Application of Semi-Analytical Model for Drilling Mud Losses Interpretation in Fractured Formations

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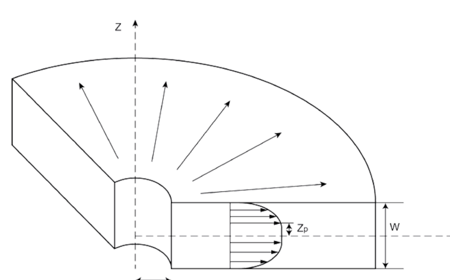
Abstract

Efficient characterization of Naturally Fractured Reservoirs (NFRs) is fundamental for a successful drilling campaign. When a drilling fluid loss is registered, by interpreting a set of drilling parameters, a potential natural open fracture is detected. A key factor for NFRs characterization is the estimation of fracture aperture, hence, fracture permeability. In this work a semi-analytical model is applied to diverse natural open fractures detected in carbonate reservoirs. Model hypotheses are Hershel-Bulkley rheology and planar fracture perpendicular to the wellbore in radial symmetry. First results on fracture aperture and permeability are discussed, model sensitivity and reliability have been investigated.

Analytical model

Mud loss into a fracture intersecting the wellbore is modelled by a laminar flow between two parallel circular disks in a radial geometry.



Drilling fluid is modelled as:

$$\tau = \tau_y + k\left(-\frac{dv}{dz}\right)^m$$

The mud advancement front is given by the overpressure:

$$\frac{dr_f}{dt} = \frac{\left[\frac{\Delta p}{k} - \left(\frac{2m+1}{m+1}\right)\left(\frac{\tau_Y}{k}\frac{2}{w}\right)(r_f - r_w)\right]^{\frac{1}{m}}\left[(1-m)\left(\frac{w}{2}\right)\right]^{\frac{1}{m}}\left(\frac{m}{2m+1}\ \frac{w}{2}\right)}{r_f\left(r_f^{1-m} - r_w^{1-m}\right)^{\frac{1}{m}}}$$

And thus the volume of drilling fluids loss into the fracture is given by:

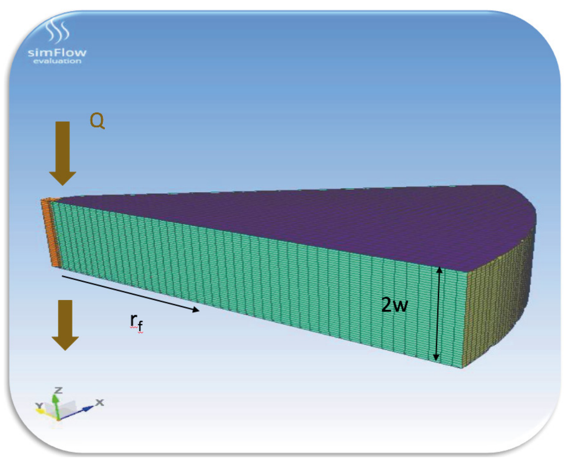
$$V_m(t) = \pi w\left[r_f^2(t) - r_w^2\right]$$

Numerical model

Analytical results (and related hypothesis) are tested by numerical simulations performed by using SimFlowⓇ.

Basic settings:
- Estimated overpressure $\Delta p(z)$=p(drilling fluid) - p(formation fluid)
- Drilling fluid rheology (τ_y, k, m)
- Fracture thickness (w) and well radius (r_w)
- Q_{in} measured

Main observables:
- Mud advancement front
- Frilling fluid volume loss

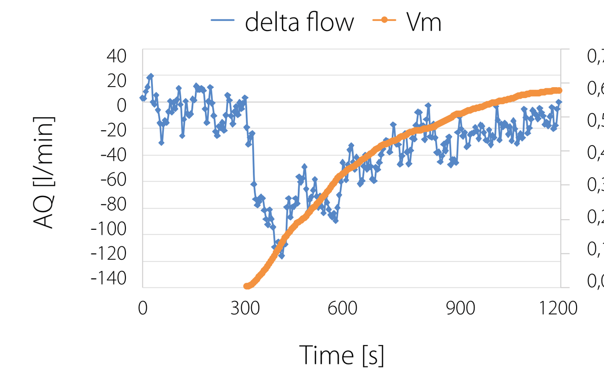


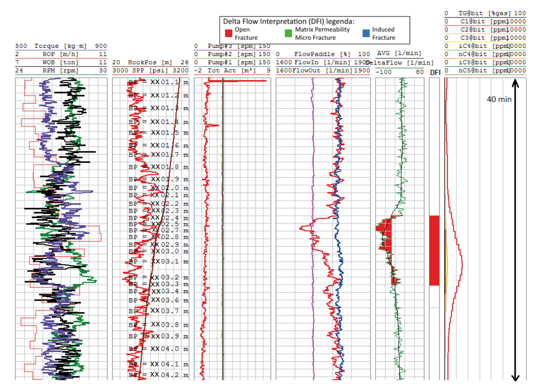
Application

On-field measurements of drilling fluid through Advanced Flow Meters installed according to diverse flowline size, type of drilling fluid and operating pressure.

