# Analyses of Step Rate Tests for Estimating Maximum Injection Pressure

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**Underground Injection Control Conference**

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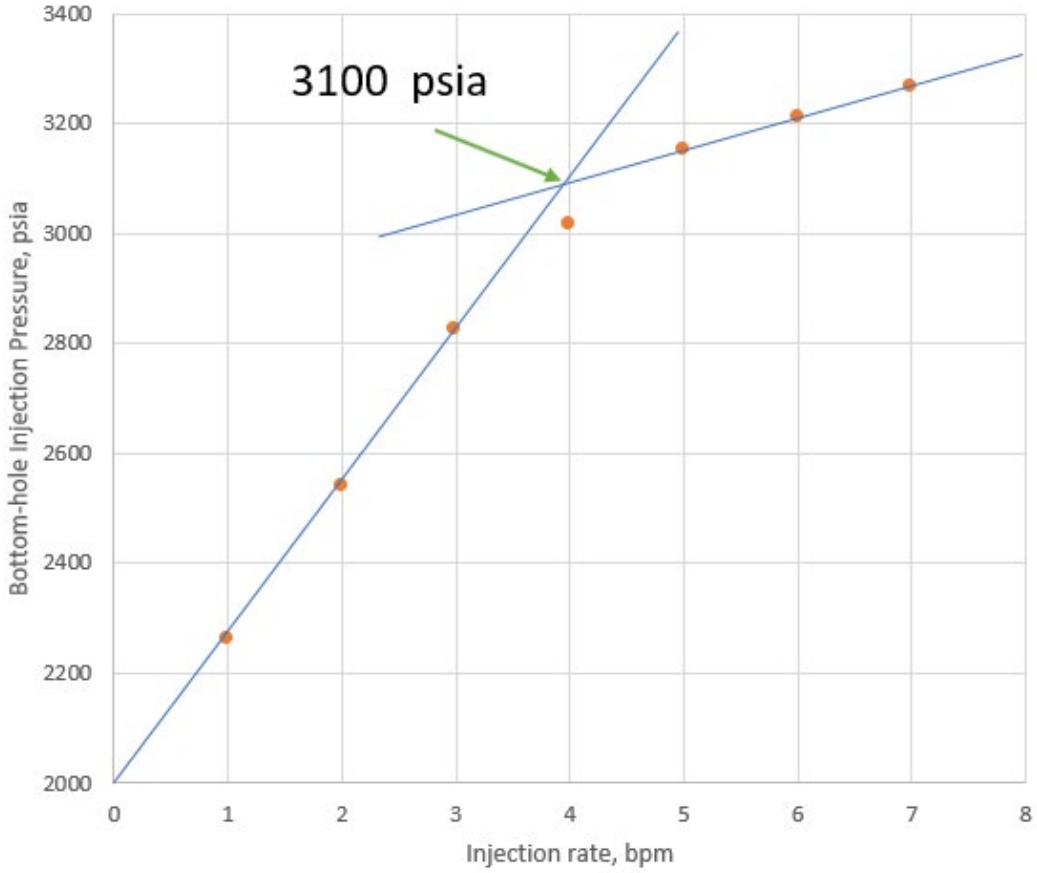
# Outline

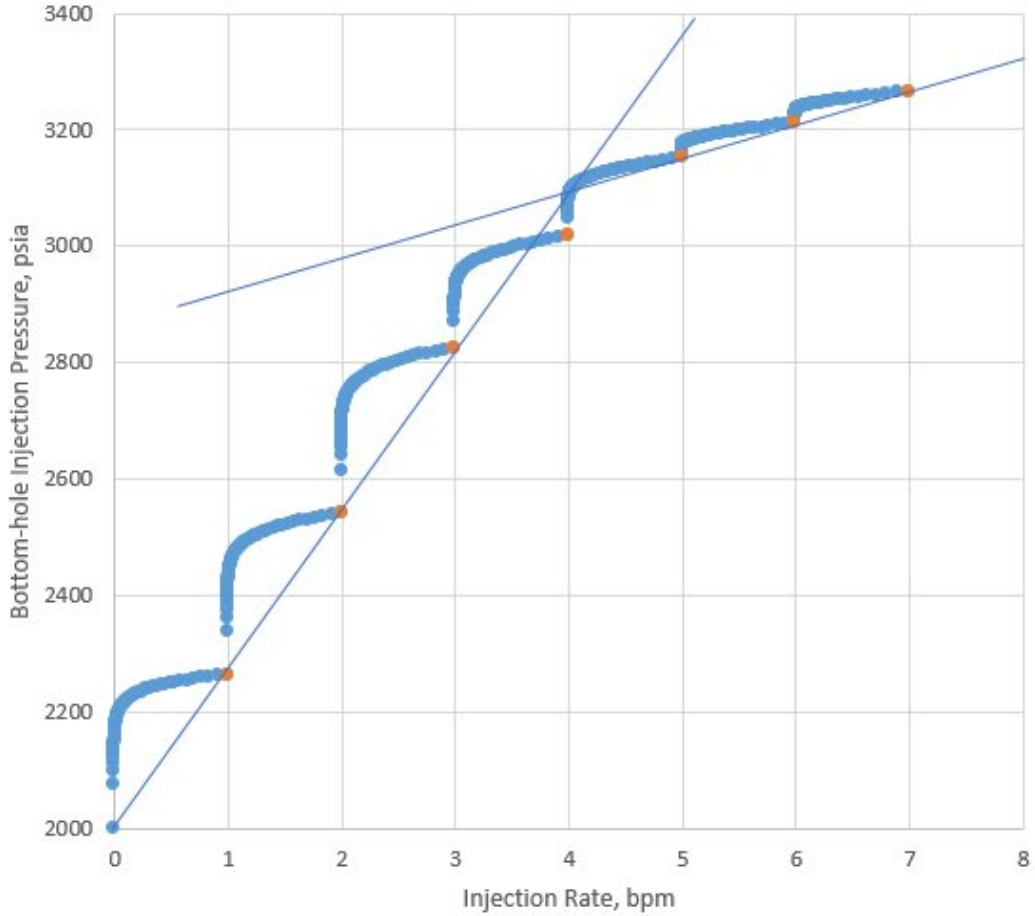
- Ideal Step Rate Test
- “Actual” Step Rate Test
- Examples
  - Initially, tubing not filled with injection fluid
  - Perfs closed through early part of test
  - Inadequate pumping equipment (maximum pressure or rate)
  - Initial fluid level well below (>100 ft) surface
  - Perfs closed but open during early part of test
  - First rate too large
  - Extended duration (with rate changes)
- Summary

