Small Scale CO_2-EOR in the Mississippian at Wellington Field, Sumner County, Kansas

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Outline

- Reservoir Characterization in the Mississippian

  -Capillary pressure curves

  -Relative permeability curves

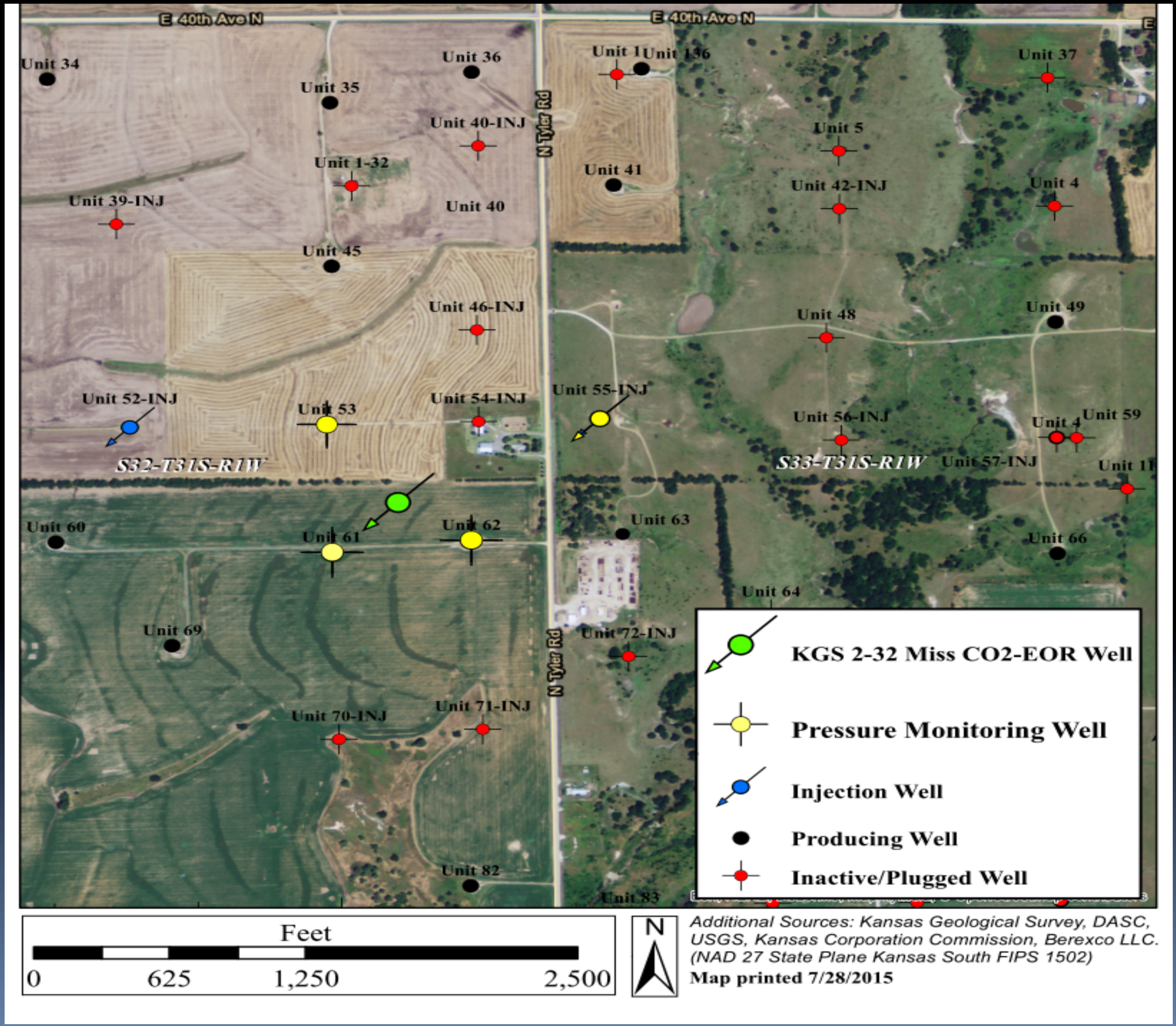
- Step-rate test in Well 2-32

  -Pressure response was measured in 2-32

- Interference test in Wells 55, 53, 62 and 61

  -Injected with different rates in the 2-32 but pressure responses were measurements in the above mentioned wells

