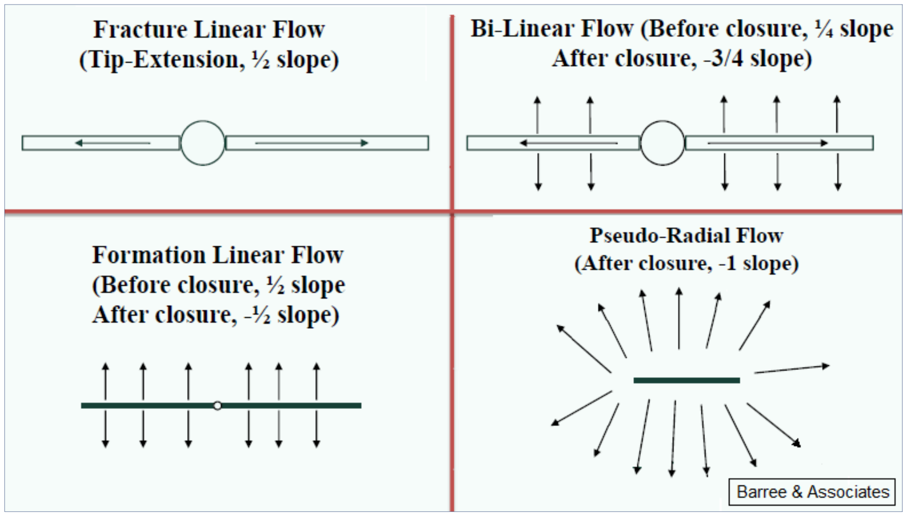
4.2 Fracture and Reservoir Transient Flow Regimes

Webinars

First step:
Determine Flow Regime



4.3 BCA Analysis & Data

Webinars

Before Closure Analysis

- Uses Special Derivatives and Time Functions:
  - G-Function
  - Square-Root
  - Log-Log
  - Linear
- Identifies Leakoff behavior, and Closure pressure

Data from Pre-Closure Analysis

- Fluid leak-off mechanisms
- Closure Pressure (P_{cl})
- Net pressure (P_{net})
- Min Horiz. Stress (σ_{min})
- Fluid/Fracture efficiency (E_f), (η)
- Flow regimes
- Reservoir pore pressure (P_r)
- Permeability (k)
- Fracture Length
- Leak-off Coefficient (C_L)

$$\eta = \frac{G_c}{2+G_c}$$

$$C_L = \frac{2h}{\pi r_p E \sqrt{t_p}} \frac{dP}{dG}$$

4.4 G-Function Derivative analysis

Webinars

- G-Function Plots:
  - Bottomhole pressure vs. G-Function
  - Derivative of pressure (dP/dG) vs. G-Function
  - Superposition derivative (GdP/dG) vs. G-Function
- Characteristic shape of plots used to find:
  - Detection of natural fractures
  - Leakoff type (Normal, PDL, Height Recession (or TS), Fracture Tip Extension)
  - Fluid Efficiency (η), η = Gc / 2 + Gc (no spurt loss)

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4.5 Algebraic Definition of G-Function

Webinars

$G \approx 2\surd\Delta t_D$ for very low perm systems

G-function is a dimensionless function of shut-in time normalized to pumping time:

$$G(\Delta t_D) = \frac{4}{\pi}\left(g(\Delta t_D) - g_0\right)$$

$$\Delta t_D = \left(t - t_p\right)/t_p$$

Barree & Associates

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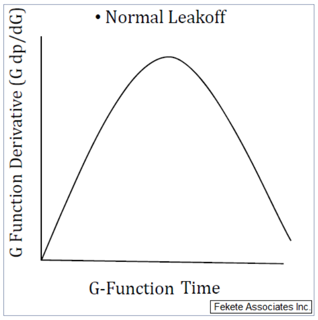
4.6 G-Function: Two limiting cases

Webinars



•Low Leakoff, high efficiency (α = 1.0)

•Fracture area open varies approximately linear w/time

$$g(\Delta t_D) = \frac{4}{3}\left((1+\Delta t_D)^{1.5} - \Delta t_D{}^{1.5}\right)$$

•High leakoff, low efficiency (α = 0.5)