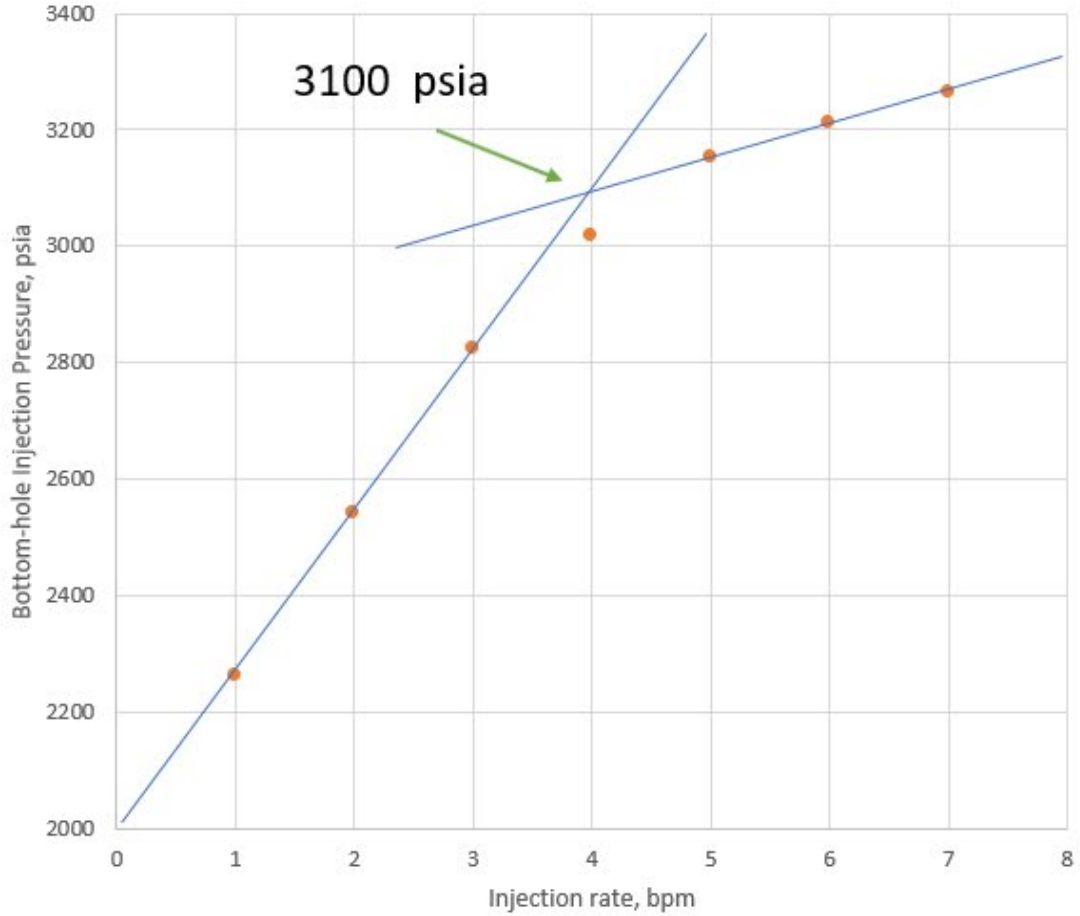
# Ideal Step Rate Test

- Start at static formation pressure
- Equal incremental rate changes
- Equal duration (time) of each rate
- Two Lines
  - Initial slope (earliest) greater
  - Final (2nd) slope much lesser
- Intersection of two lines is the Fracture propagation pressure
- Zero rate and initial pressure fall on first line



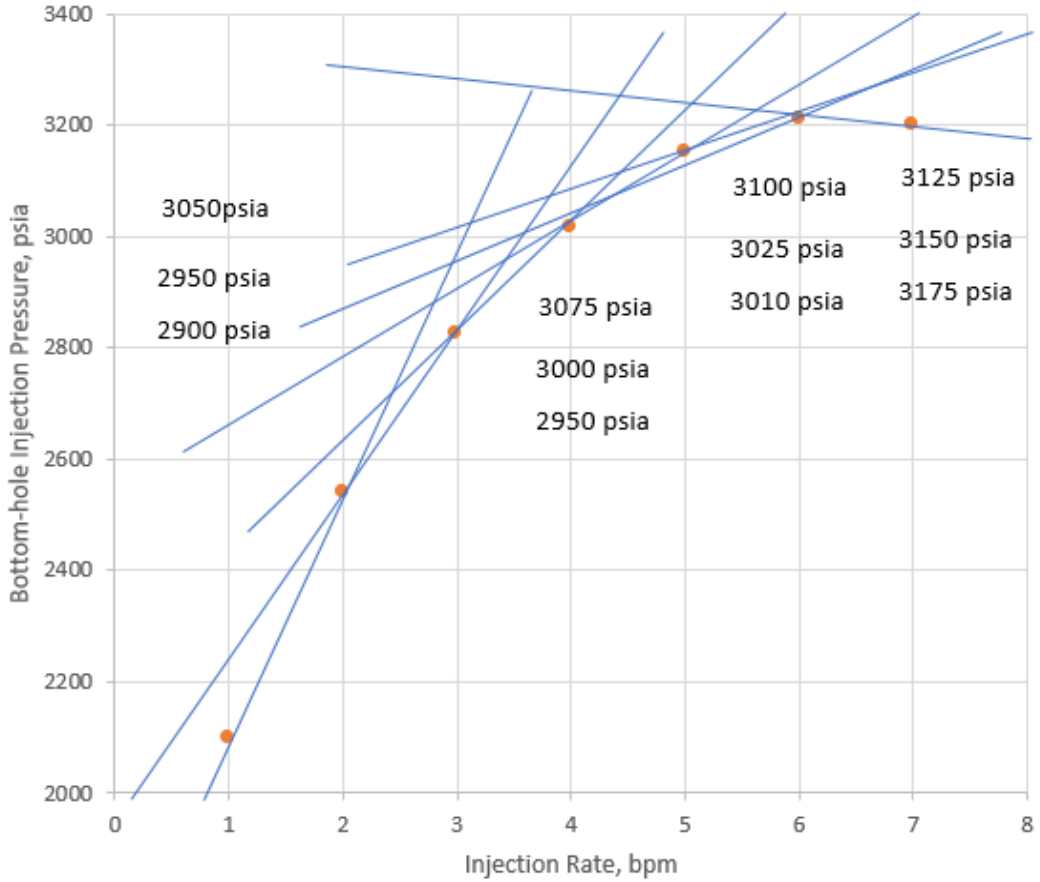
# Ideal Step Rate Test-Data “Behind” the Plot



# “Actual” Step Rate Test

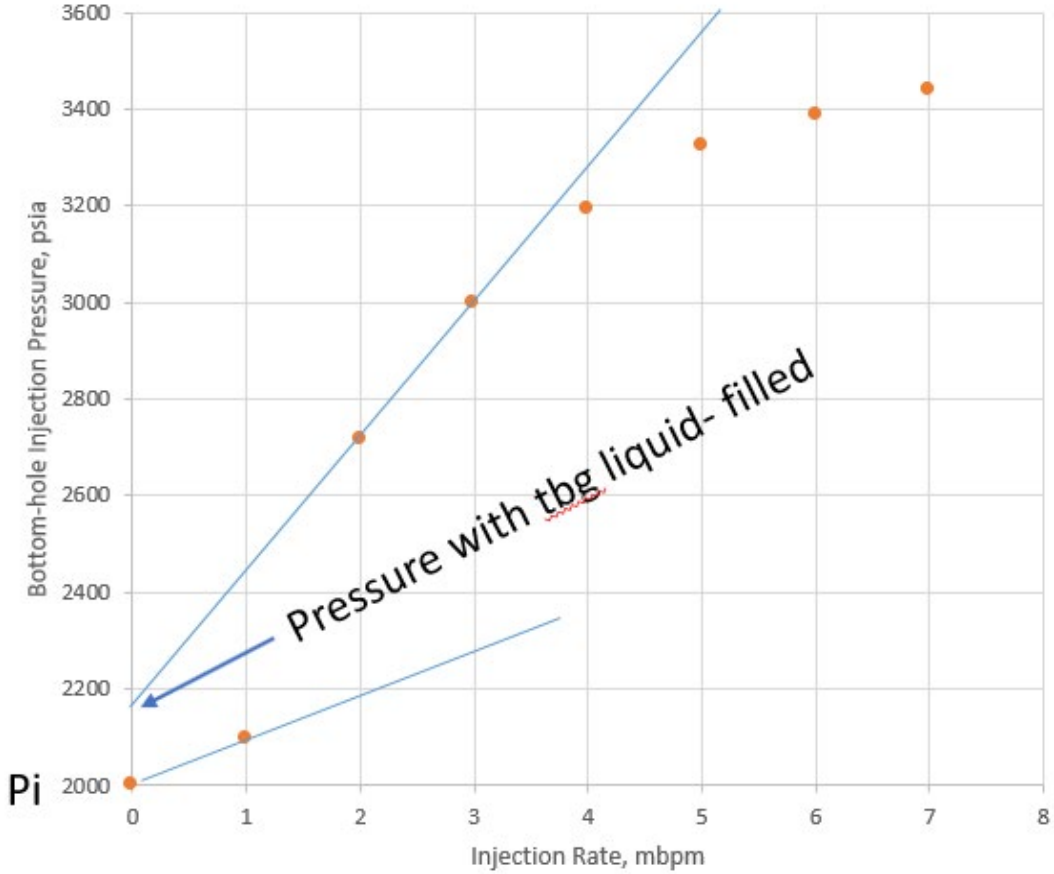
- Starts ~~at static formation pressure~~
- ~~Equal~~ incremental rate changes
- ~~Equal~~ duration (time) of each rate
- Two ~~Lines~~ *linear trends of points*
  - Initial slope (earliest) ~~greater~~
  - *2nd, 3rd, …slope…*
  - Final (2nd) slope ~~much lesser~~ *is where*
- Intersection of two ~~lines~~ *trends* ~~is the Fracture propagation pressure~~…*intersect*
- Zero rate and initial pressure fall ~~on first line~~ *somewhere*



