Mini Frac
Application for mini-frac analysis

To obtain reliable data on rock geomechanical properties, reservoir conditions and fracturing fluid properties, a calibration test - **a mini-fracturing test** - is conducted before the main fracturing of the reservoir. Mini-frac is the most important test before the main treatment; it is defined as a relatively short-term injection that utilizes all pumping modes and relatively large volumes of fracturing fluid. The parameters obtained from a mini-frac analysis with a small-sized fracture are used to calibrate the model of the main hydraulic fracturing and predict the behavior of a larger fracture.

The application can be used **to analyze a mini-frac test** and calculate the fracture half-length to width ratio, fracturing fluid efficiency and leakoff coefficient - parameters necessary for planning a major fracturing.

The calculations in the application are based on the **Nolte-Shlyapobersky** methodology.

1. Input parameters

h_p	Permeable (leakoff) thickness, m – it is assumed that there is no leakoff beyond the permeable layer
h_f	Fracture height, m
E	Young modulus, atm - ability of the rock to resist tension, compression under elastic deformation
ν	Poisson ratio - ratio of transverse compression to longitudinal tension $(\partial e_x / \partial e_z)$
p_c	Fracture closure pressure, atm

Table data:

t	Time, min - from start of pumping
q_i	Liquid injection rate, m^3/min
p_{bh}	Bottomhole pressure, atm

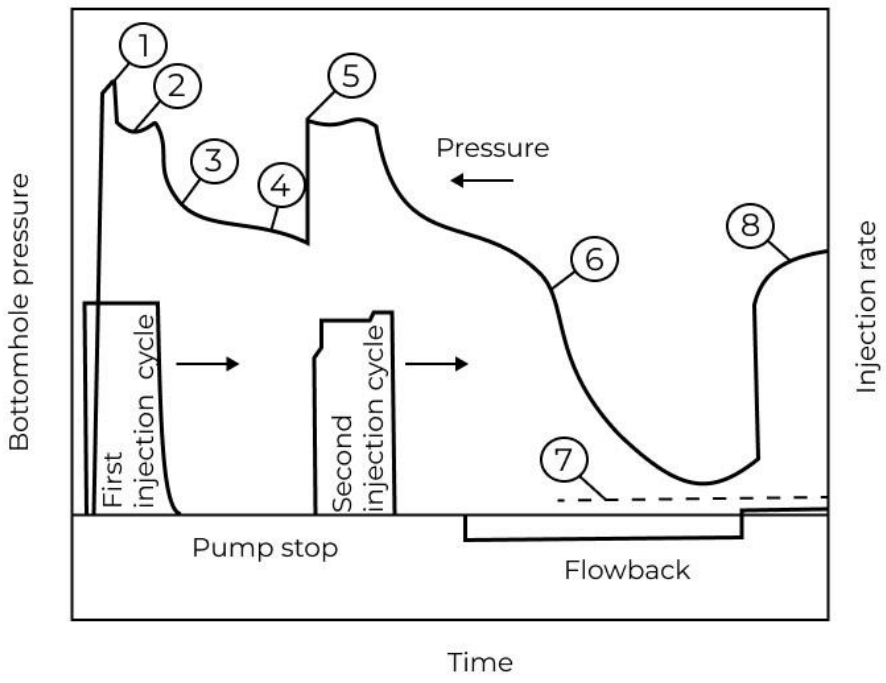
Include into the injected volume*	Indicator taking the value 0 or 1: 1 - during the pumping period 0 - after the pump has stopped
Include into g-function*	Indicator taking the value 0 or 1: 1 - for all points corresponding to a straight line on the pressure drop curve 0 - for all other points

Note:

* - set by the user independently in the uploaded Excel spreadsheet

2. Mini-frac analysis

K.Nolte's concept of pressure curve analysis is based on the observation that the degree of pressure drop during the fracture closure process contains useful information about the intensity of the leakoff process. It is different from the injection period, where pressures depend on many other factors.