•Fracture area varies w/ square-root of time

$$g(\Delta t_D) = (1+\Delta t_D)\sin^{-1}\left((1+\Delta t_D)^{-0.5}\right) + \Delta t_D{}^{0.5}$$

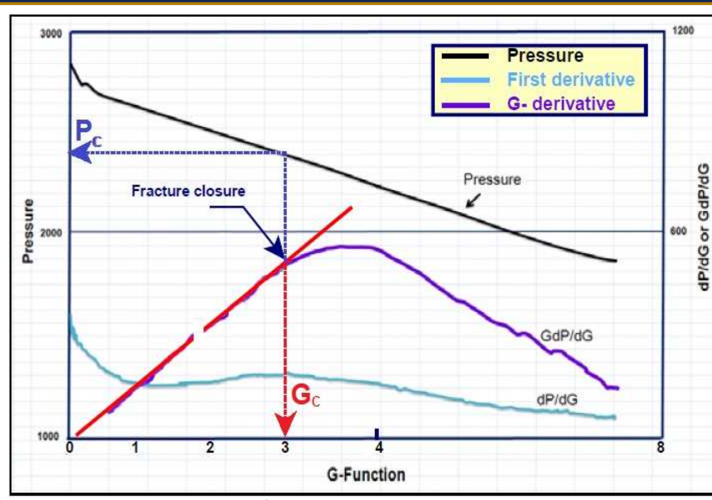
Barree & Associates

4.7 Normal (Ideal) Leakoff (NL)

Webinars

- Fracture area constant during shut-in.
- Leakoff through homogeneous matrix.

- Hump in First derivative (dP/dG)
- G-Function derivative (GdP/dG) matches tangent that passes through origin.
- Deviation of G-Function from tangent indicates Fracture Closure.



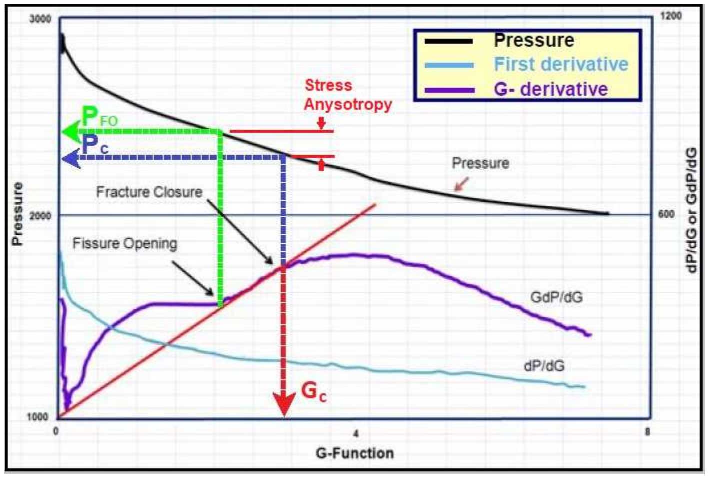
Adopted and Modified: Barree et al. (2007)

4-8 Pressure Dependent Leakoff (PDL)

Webinars

- Indicates existence of secondary fractures in communication with the main fracture.

- G-Function derivative (GdP/dG) exhibits large hump above the tangent line.
- Normal Leakoff after hump.
- End of hump indicates Fissure Opening.
- Deviation of G-Function from tangent indicates Fracture Closure.



Adopted and Modified: Barree et al. (2007)

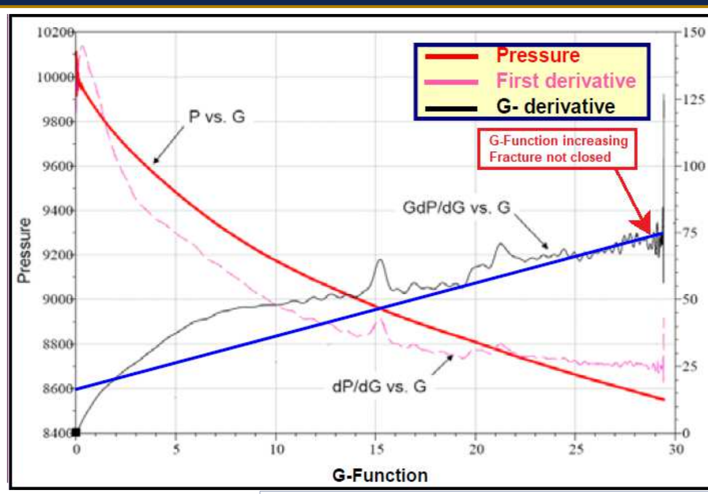
4.9 Fracture Tip Extension Leakoff (FTE)