Location of Step-Rate and Interference Test



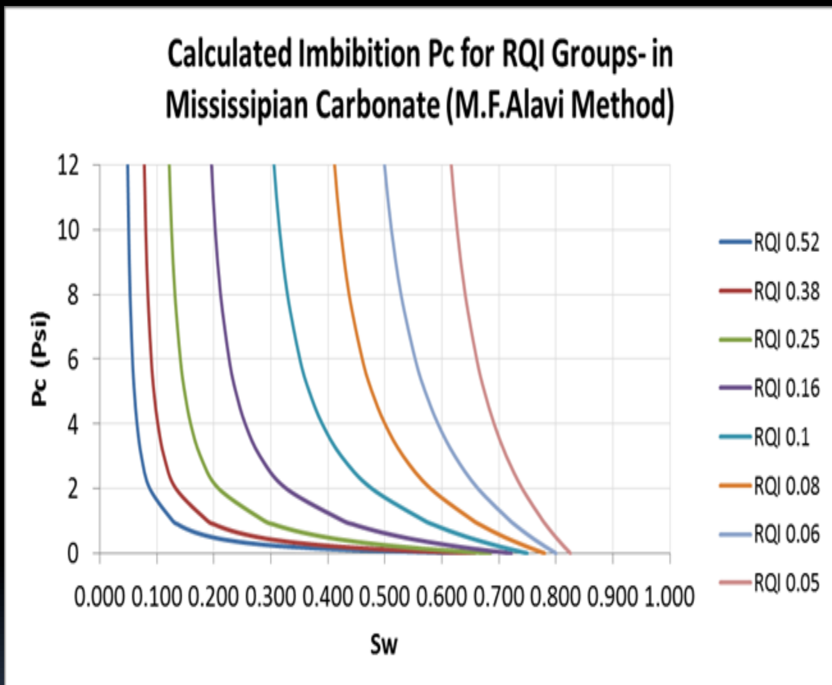
Application of Capillary Pressure and Relative Permeability Curves

- Capillary pressure curves are important:

  -To calculate initial saturations (IOIP and Swi) of a reservoir prior to the production

  -Waterflood performance is affected by imbibition Pc
- Imbibition Pc curves were considered for the Mississippian
- Performance of flow in the reservoir and waterflood is characterized by relative permeability curves

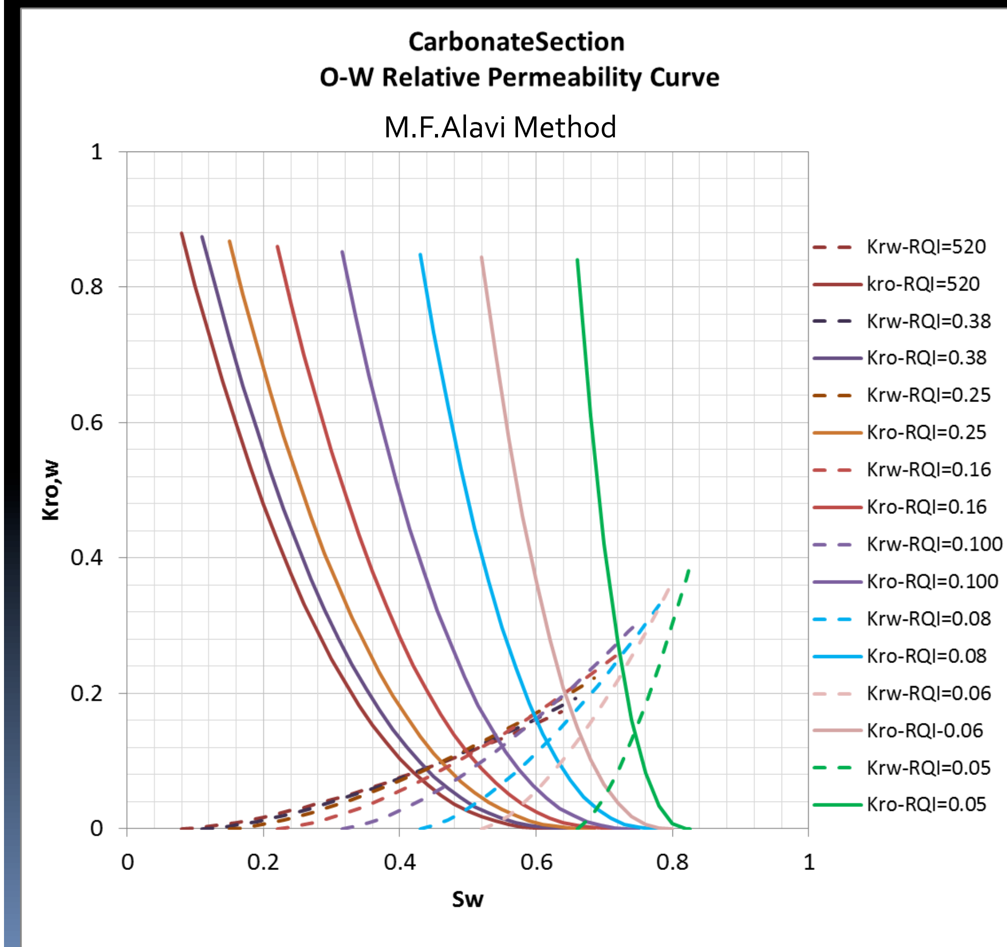
Calculated Capillary Pressure Curves for each Reservoir Quality Index(RQI) Range (Oil-Brine)