1. Formation fracturing
2. Fracture spreading
3. Instantaneous shutdown
4. Closure pressure based on abrupt decrease in pressure
5. Resumption
6. Closure pressure based on flowback
7. Asymptotic reservoir pressure
8. Closure pressure based on reverse stroke

Assuming that the fracture area expands with a constant exponential α and remains constant when the pump stops, at time $(t_e + \Delta t)$ the fracture volume is determined as:

$$V_{t_e} = V_i - 2A_eS_p - 2A_e g(\Delta t_D, \alpha) C_L\sqrt{t_e} \quad (2.1)$$

where is the dimensionless time interval:

$$\Delta t_D = \Delta t / t_e \quad (2.2)$$

and the function of two variables $g(\Delta t_D, \alpha)$ can be obtained by integration:

$$g(\Delta t_D, \alpha) = \frac{4\alpha\sqrt{t_D} + 2\sqrt{1+t_D} \times F\left[\frac{1}{2}, \alpha, 1+\alpha, (1+t_D)^{-1}\right]}{1+2\alpha} \quad (2.3)$$

The Grasgof function (g-function) is used for calculation purposes.

The g-function is a dimensionless time function relating the stopping time (Δt) to the total injection time (t_e), assuming constant flow rate injection.

In the mini-frac analysis application, *the Perkins-Kern-Nordgren (PKN) model* was used as the fracture propagation model. The constant α is assumed to be equal to $\frac{4}{5}$.

The approximation of the g-function for a given value of α:

$$g\left(d, \frac{4}{5}\right) = \frac{1{,}41495 + 79{,}4125d + 632{,}457d^2 + 1293{,}07d^3 + 763{,}19d^4 + 94{,}0367d^5}{1 + 54{,}8534d^2 + 383{,}11d^3 + 540{,}342d^4 + 167{,}741d^5 + 6{,}49129d^6} \quad (2.4)$$

where d is dimensionless time.

The change of pressure corresponds to the expression:

$$p = \left(p_c + \frac{S_f V_i}{A_e}\right) - \left(2S_f S_p\right) - \left(2S_f C_L \sqrt{t_e}\right) \times g(\Delta t_D, \alpha) \quad (2.5)$$

where p_c - closure pressure, atm; S_f – fracture hardness, Pa/m; S_p - instantaneous leakoff, m^3/m^2; C_L - apparent leakoff coefficient, $m \cdot min^{1/2}$

The proportionality coefficient S_f, or fracture hardness, for the PKN model is defined as:

$$S_f = \frac{2E'}{\pi h_f} \quad (2.6)$$

The plane strain modulus E' is calculated through the given Young modulus E and Poisson ratio ν:

$$E' = \frac{E}{1 - \nu^2} \tag{2.7}$$

Expression (2.5) shows that the pressure drop in the period after the pump stops will follow a straight trend line:

$$p = b_N - m_N \times g(\Delta t_D, \alpha) \tag{2.8}$$

where b_N - straight line shift coefficient, atm; m_N - slope coefficient, atm.

Apparent leakoff coefficient:

$$C_L = \frac{-m_N}{2\sqrt{t_e} S_f} \tag{2.9}$$

Instantaneous leakoff coefficient:

$$S_p = \frac{V_i}{2A_e} - \frac{b_N - p_c}{2S_f} \tag{2.10}$$

Assuming zero instantaneous leakoff, the unknown fracture half-length can be determined.

Fracture half-length:

$$x_f = \frac{2E'V_i}{\pi h_f^2 (b_N - p_c)} \tag{2.11}$$

Fracture width:

$$\overline{w_e} = \frac{V_i}{x_f h_f} - 2g_0(\alpha) C_L \sqrt{t_e} \tag{2.12}$$

The leakoff coefficient in the permeable layer is determined from the apparent leakoff coefficient:

$$C_{L,res} = C_L \cdot \frac{1}{r_p} \quad (2.13)$$

$$r_p = \frac{h_p}{h_f} \quad (2.14)$$

Fracture fluid efficiency:

$$\eta_e = \frac{\overline{w_e}}{\overline{w_e} + w_{Le}} \quad (2.15)$$

$$\eta_e = \frac{x_f \cdot \overline{w_e} \cdot h_f}{V_i} \quad (2.16)$$