Webinars

- Fracture continues to grow after injection has stopped.
- Happens in very low permeability Reservoirs.
- Fluids which normally leakoff through adjacent zones, are transferred to the end of the fracture extending fracture at the tip.

================================

- G-function derivative (GdP/dG) initial has steep slope, which decreases with shut-in time, and yields concave-down curve.
- Tangent through the G-Function derivative (G dP/dG) intersects the y-axis above origin.



Adopted and Modified: Barree et al. (2007)

4.10 Height Recession Leakoff (HR)

Webinars

- **Fracture grows into adjacent impermeable layers during injection.**

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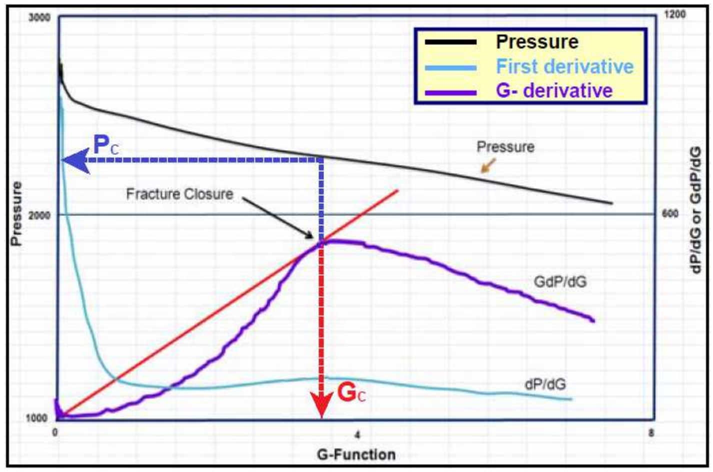
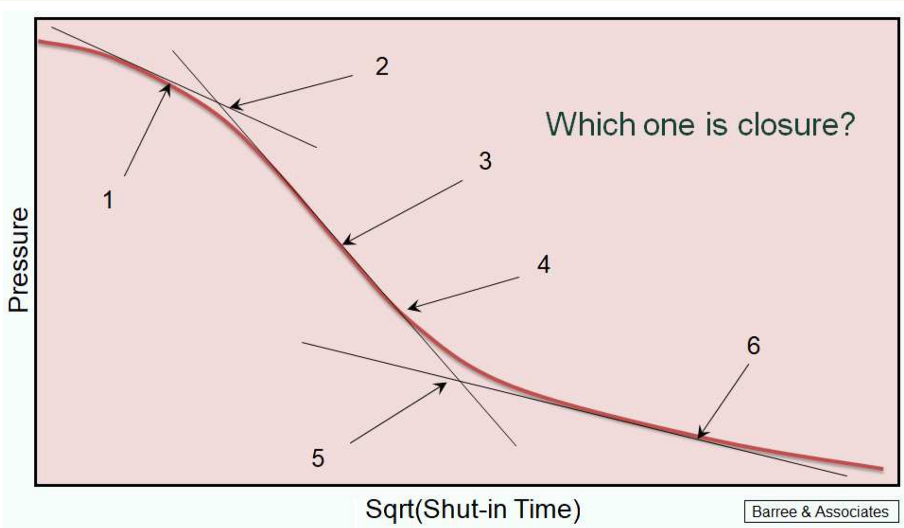
- The G-Function derivative (G dP/dG) plots below the tangent line extrapolated through the normal leakoff data.
- Both G-Function and the first derivative exhibits a concave up trend.



