Eagle Newsletter

Eagle Reservoir Services Third Quarter 2023

More Details? Send us your e mail, we will send a link. Also, our website is www.eaglereservoir.com

Inside this issue:

State Requirements for Setting an Injection Packer

Background:

An operator is needing to set an Injection Packer in a very old well.

The state requires that the Packer be set at a depth no shallower than 3460'. Attempts were made to set the packer below 3510', but the packer did not hold.

A 40 arm caliper was run to evaluate the casing.

Figure 1 shows the field print indicating good casing until about 3480', marginal until about 3508', and poor below this depth

Figure 2 shows the associated grading. Figure 3, 4 and 5 on next page are snapshots taken from the 3D video of the casing

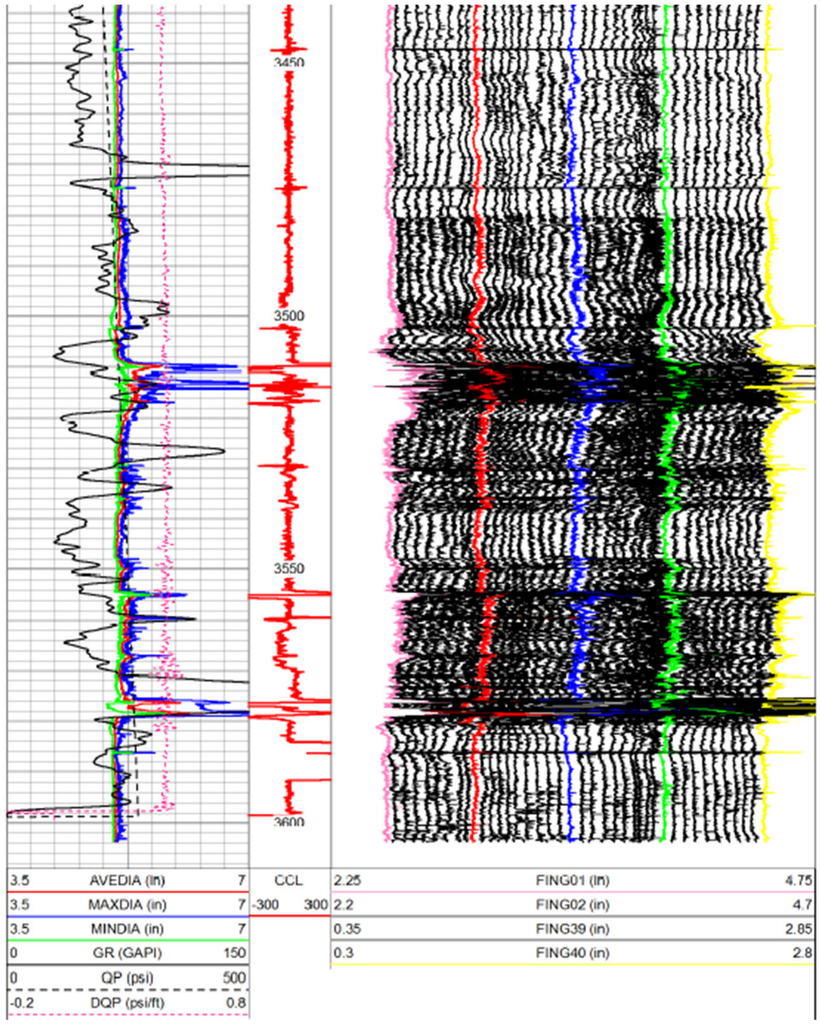


Figure 1

Figure 2

MIT Grade 1[0%-19%] 2[20%-39%] 3[40%-59%] 4[60%-69%] 5[70%-100%] — Penetration / Metal Loss