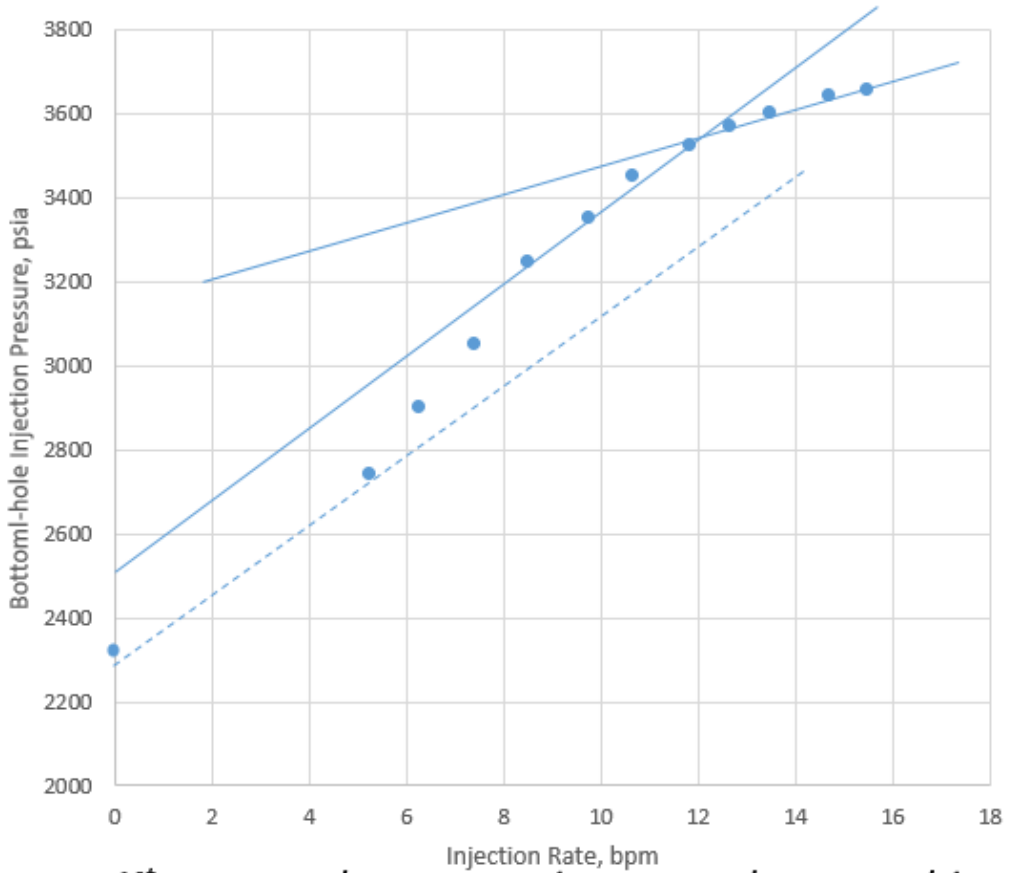

*Courtesy of the person who recognized two points make a line*

# Example (Simulated): Tubing Not Filled Prior to Test

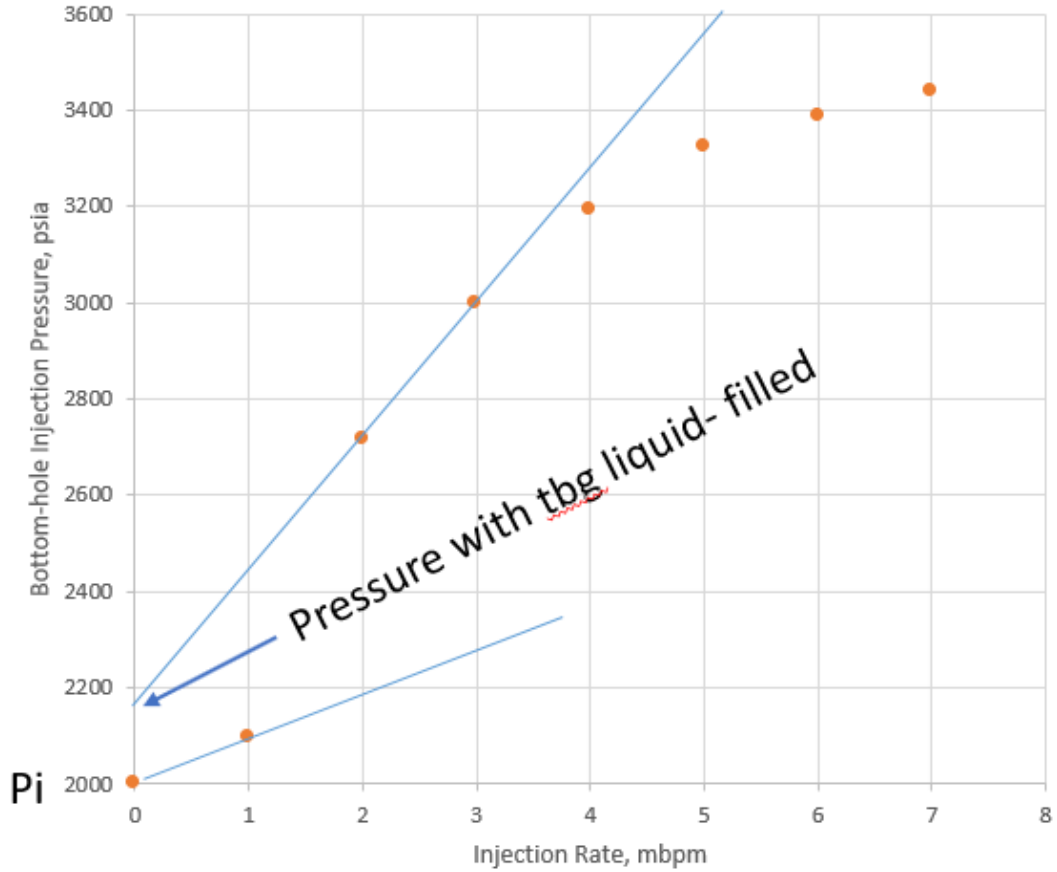
- Initial pressure (pi) and injection rate (q=0) a valid point only on the SRT
  - If injection tubing is liquid filled to surface
- Early trend's y-intercept (q=0)>$p_i$
- Often close to pressure of injection tubing filled with injection fluid.