- 8 Pc curves were calculated for 8 RQI ranges
- In this technique, endpoints of Pc curves are related to RQI
- It was shown that endpoints of Pc curves (Sor and Swir) have stronger relations with RQI than K, ϕ or FZI

RT	From	To	Avg RQI
1	0.450	0.590	0.520
2	0.315	0.450	0.380
3	0.205	0.315	0.250
4	0.130	0.205	0.160
5	0.090	0.130	0.100
6	0.070	0.090	0.080
7	0.055	0.070	0.060
8	0.045	0.055	0.050

Imbibition Relative Permeability for Each RQI Range (Oil-Brine)



- 8 relative permeability curves for brine and oil were calculated for each RQI range
- Endpoints of relative permeability curves are related to RQI
- These endpoints have a stronger relationship with RQI than K , ϕ or FZI (Flow Zone Indicator)
- Corey exponents used for oil and water are 2.5 and 1.5

Step-Rate Test & Interference Test Analysis

Step-rate test consists of a series of steps:

- Injections and fall offs
- Each injection step has a different rate and pressure

Application of step-rate test:

- Obtaining permeability (K) and skin (s)
- Reservoir pressure
- Fracture pressure and closure pressure (Minimum Stress)
- Detection of any induced or natural fracture

Interference test:

- Determination of interwell permeability and detection of any fault, fracture and discontinuity

Inferred from the Step-Rate Test

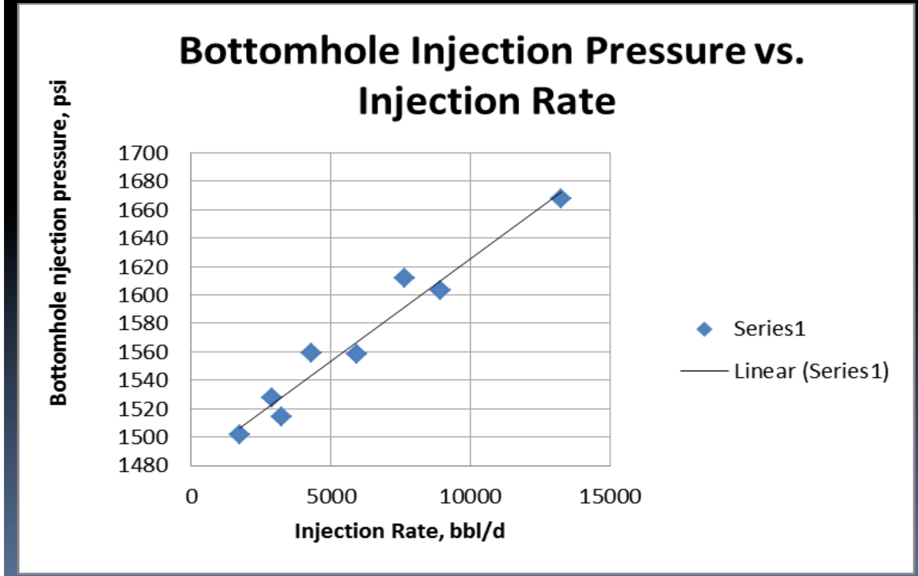
- Fracture did not occur during the test (left fig.)
- There was an existing fracture (2 reasons)

