How to Locate, and Flow Test, every Major Fracture in a Borehole in One Hour

by

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(FLUTe™)
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The Challenge:

Locate every significant flow path in the borehole, and measure the flow rate in each flow path as quickly as possible.

The Result:

All significant flow paths identified and their flow rates measured in $\frac{1}{2}$ hour to 4 hours in boreholes 150 – 600 ft deep.
Topics to be addressed

• How a blank flexible liner is installed
• What controls the installation rate
• How the installation is measured to obtain the required data for flow path mapping
• How the data is analyzed
• Results of measurements
• Comparisons with other measurements
The blank liner installation seals the hole.

- Fully lined hole
- Liner peeled from hole
- Nearly removed

- Tether
- Excess head in liner
- Liner
- Reel
- Inverted liner

Removal sequence:

Installation sequence:
To install a blank sealing liner,

**Just Add Water!**

1. **water hose** to the liner
2. **shipping reel**
3. **water level in liner**
4. **Original water in hole is displaced or, it can be removed by pumping during the installation**
Measuring the installation rate and head yields a transmissivity profile.
The liner descent velocity is controlled by the flow paths.

Velocity of liner in uniform medium

Possible velocity profile in fractured medium
The liner velocity drops when each fracture is sealed.

Flow rate into the fracture, $Q$, is $A(V_1 - V_2)$, where $V_1 > V_2$.

Average flow rate into the hole wall over the interval $dZ$ is:

$$\frac{Q}{(dZ \pi D)} = fctn(C,dP,D,\ldots)$$
Straddle packers have more or less leakage

Flow rate into the fracture is $Q - L_1 - L_2$.
Average flow rate into the hole wall over the interval $dZ$ is:

$\frac{(Q - L_1 - L_2)}{(dZ \pi D)} = fctn(C, dP, D, L, \ldots)$
Comparison of flow fields

Which can measure to the greater range??

The one that flows for the longer time, without any leakage?
In a breakout, a liner slows and then accelerates as it exits.

\[ V_i = \frac{Q}{A_i} \]

Hence, only a breakout with flow paths causes a persistent drop in the velocity.
How well does the liner seal the hole?

• The following photo was taken inside a 6” diameter 328 ft hole at Cambridge, Ontario by Peter Pemhe.

• The liner is a 400denier urethane coated Nylon fabric. The liner is about 6.5 inches in diameter with about 40 ft of excess head.

• In the lower left hand corner is a 1” wide welded seam tape. This is the typical blank liner.
This machine collects the data to a laptop and controls the tension (8” hole)
Data collected every 1-2 seconds:

- Position
- Time
- Head inside the liner
- Tension on the liner

And, the tension on the liner is controlled at an essentially constant value.
The calculations are:

- Velocity of the liner descent
- The position of the liner in the hole
- The change in velocity between each time step
- The persistent change in velocity with depth
- The transmissivity of the hole with depth
- The conductivity of each increment in depth
The results: amazing detail

By 64 ft, the flow rate is down to only 8% of the initial flow
35% of the flow is out the last two fractures

Approximately a 30 minute data collection time.
4” diam. x 408’ borehole in shale, we took about 4 hrs of data

**FLUTe Monotonic velocity/dH profile**

**Transmissivity of hole with depth**

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Transmissivity (cm²/sec) vs. depth below surface (ft) graph.
This was taken in an 8” hole and compared to straddle packer tests.
Integrating the Profiler results over the same interval as the packer tests produces very good agreement.

![Graph showing median conductivity vs. median depth of packer.](Image)
Limitations?

- Primarily related to adhesion of the liner to itself above the water level in the liner.
- Hence the following combination is the most difficult:
  - Deep water table (long wet film possible)
  - With high transmissivity (limited excess head)
  - Small diameter hole (high velocity and low towing force to overcome any drag effects)
- These have been overcome in most cases.
- Easy to identify data quality in the data plots.
Definition of the FLUTe Trio

1. A sealing *Blank Liner* to prevent cross contamination in a borehole

2. The *Hydraulic Conductivity Profiling* of a hole while installing a blank liner

3. The installation of a multi level sampling liner, called a *Water FLUTe*, for the head profile and water quality measurements
Conclusions

• The flow path resolution of this profiling technique is far greater than packer testing can provide.

• The time to obtain these results is 5-15% of the time for a complete suite of packer tests of the entire hole.

• The profiling blank liner is often installed for the purpose of sealing the hole, so the additional cost is low.

• There is no significant leakage with this method, it conserves the entire hole volume flow.
Conclusion (cont.)

- Preliminary data sets show better resolution than expected and excellent comparison with video, packer tests, and geophysical logs.

- The equipment and procedures are still being refined to even higher levels of resolution.

- The *Trio* produces a nice groundwater measurement medley
Thanks for your attention

• More information is available at our website:  www.flut.com
• And at our booth at this conference.
• And in the paper in the proceedings.