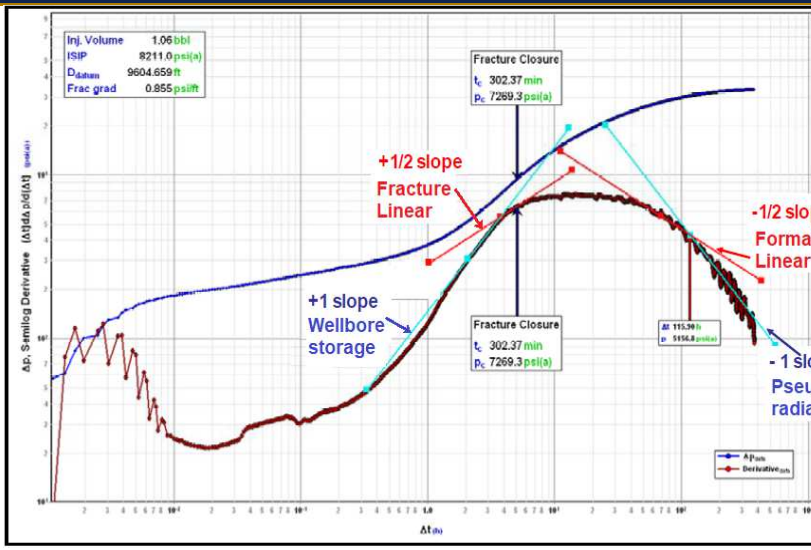
Adopted and Modified: Barree et al. (2007)

4.11 Square Root plot

Webinars



4.12 Log-Log Plot



Diagnostic log-log plot of pressure falloff

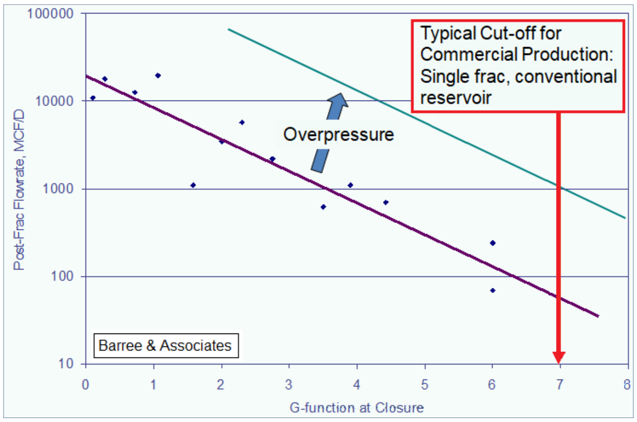
Martin et al. (2012)

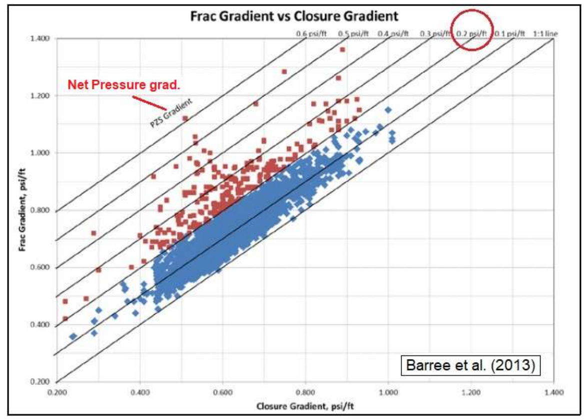
4.13 Log-Log Plot: Flow Regimes

	Slope	Flow Pattern	Description
Before Closure	¼	Bilinear	Fluid flows from the fracture along linear flow paths normal to the fracture and along the fracture.
	½	Fracture linear	Fluid flows along the fracture thus increasing fracture width.
After Closure	-¾	Bilinear	Fluid flows from the fracture along linear flow paths normal to the fracture and along the fracture. (In reality, closure is unlikely to be truly instantaneous.)
	-½	Formation linear	Fluid flows into the formation in paths normal to the fracture plane.
	-1	Pseudo-radial	Fluid flows radially into the formation from the wellbore.