1) Most certainly, the fracture was induced during the acid treatment

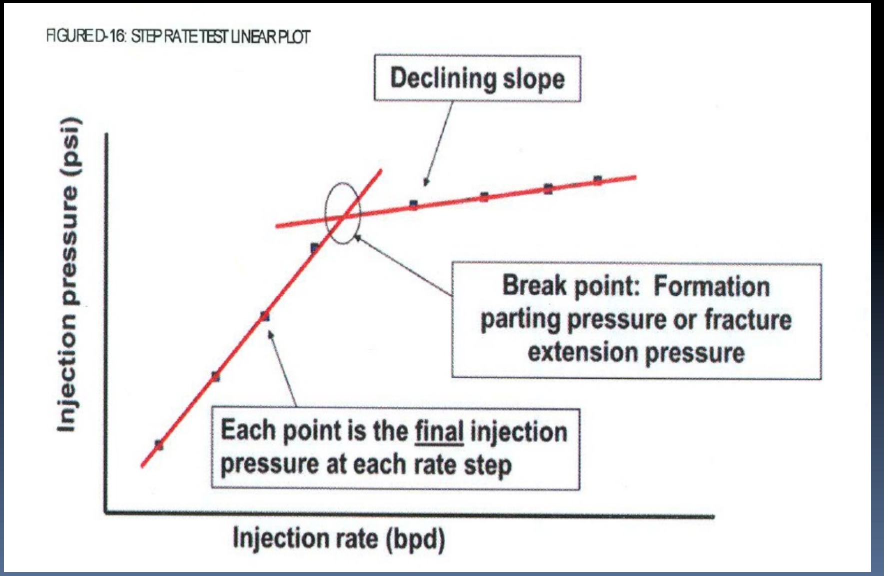
-Well head pressure 1300 psi

-Bottom hole pressure 3035 psi, which exceeded fracture pressure (~ 2214 psi)