# Example (Field):
# Tubing Not Filled Prior to Test

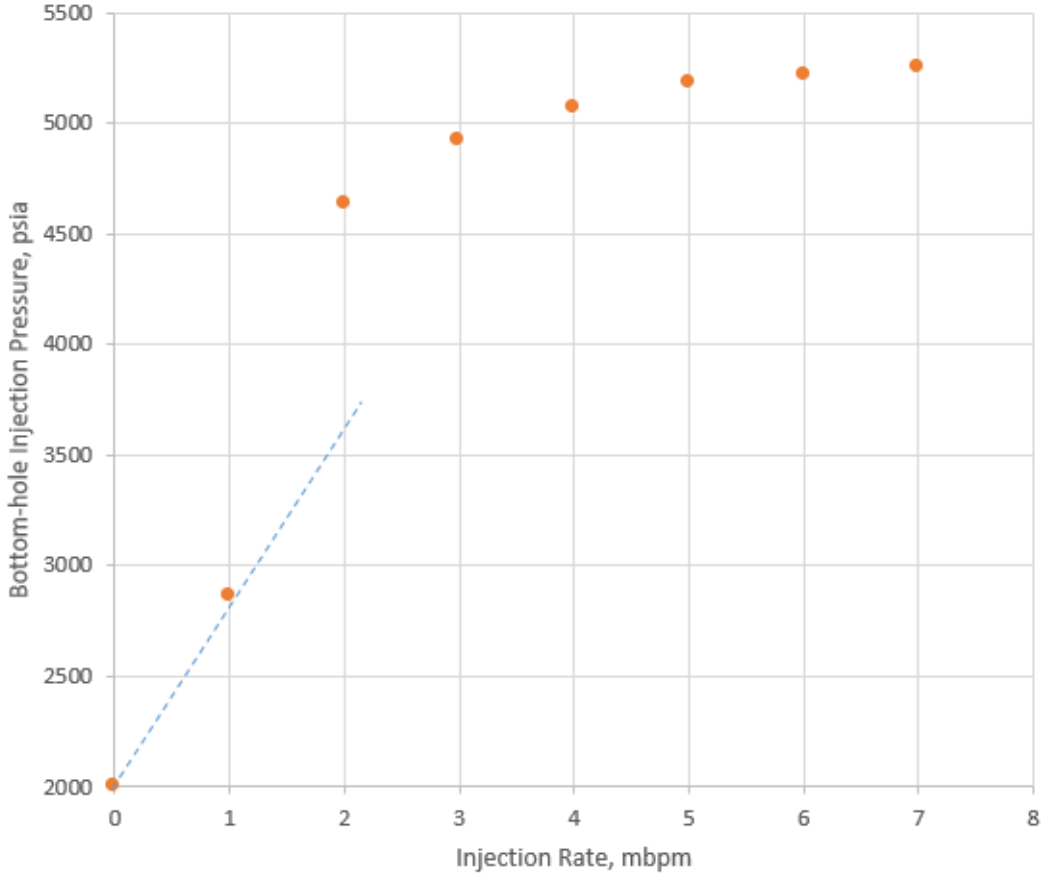



*1st rate and pressure increase due to tubing filling and not formation permeability*

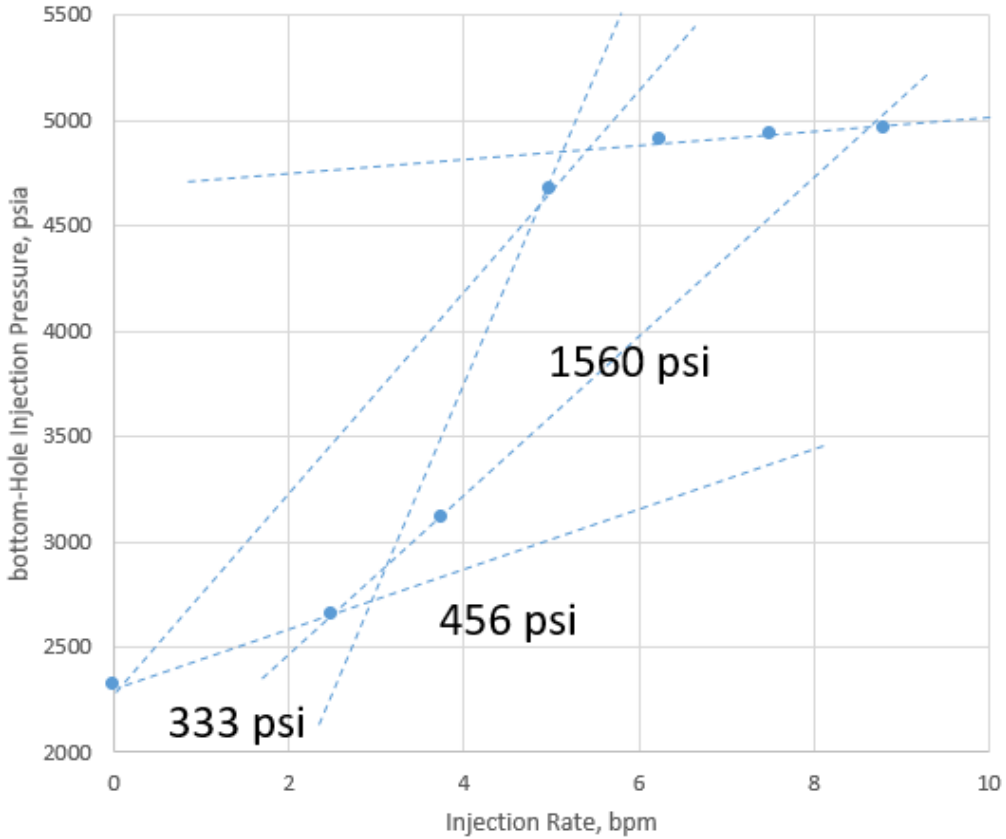


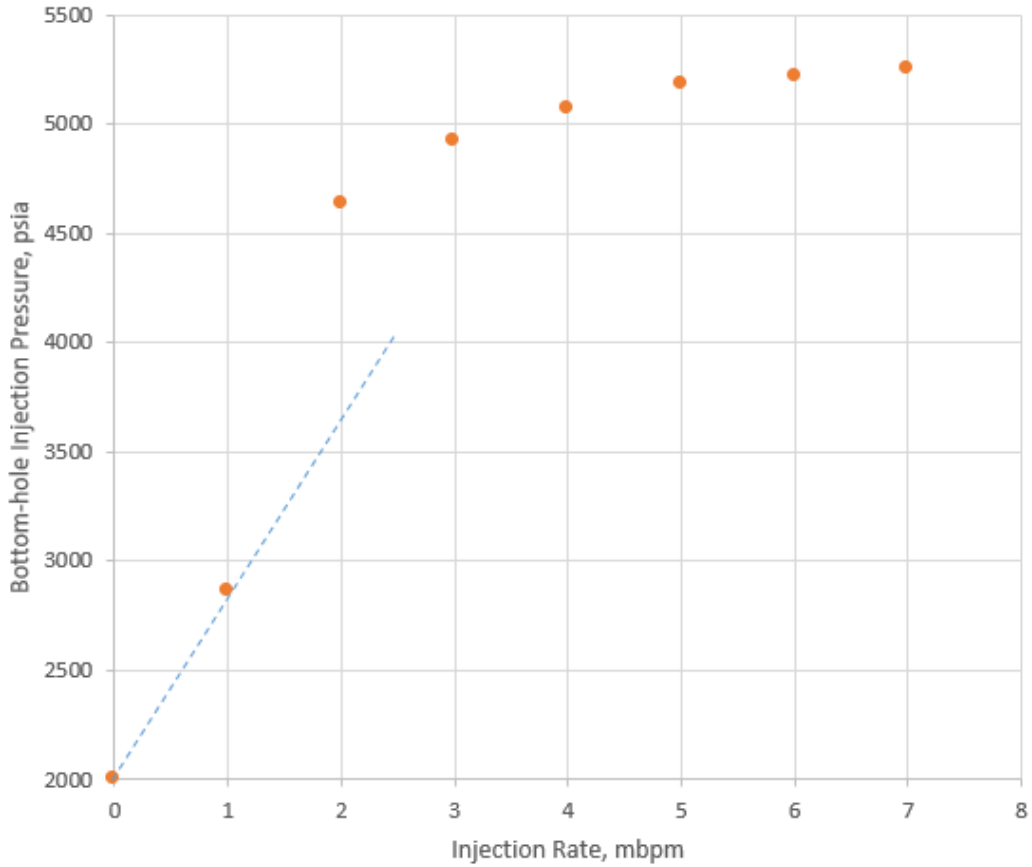
# Example (Simulated): Perfs Closed Prior to First Injection Rate