4.14 Commercial Production Cutoffs

Webinars





G-Function time ≥7 - no flow

Pnet Gradient ≥ 0.2 psi/ft - no flow

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5.1 ACA Techniques - Data

Webinars

- Nolte (1997) based on Carslaw et al. (1959)
- Gu et al. (1993) based on Ayoub et al. (1988)
- Abousleiman et al. (1994)
- Soliman (2005) and (1986)
- Craig and Blasingame (2005)
- Mohamed et al.(2011)

- After Closure Analysis (ACA) has similar workflow to traditional PTA.
- Uses “impulse” solution to establish:
  - Formation permeability (k)
  - Reservoir pressure-Initial (P_i)
- Other Parameters
  - Flow Regime
  - Permeability (k)
  - Flow Capacity (kh)
  - Transmissibility (kh/µ)

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5.2 Linear Flow Time Function (FL)

Webinars

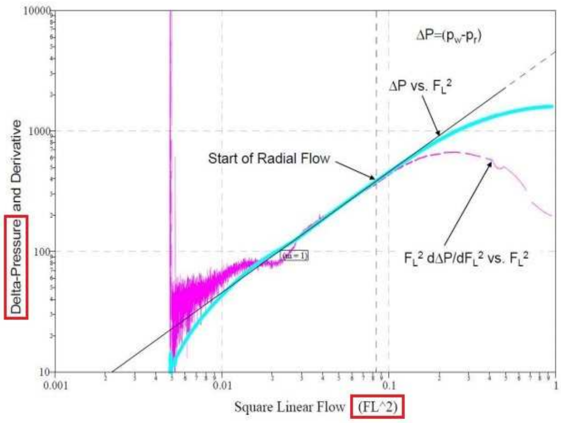
After closure analysis (ACA) is performed to identify the flow regime after closure takes place. The flow regimes can be described using characteristic slopes on a log-log plot of monitored pressure difference which is defined as fall-off pressure minus pore pressure versus the square of the linear flow time function (F_L^2).

The linear flow regime function (F_L) is described by Barree et al. (2007) as:

$$F_L(t, t_c) = \frac{2}{\pi}\sin^{-1}\sqrt{\frac{t_c}{t}} \quad \text{for } t \ge t_c \qquad \text{and, } \Delta P = P - Pr$$

Pseudolinear flow, the slope of the derivative curve on the log-log plot should be 0.5

Pseudoradial flow, the slope of the derivative curve on the log-log plot should be 1 and the curves should coinside.



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Barree et al. (2007)

5.3 Radial Flow Regime Function (FR)

Webinars

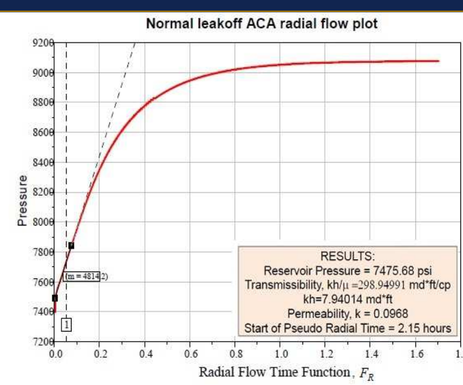
Cartesian plot of pressure versus F_R should yield a straight line with intercept equal to p_i and slope of m_R.

$$F_R(t, t_c) = \frac{1}{4}\ln\left(1 + \frac{\chi t_c}{t - t_c}\right), \qquad \chi = \frac{16}{\pi^2} \cong 1.6$$

In the pseudoradial flow period the reservoir far-field transmissibility can be determined from the slope, fracture closure time, and volume injected.

$$\frac{kh}{\mu} = 251{,}000\frac{Q_t}{m_R t_c}$$

k, permeability, md	t_c fracture closure time, mins
h, net pay thickness, feet	Q_t, volume injected, bbls
μ, far-field fluid viscosity, cp	m_R, slope, psi