2) Next slide- Test data could be simulated only with fracture model

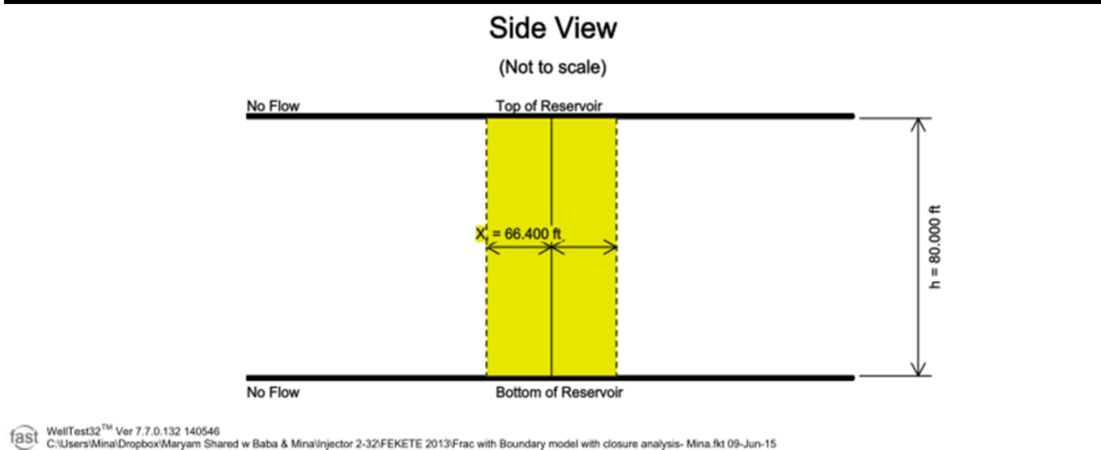


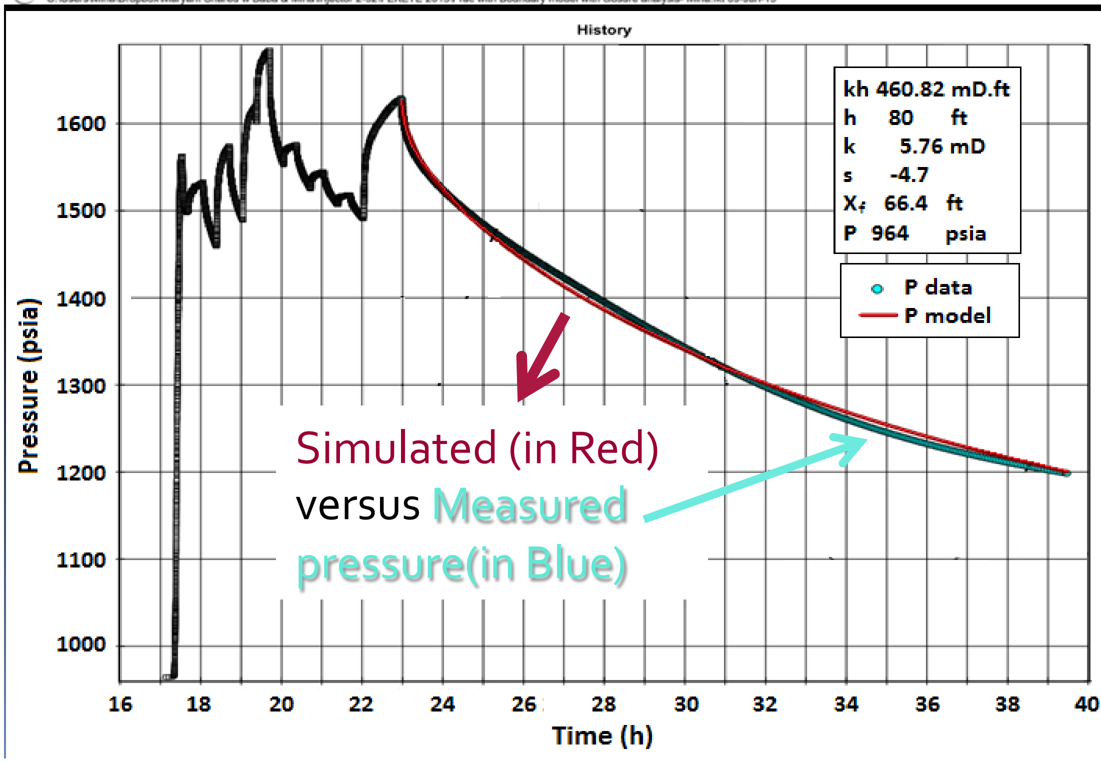
Step-Rate Bottom hole Inj P vs. Inj Rate



EPA test design

Step-Rate Test Analysis





- Model used: Fracture analysis with open boundary
- All fall offs could not be matched with a single model because each fall off has a different length of fracture and skin
- The last fall off was analyzed first to determine K and fracture half length
- Estimated K was used in other fall-offs to get fracture half-length and skin
- Simulated pressure matches well with the observed pressure

Step-Rate Test Results

Result from all Fall offs in Well 2-32						
Permeability, Fracture Half Length and skin						**Summary of Results**
Step No	**Cum Inj, BBL**	**Pwf, Psia**	**K**	**Frac Xf, Ft**	**Sxf**	permeability to water5.8 md.
fall-off 9	50.6	1626	5.8	66.4	-4.7	Absolute permeability 17.8 md
fall-off 8	131	1517	5.8	22.7	-3.6	Frac closure press 1410 psia
fall-off 7	442	1544	5.8	29.5	-3.89	Frac closure press is reduced by cooling
fall-off 6	505	1575	5.8	35.8	-4.08	Press in all steps above closure press
fall-off 5	547	1681	5.8	71	-4.77	Fracture skin is negative
fall-off 3	573	1571	5.8	32	-3.98	Max frac half length 71 ft
fall-off 2	891	1529	5.8	0.7	-0.154	Reservoir press at 2-32 before test 964 psia
						Depth of pressure 3710 ft from 12' KB

- Calculated permeability from step-rate test is effective permeability (Kw_{eff}=5.8 mD) to water and not absolute