- Initial pressure ($p_i$) and injection rate (q=0) a valid point only on the SRT
  - If all perforations are open to injection fluid prior to the test.
- Very steep, rapid pressure increase on first rate (if liquid- filled) or 2nd rate (if not liquid-filled)
- 2nd to 3rd rate likely above projected fracture pressure and near pump limits



# Example (Field):
# Perfs Closed Prior to First Injection Rate

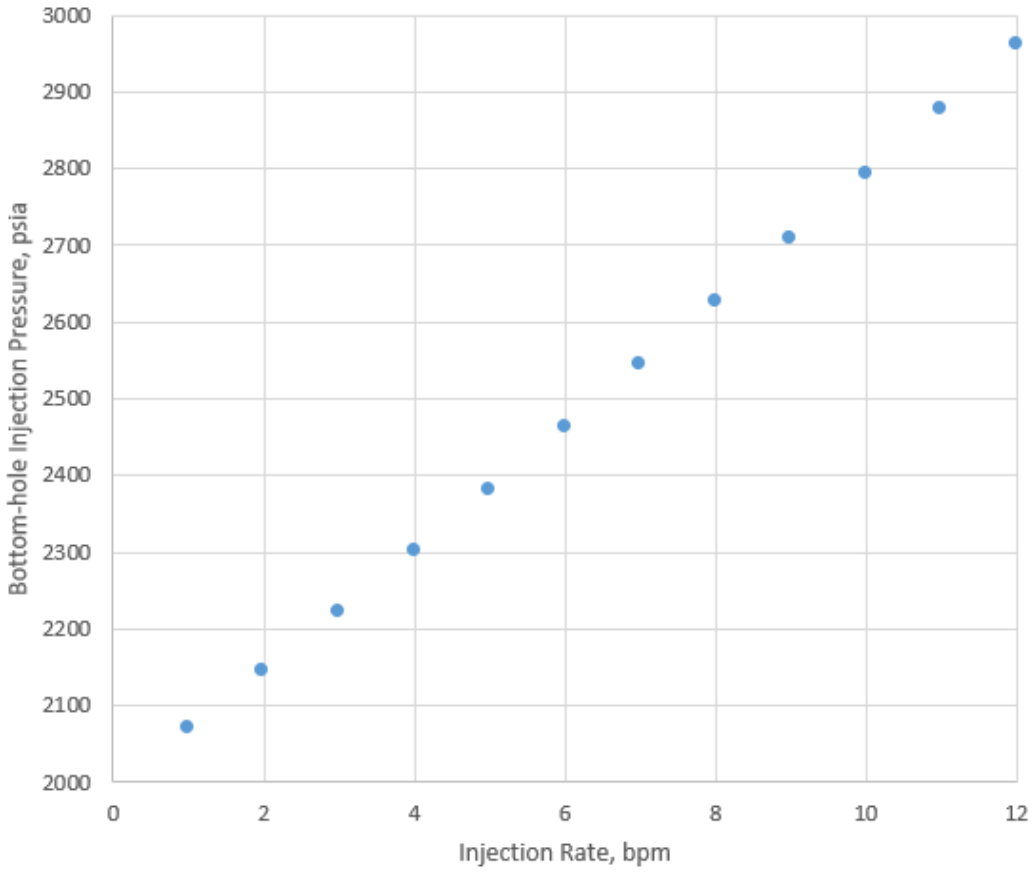



*Initial disproportionate and increasing pressure with incremental rate changes. (100s psi up 1500 psi)*

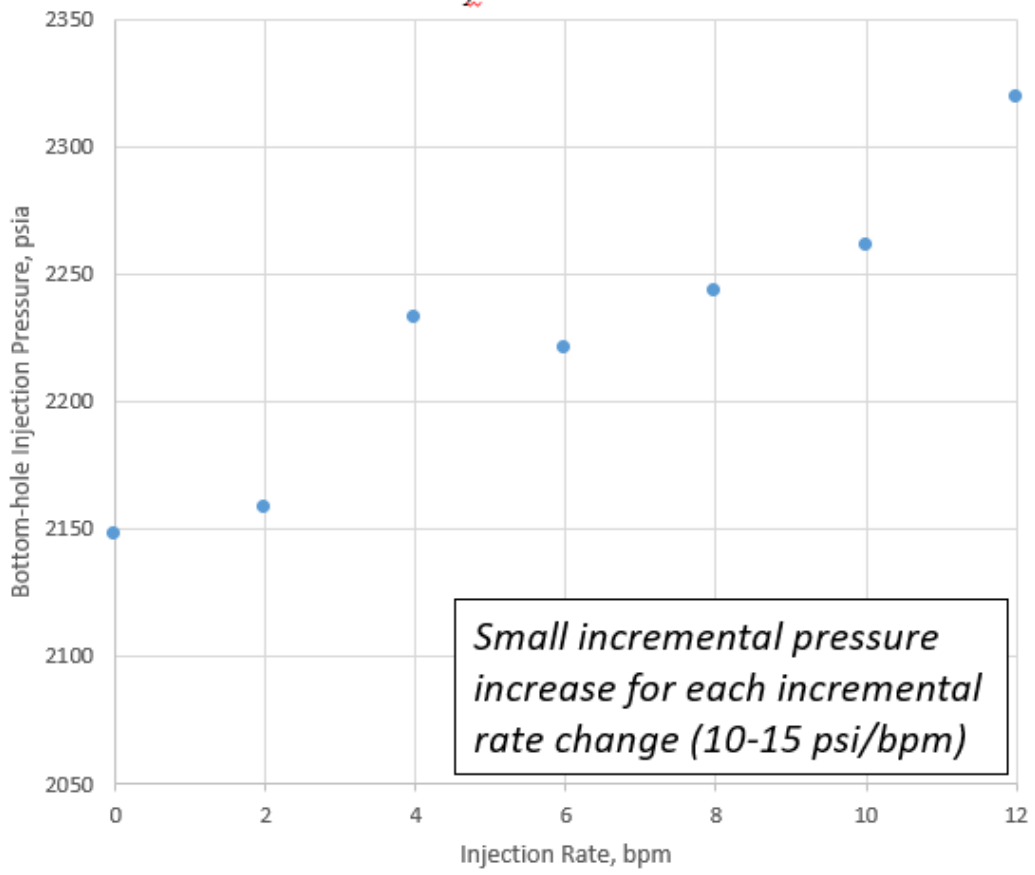
# Example (Simulated): Inadequate Pumping Equipment (Pressure/Rate)

- Pumps unable to achieve rates high enough to increase pressure to the fracture pressure
- Causes: anything that causes *less* resistance to flow
  - Large perforated interval
  - Stimulated well
  - High permeability
- Smaller pressure increases, straight line with no breakover