$$\Delta Q = Q_{out} - Q_{in}$$

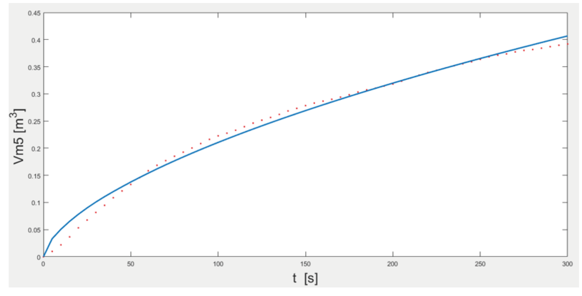
While drilling, the behavior of the ΔQ is strictly related to presence of open fractures.





The temporal evolution of the volume of drilling fluid losses is computed from ΔQ data. Rheological parameters for H-B model are computed from rotational viscometers.

Model Calibration



Fit: analytical model fed with measured mud volume loss using MatlabⓇ routines.

Input parameters:
- τ_y, k, m, ΔP, r_w (+uncertainties)
- initial guess of *w*

Output:
- Fracture aperture
- Mud advancement front

Monte Carlo approach

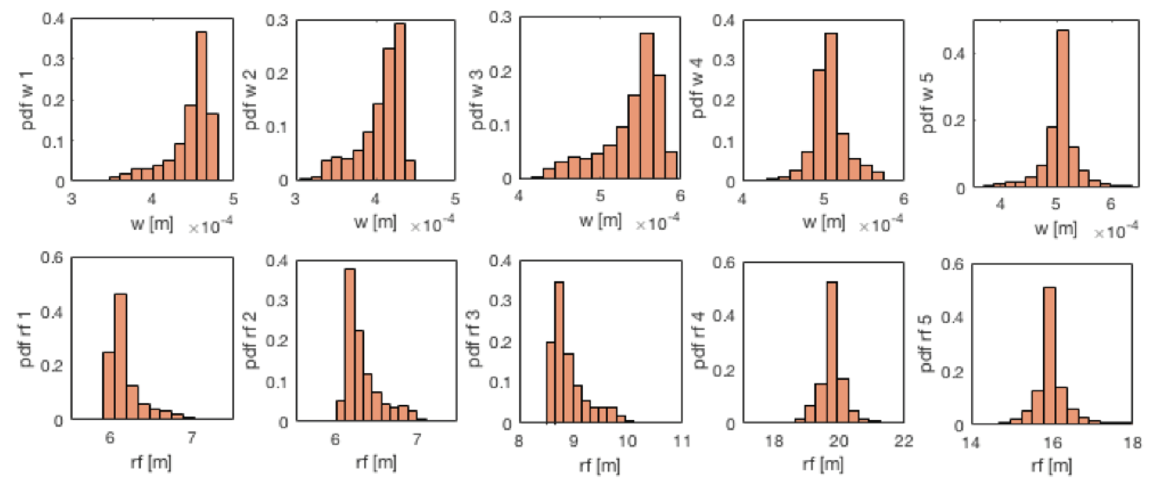
A large number of model calibrations has been performed by taking into account the measurement errors and intrinsic model parameter uncertainty:

$$\tau_y \pm \Delta\tau_y,\ \ k \pm \Delta k,\ \ m \pm \Delta m,\ \ \Delta P \pm \Delta(\Delta P),\ \ r_w \pm \Delta r_w$$

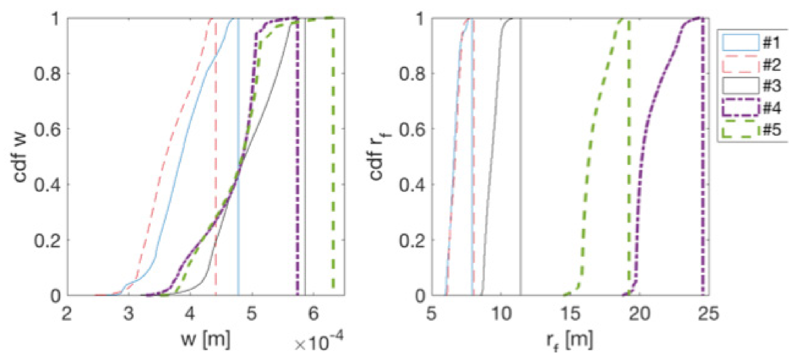
Distribution of possible values of fracture aperture, pdf *w* and fracture extension, pdf r_f