- Average absolute permeability was calculated using K= Kw_{eff}/Krw

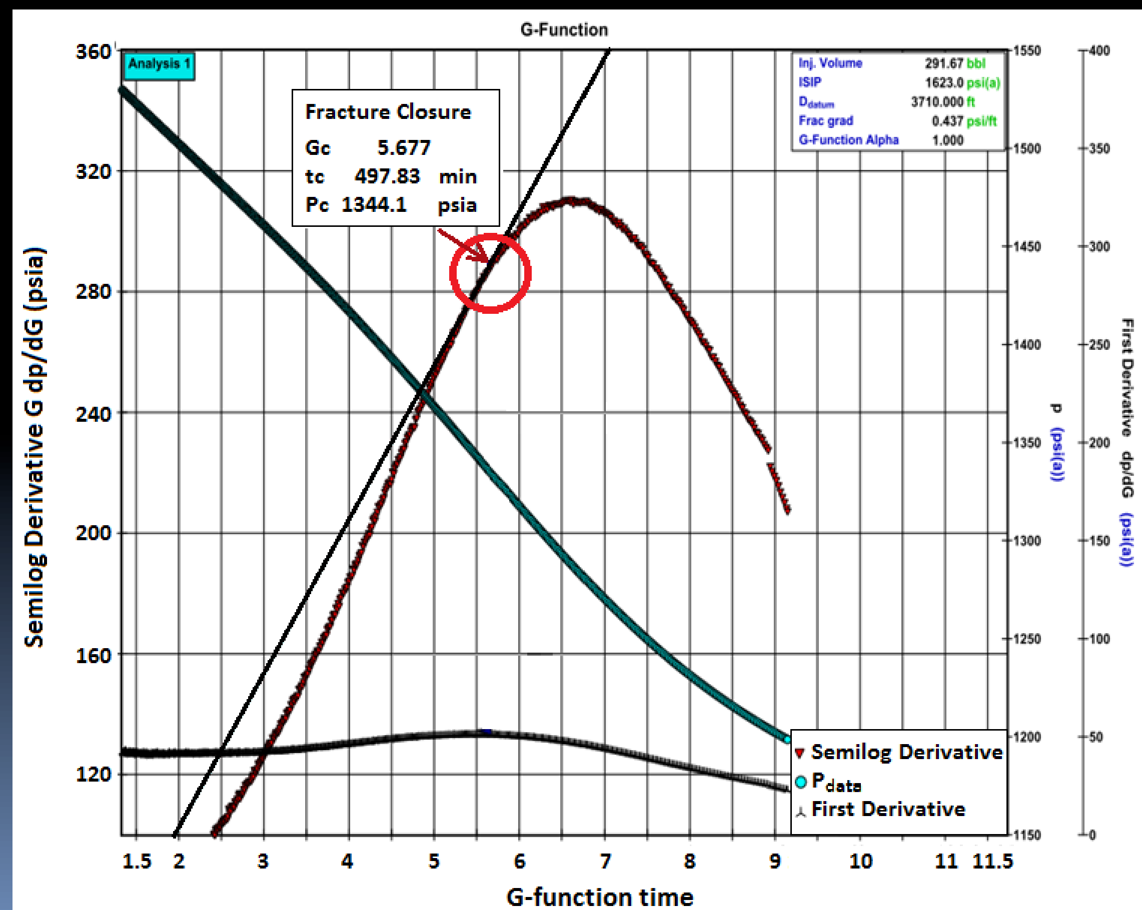
  Where, Kw_{eff}=5.8 mD
  Krw @75% Sw from relative permeability curves is about 0.32
  Therefore, K=17.8 mD (Absolute)

- Fracture was open in all injection steps and was not closed during any fall-off period, except for the last fall-off which was long (16hrs)

- Fracture half length was increased from the wellbore as P_{inj} was increased. Maximum Fracture half length from the wellbore was 71ft during fall-off #5 where rate was 9 BBL/min