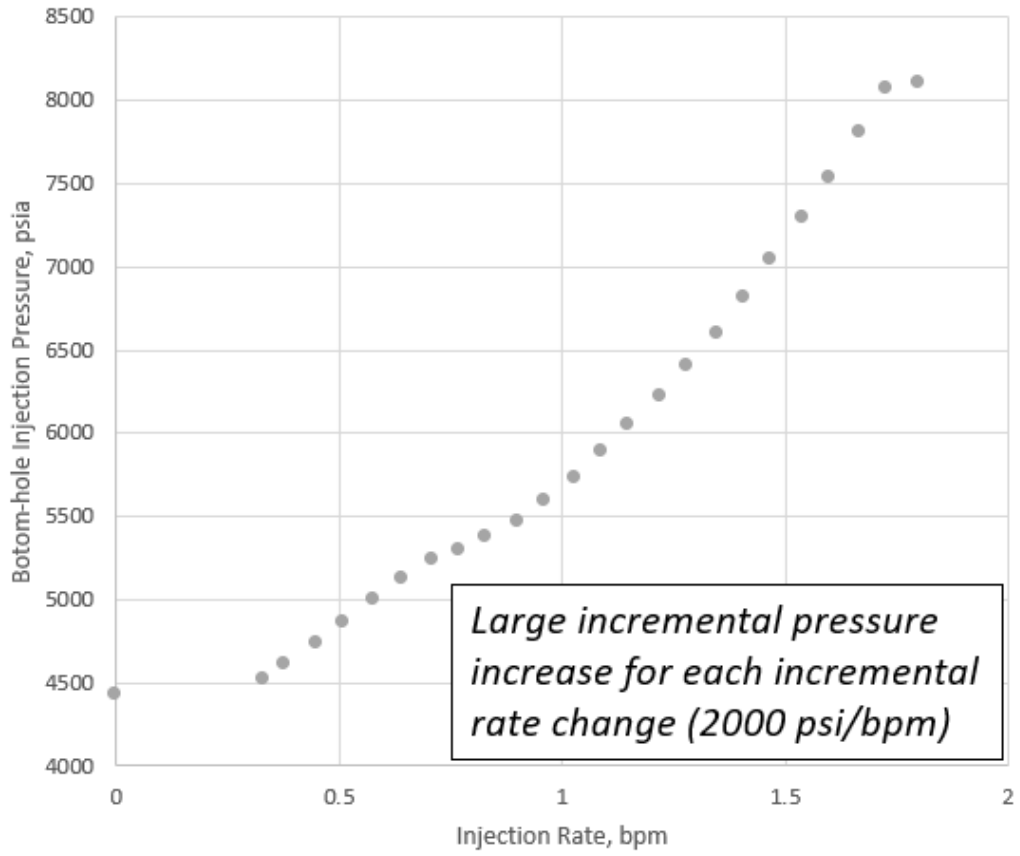
# Example (Field):
# Inadequate Injection Equipment (Pressure/Rate)