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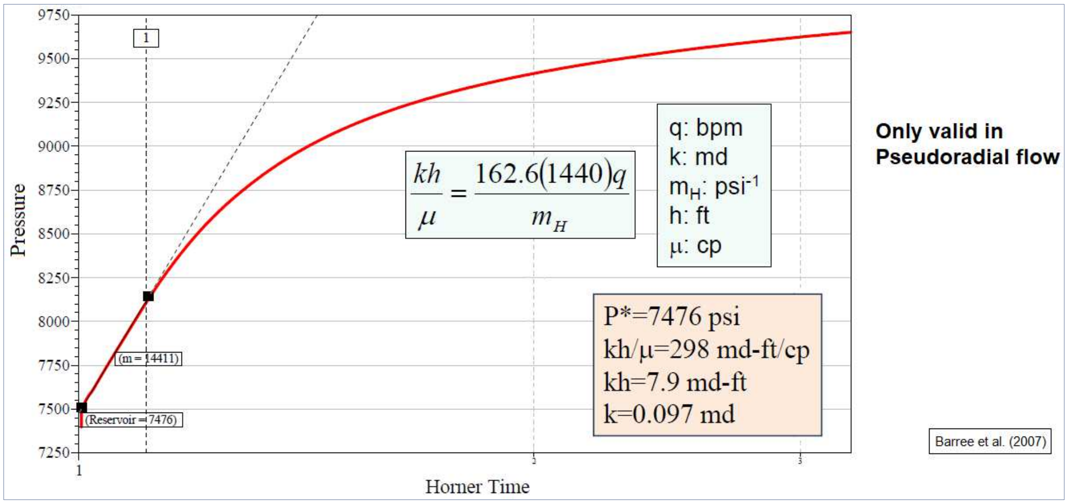
Barree et al. (2007)

5.4 Horner ACA

Webinars



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5.5 Permeability – G-Function Time (Empirical)

Webinars

Matrix permeability estimation with G-Function time at closure (Gc):

$$k_m = \frac{0.0086\mu_f\sqrt{0.01\ Pnet}}{\varphi c_t\left(G_c E r_p / 0.038\right)^{1.96}}$$

where:

k_m = estimated matrix permeability,

P_{ISIP} = Instantaneous Shut-In Pressure (ISIP)

p_c = closure pressure

$Pnet$ = Net Pressure = $P_{ISIP} - p_c$

φ = porosity

E = Young`s modulus

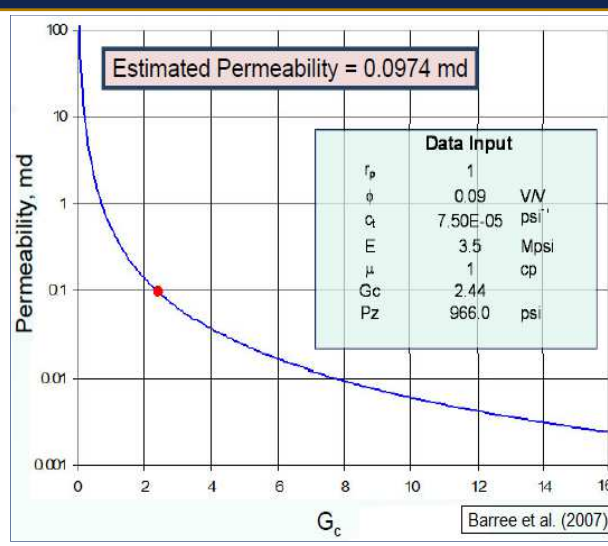
c_t = total compressibility

r_p = storage ratio

μ_f = fluid viscosity

G_c = G-time at closure

Barree et al. (2007)



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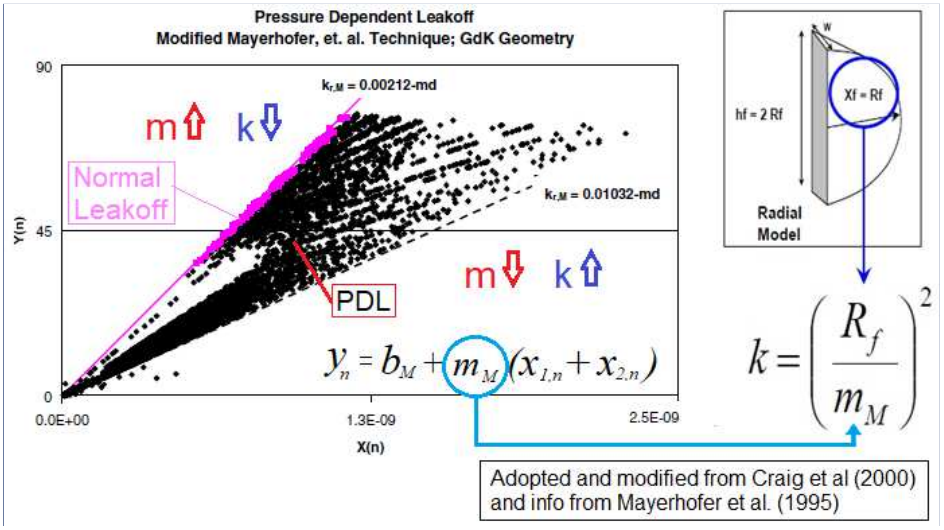
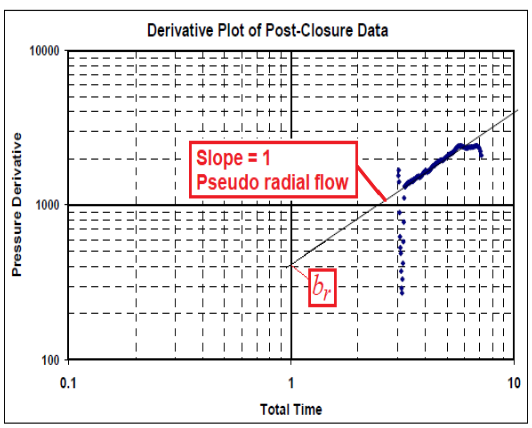
5.6 Modified Mayerhofer: *k*