Joint	Depth ft	Nom ID in	Mode ID in	Modal Change %	Penetration Body in	Penetration Body %	Coupling in	Coupling %	Metal Loss %	Grade	Damage Description	Profile (%) 0 100
1	3340.3	5.000	5.00	0.0	0.11	44.1	0.07	28.3	21.7	3	Moderate Ring Damage; Heavy Corrosion;	
2	3355.7	5.000	5.07	1.4	0.07	27.4	0.03	10.6	2.1	2	Moderate Corrosion; Moderate Pitting;	
3	3383.7	5.000	5.00	0.0	0.11	42.7	0.07	28.1	19.5	3	Moderate Ring Damage; Heavy Corrosion;	
4	3415.7	5.000	5.00	0.0	0.11	42.8	0.06	23.4	24.5	3	Moderate Ring Damage; Heavy Corrosion;	
5	3447.4	5.000	5.00	0.0	0.13	53.9	0.08	33.3	21.4	3	Moderate Ring Damage; Heavy Corrosion;	
6	3474.6	5.000	5.00	0.0	0.25	100	0.15	61.8	28.5	5	Multiple possible holes; Moderate Ring Damage;	
7	3502.5	5.000	5.00	0.0	0.25	100	0.11	42.2	93.8	5	Multiple possible holes; Heavy Ring Damage;	
8	3529.5	5.000	5.00	0.0	0.25	100	0.25	100	52.0	5	Multiple possible holes; Heavy Ring Damage;	
9	3554.8	5.000	5.00	0.0	0.25	100	0.25	100	97.9	5	Multiple possible holes; Heavy Ring Damage;	
10	3586.3	5.000	5.00	0.0	0.20	79.1	0.07	28.5	17.1	5	Moderate Ring Damage; Heavy Corrosion;	

A COMPLETE REPORT GRADES EACH JOINT OF CASING FOR METAL LOSS OR SCALE

Figure 3 at 3461' shows good casing.

The packer was subsequently set and held at 3464'

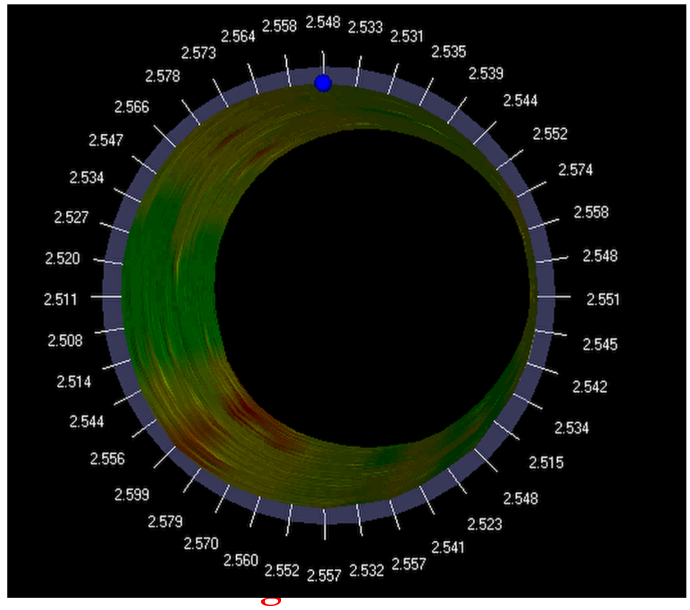


Figure 4 at 3508' shows the start of very bad casing which will not allow a packer to hold.

The packer was subsequently set and held at 3464'

Figure 5 at 3578' shows very damaged casing with holes where a packer will never hold