Results

Probability distribution of *w* for 5 fractures detected while drilling in carbonate reservoir:

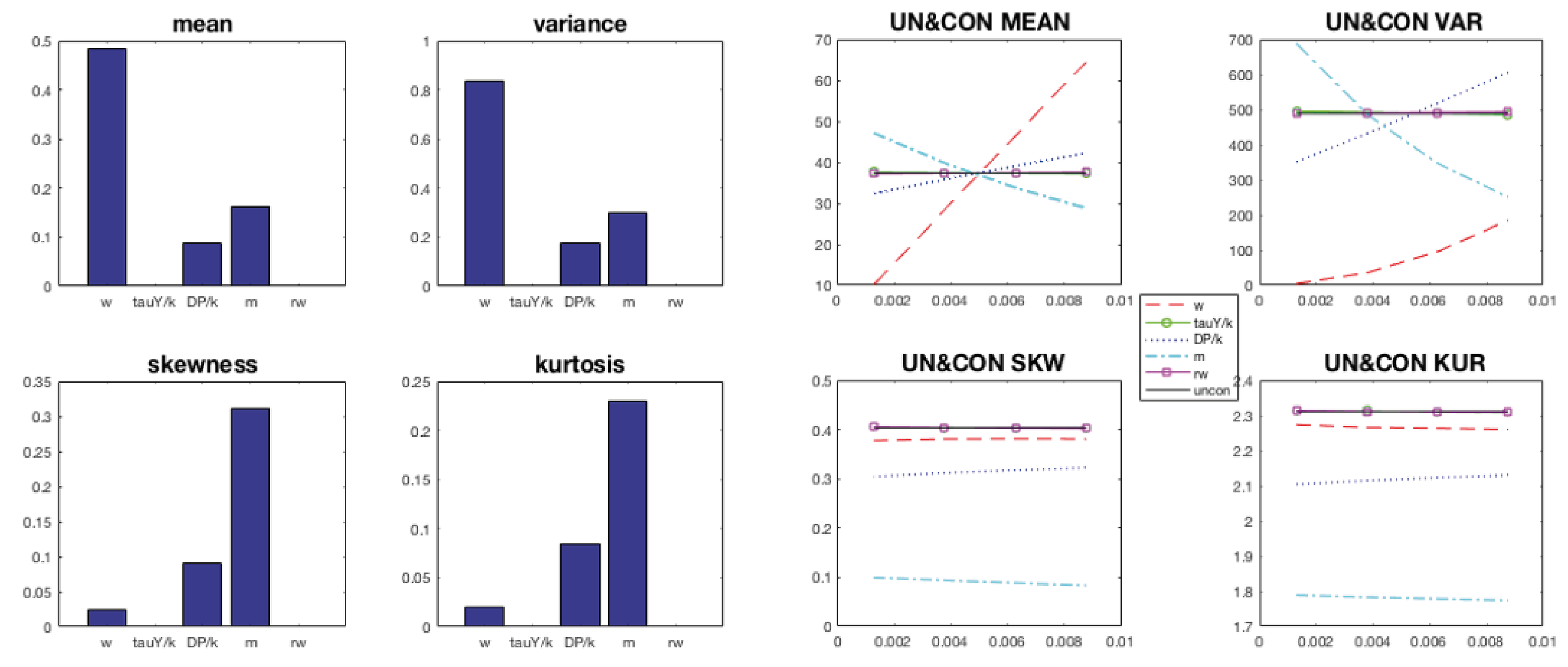


Cumulative density functions of fracture aperture and mud advancement front for 5 different fractures in carbonate reservoir



Sensitivity Analysis

Impact of parameter uncertainties to understand which parameter uncertainty mostly affect the statistical moments of model output (Vm).



Skewness: measure of the asymmetry of the pdf about its mean

Kurtosis: indicator of the behavior of the tail of the pdf (important for risk analysis)

Conclusions

In this work we present and apply a relatively simple analytical model that allows to estimate the fracture aperture in real time during drilling.

- **Reduce Borehole Logging time** and **save costs**
- Increase drilling efficiency by **optimizing LCM plan** and well completion, reducing **ILT and NPT**
- It is **not invasive**, it does not require specific operations and it is easy to implement
- Time savings can be estimated between hours to a few days of drilling operations

Future work: Model Validation with additional field data; Inverse Modelling Algorithm Optimization

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