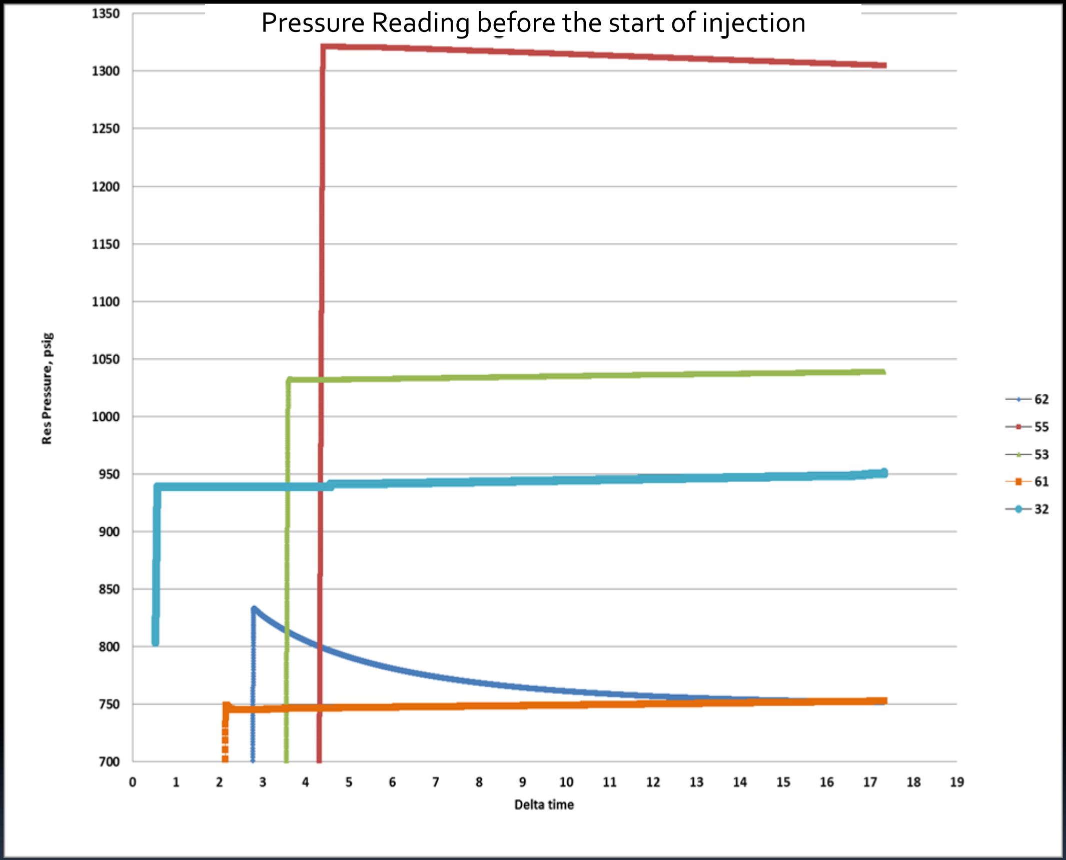
Closure Pressure

- The slope on the G-function derivative defines the closure pressure where the derivative departs from the slope
- Closure pressure is 1334 psi
- Closure pressure gradient is 0.36 psia/ft
- Closure pressure is abnormally low
- Fracture pressure and closure pressure are reduced due to pressure depletion, water injection and cooling