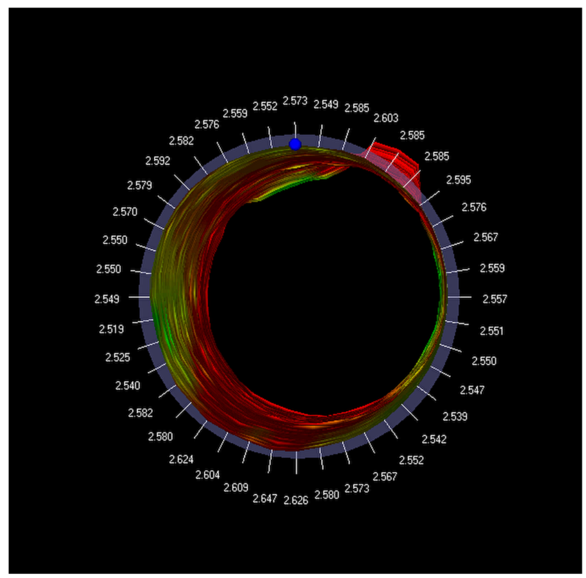
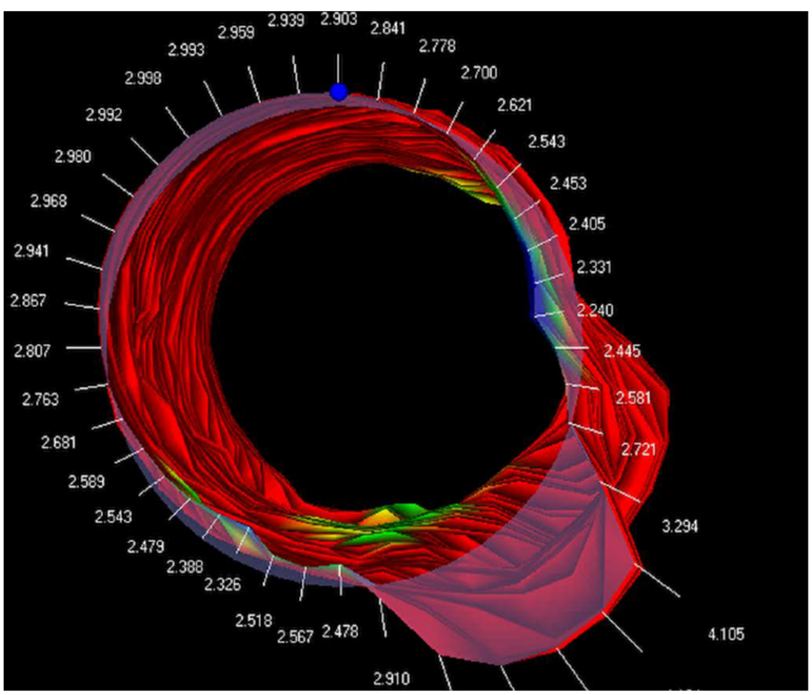


Figure 4



EPA Requirements for Pressure Fall Off and Transient Analysis for a Disposal Well (For a more detailed example of full report, we can send a link to your e mail.

The EPA has specific requirements for injection / disposal wells that must be met annually. These requirements are addressed more specifically (and particularly for the area of the example in this Newsletter) at www.epa.gov/uic/underground-injection-control-epa-region-8-co-mt-nd-sd-ut-and-wy.

Assurances must be made to insure that the investigated injection wellbore is not a conduit for unwanted fluid flow to other injection wellbores or aquifers in an area of review that are protected under the federal UIC program. Eagle Reservoir Services can fulfill these requirements by advising and obtaining necessary data in the field, communicating directly with the EPA on requirements, and assuring the fulfillment of requirements with robust analysis and follow up.

Summarization of EPA requirements (3 need to knows) and excellent fulfillment of these requirements)

EPA Needs To Know: The nature of fluid flow in the injection zone – radial vs linear flow behavior.

*The modeled results indicate that the early portion (7-8 hours) of the test was dominated by linear flow along wing fractures created by hydraulic fracturing that are approximately 440 feet in half length (on either side of wellbore). The later portion of the test revealed that pressure transient (pressure pulse from injection to shut in) became dominated by radial flow, with the flow following a radial direction in all directions away from the wellbore as widened by the fracture (see diagnostic plot (**Fig. 1**) and the PFOT analysis plot (**Fig. 2** next page), **In short, almost the entirety of the injection history, and the vast majority of the PFOT experienced radial/ pseudo-radial flow behavior***