*Projected $P_f$ = 2500 -2900 psia*




*High perm (>100 md), reach max rate of pump*

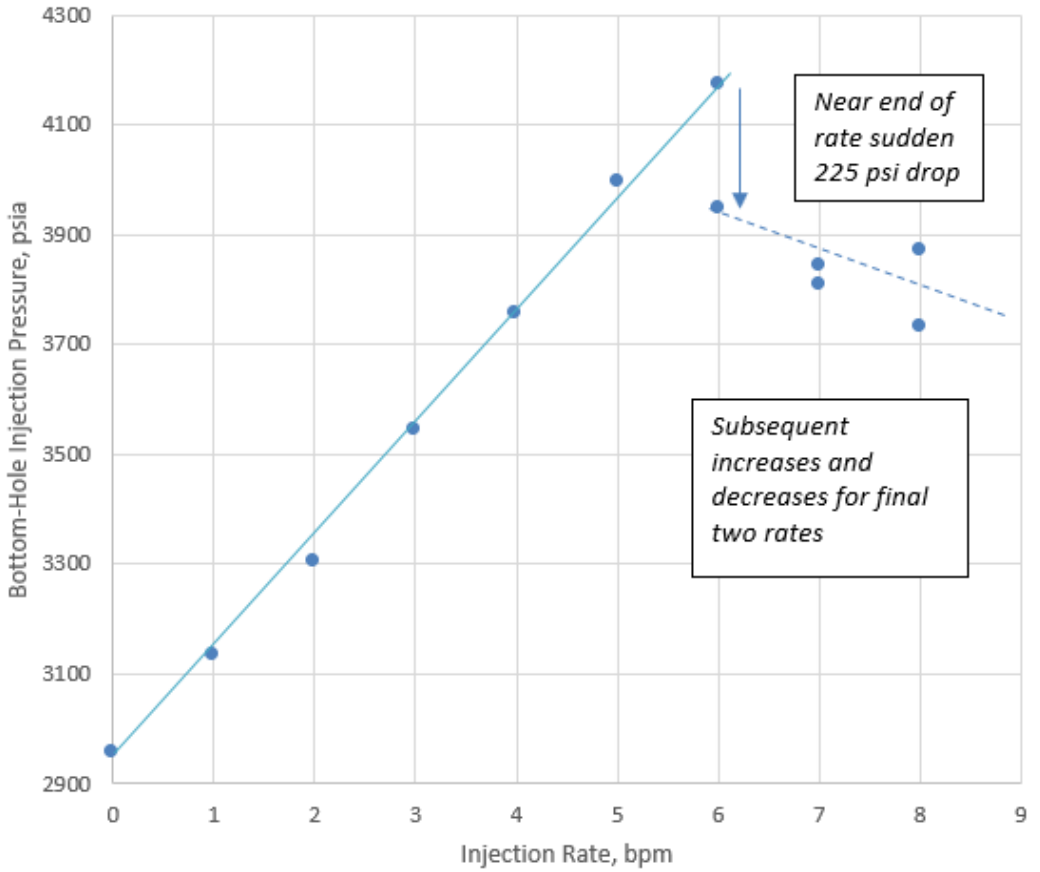
*Projected $P_f$ = 6500 -7600 psia*




*Low perm (<1 md), reach max pressure of lubricator.*

# Example (Field):
# Perf Interval w/ Plugged Perfs Opening During Test

*Projected $P_f$ = 4600 -5500 psia*

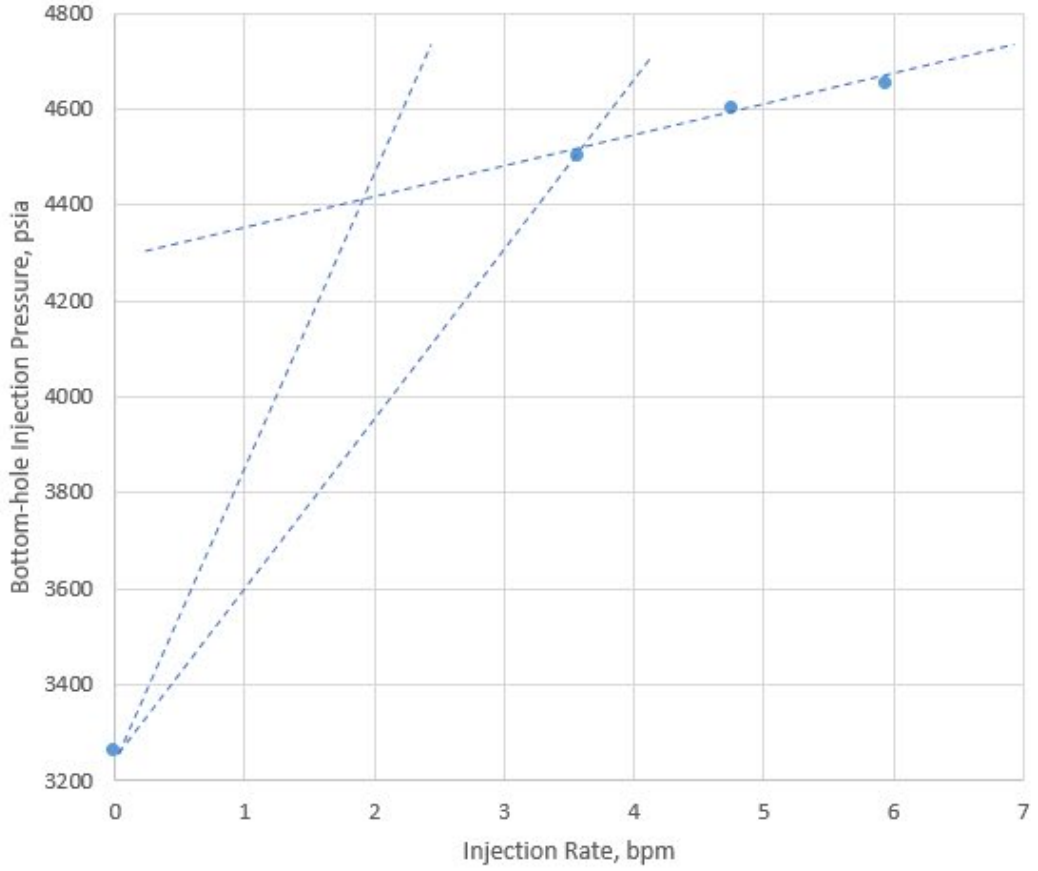



*Large perforated interval (>150 ft)*

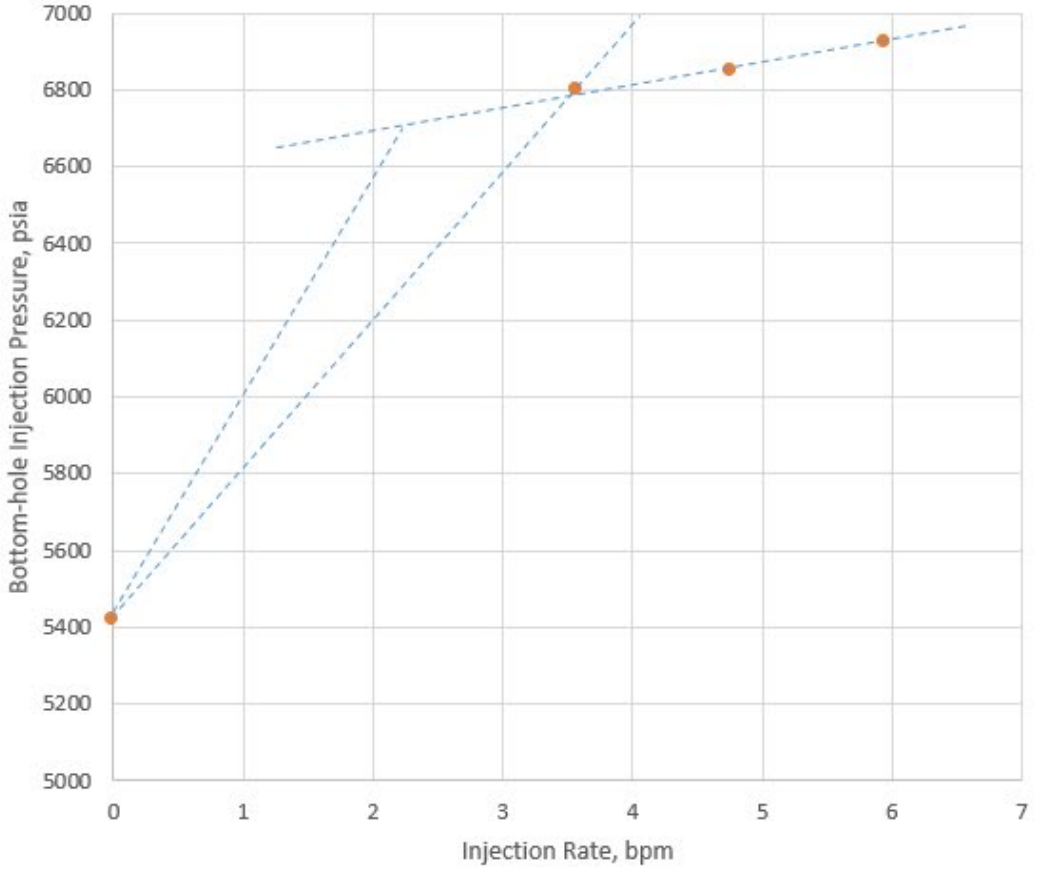
- Perfs opening during a step is more likely to occur pre-fracture because
  - fracture growth likely to take less incremental pressure compared to that to open a perforation AND
  - Vertical fracture growth behind the closed perfs and have less $\Delta p$ across the closed perfs

*Spinner test during SRT showed perfs opening from initial 10-20 ft up to 30 ft during last rate. Analyses of subsequent falloff test, small interval open (<30 ft) with high kh to support 8 bpm without fracturing formation.*

# Example (Field):
# 1st Rate Too High (and unequal increment)

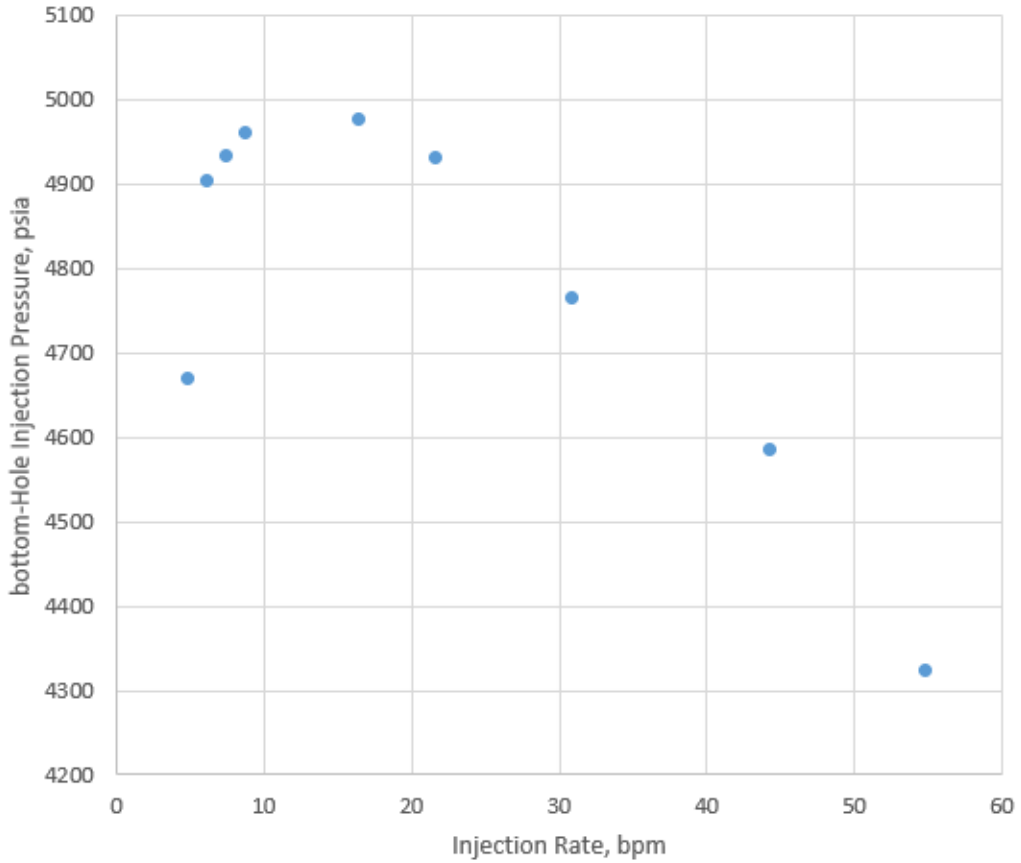



Test rate started high and unequal increment; fracture pressure expected at 5300 psia