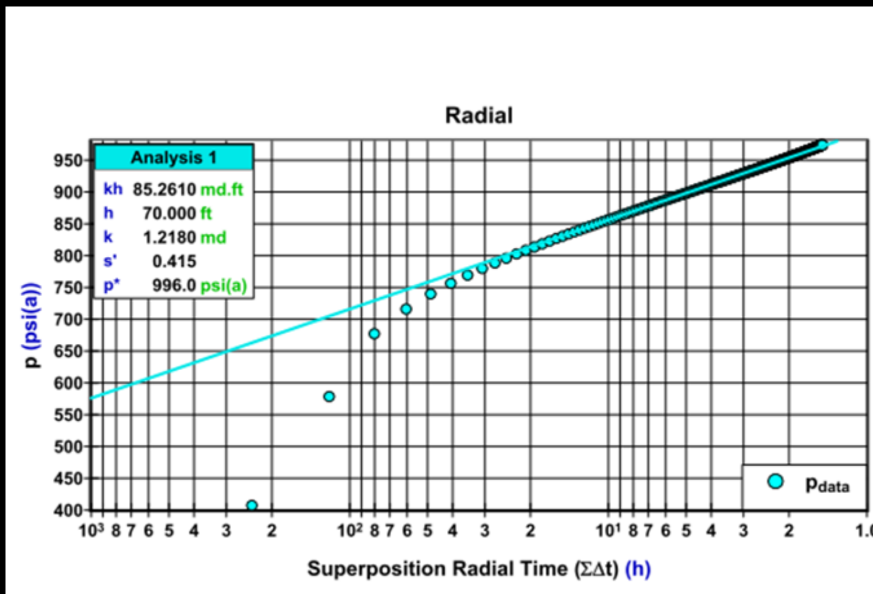


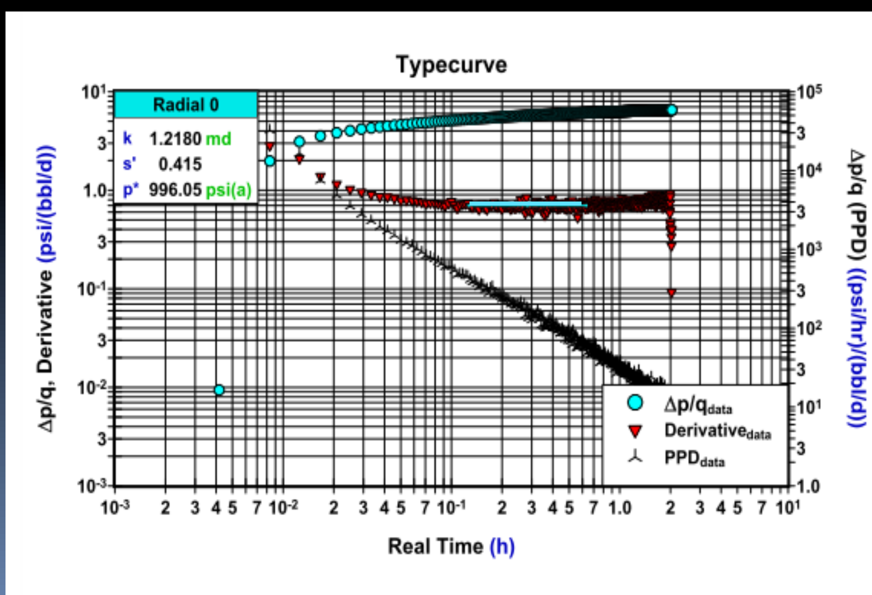
Interference Test

- Pressure gauges were installed in Wells 55, 53, 62 and 61 to record the effect of water injection in Well 2-32
- Pressures were recorded for about 17 hrs before the start of step-rate injection
- BHPs of these wells were changing before the start of step-rate injection test due to surrounding production and injection wells
- Because BHPs of these wells were influenced by injection and production of surrounding wells, interpretation of the interference test will give inferior results



DST Analysis





Parameters and Results

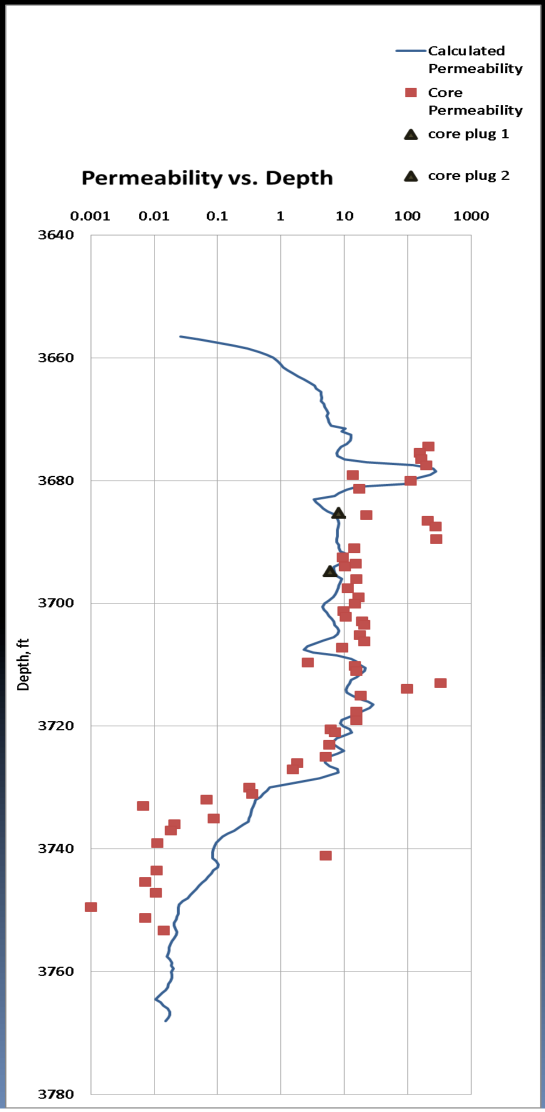
- DST in 2-32 was analyzed with FEKETE well test software
- 70 ft net thickness was used
- Calculated effective permeability to water is 1.2mD
- Skin (s) is 0.4
- Reservoir pressure is 996 psia

Conclusion

- Effective permeability from DST is lower than effective permeability from the step-rate test
- Low permeability might be due to flow rate being inferior
- flow rate of 87 bbl/d used for analysis
- If the flow rate is higher than 87 bbl/d, permeability will be greater

Permeability from Step-Rate & DST Test Compared with Log-Derived Permeability

- Effective permeability from the step-rate test was 5.8 mD, which will be equivalent to 17.8 mD in absolute permeability
- Effective permeability from the DST was 1.2 mD, which results in a lower absolute permeability and inaccurate
- Average log-calculated absolute permeability for the equivalent interval of the step-rate and DST test is 19 mD
- The two absolute permeabilities from the step-rate test and logs are in agreement but permeability from DST is unreliable



Conclusion

- Permeability from the step-rate test is in agreement with the calculated log permeability
- Permeability and skin from DST are inferior; however, pressure is reliable
- There was an induced fracture by the acid treatment, which was extended to 70 ft from the borehole when injection rate was 9 BBL/min
- Fracture half length increased with rate
- Skin decreased with increasing the rate and by extending the fracture from the wellbore during the Step-Rate test
- Reservoir pressure in the monitoring wells are different and changing due to injection and production