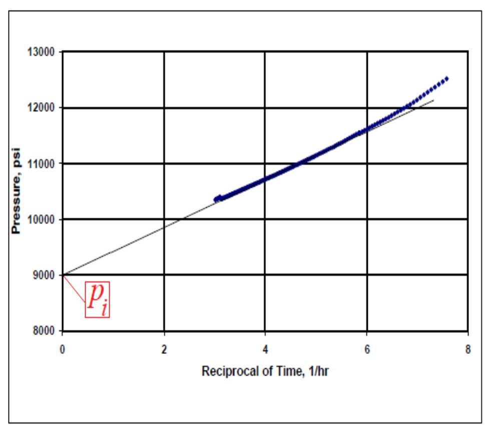
5.7 ACA Soliman-Craig: Radial - *k* and *Pi*



$$k = \frac{1694.4 V\mu}{b_r h}$$

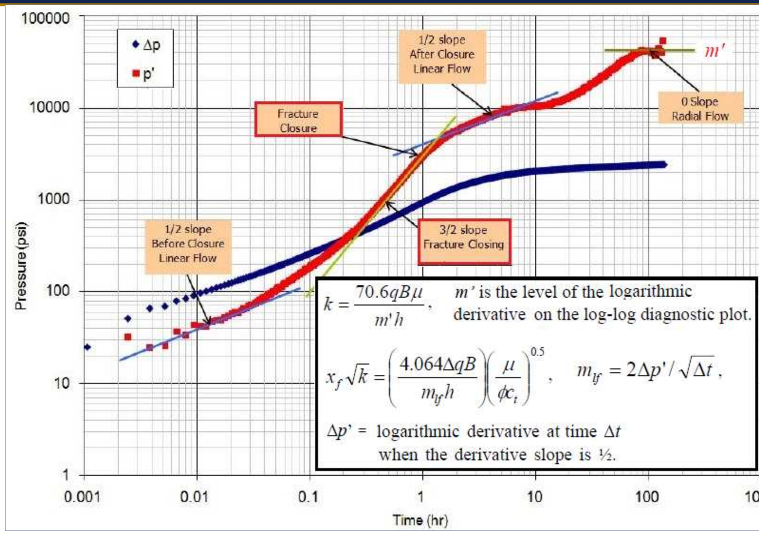
- V Injected volume bbl
- μ Viscosity, cp
- h Net pay thickness, ft
- b_r Intercept at time = 1
- p_i Initial reservoir pressure, psia

Modified from Soliman et al. (2005a)



5.8 Global Model for Minifrac Analysis

Webinars



Log-log diagnostic plot for data from the Cotton Valley gas reservoir

slope	
unit	Well-bore-storage
zero	Pseudo-radial flow
1/2	Linear flow
1/4	Bi-linear flow
-1/2	Spherical flow

Deviation of the derivative from the radial-flow straight-line indicates reservoir heterogeneities

Mohamed et al., (2011)

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End & Questions

Webinars

The End

Questions?

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