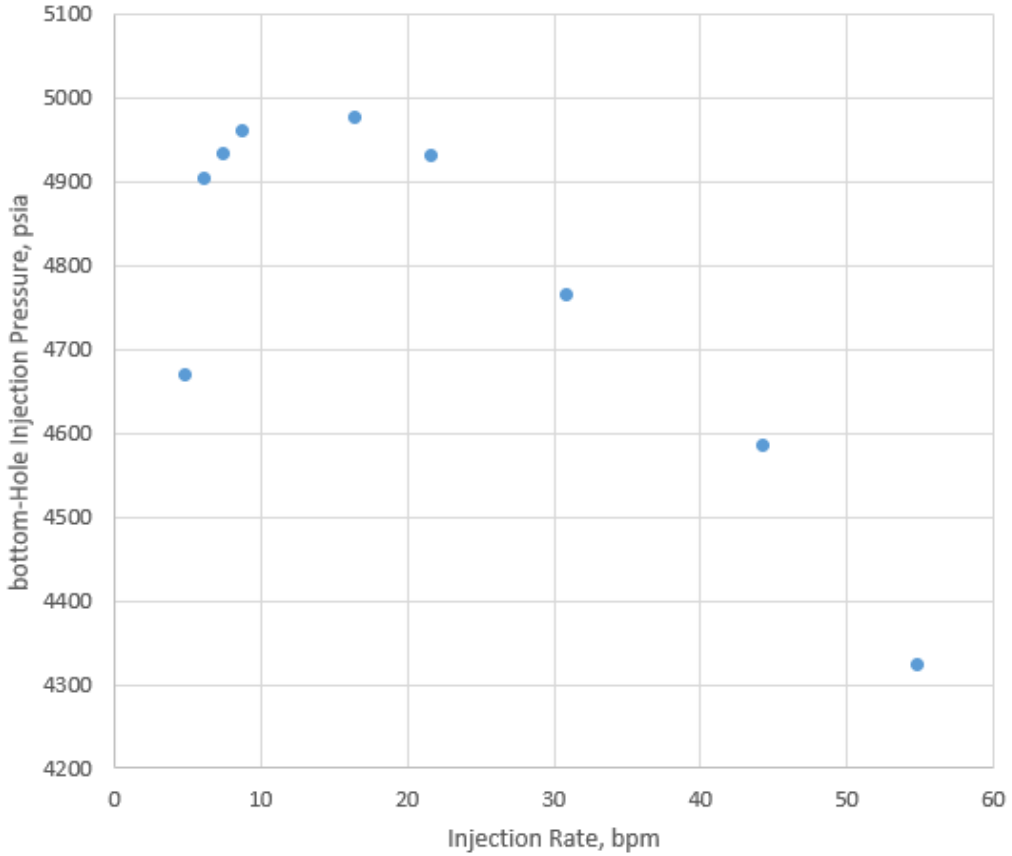

Test rate started high and unequal increment; fracture pressure expected at 8800 psia

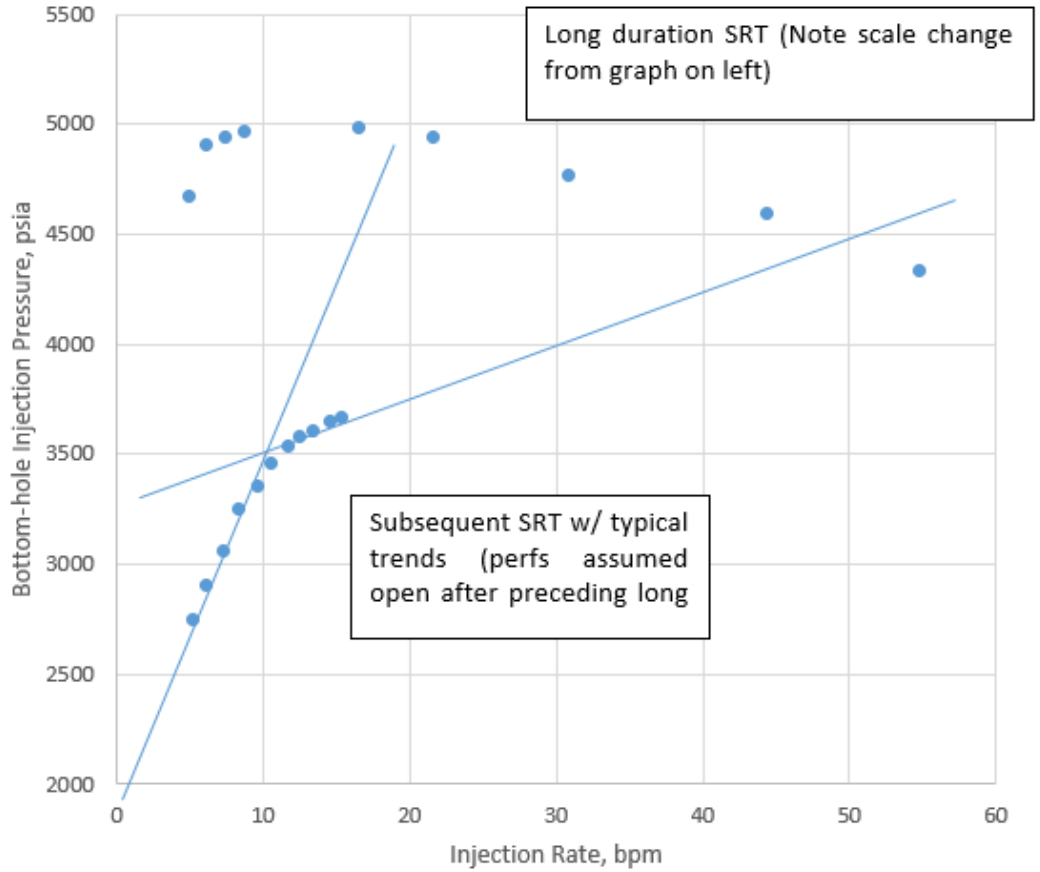
# Example: Long SRT duration




- Test started at initial pressure
- Rapid pressure increase, disproportionally increasing with respect to rate changes
- Reached close to wellhead max pressure, noticeable decreasing trend that continued on each subsequent rate increase
- Attributed to continued fracture growth (vertically and/or horizontal into unpressured formation

# Example: Long SRT duration, Subsequent SRT




Long duration SRT (previous slide)

# Summary

- Overestimates of fracture pressure
  - Initially “closed” perfs (not “cleaned” i.e. swabbed or produced)
  - Extended SRT duration (negative slope)
- Underestimates of fracture pressure
  - Test started with partially filled tubing
  - Inadequate pump rate or pressure
  - Perfs opening during injection
  - Pump/pumping failure

# Acknowledgements


- SRTs were acquired through Illinois State Geological Survey managed projects:
  - CarbonSAFE Illinois-Macon County project via U.S. Department of Energy's National Energy Technology Laboratory (USDOE-NETL) CarbonSAFE Program (DE-FE00 FE00029381). Field Support was provided by Nick Malkewicz (Projeo) and Bill Armstrong (Geostock), and
  - Midwest Geological Sequestration Consortium which is funded by the USDOE-NETL via the Regional Carbon Sequestration Partnership Program (DE-FC26-05NT42588) and by a cost share agreement with the Illinois Department of Commerce and Economic Opportunity, Office of Coal Development through the Illinois Clean Coal Institute.

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