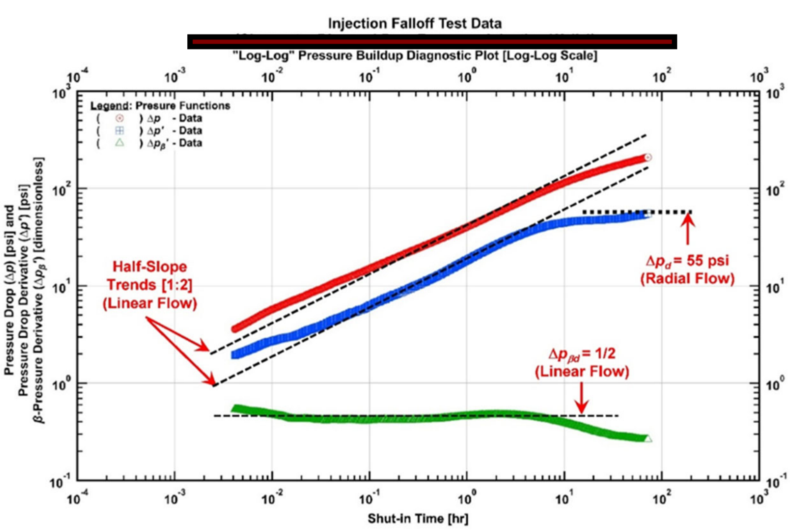


Figure 1

In **Fig. 1,** The pressure drop, pressure drop derivative, and the β–pressure derivative functions for the PFOT data are presented Note that the pressure drop derivative yields a constant (horizontal) trend for infinite-acting radial flow (IARF), and the β–pressure derivative function yields a constant (horizontal) trend for a given power-law function, confirming am IARF regime from approximately 20 to 72 hr, and the "linear flow" regime (β–pressure derivative = 1/2) from approximately 0.02 to 7 hr. Based on these diagnostics, *the permeability from the IARF regime can be estimated, and the fracture half length can be estimated from the portion of the data designated as the linear flow regime.*

EPA Requirements for Pressure Fall Off and Transient Analysis for a Disposal Well

Permeability is estimated from the pressure drop derivative and fracture half length is estimated by the β–pressure derivative. The data also indicates no wellbore storage domination effects or no late time boundary effects. This data, therefore; will provide a robust and unique analysis.

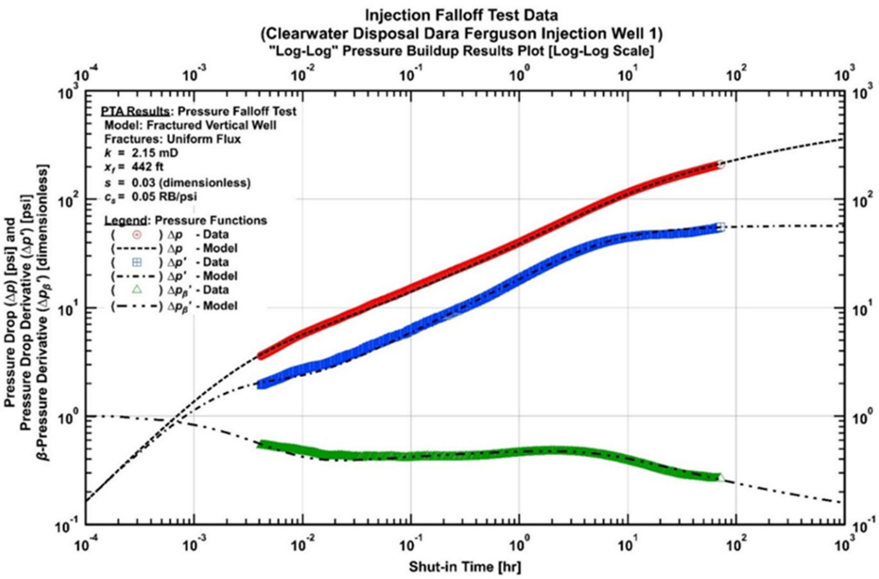


Figure 2

Excellent Model Match of pressure and derivative functions for the pressure fall off data. Hydraulic fracture model used to capture linear flow behavior.

From **Fig. 2** there are no late time boundary effects, nor is there evidence of wellbore storage "domination" (*i.e.*, the observance of a unit-slope line in the pressure drop and pressure drop derivative data functions), although there are some (apparent) very early time wellbore storage features.

The PFOT data and diagnostics are outstanding and subsequent analyses are very robust

EPA Requirements for Pressure Fall Off and Transient Analysis for a Disposal Well

Model-Based Analyses:

Based on the diagnostics of the PFOT data shown in **Fig. 1**, an analysis and history match of the given data with the results presented in **Table 3** and the analysis plot is shown in **Fig. 1.** As comment, all of the results are reasonable — *i.e.*, should be considered relevant / accurate based on the input data.

Table 3 — Results of the Pressure Fall-Off Test (PFOT) analysis (note that these results were also used for the Injection Analysis (RTA-equivalent) of the historical injection data).

Analytical Model — Fractured Vertical Well				Numerical Model — Fractured Vertical Well			
Fracture type: uniform flux				Fracture type: infinite-conductivity(1)			
k	=	2.15	md	k	=	2	md
x_f	=	442	ft	x_f	=	437	ft
s	=	0.03	dimensionless	s	=	0.05	dimensionless
C_s	=	0.05	RB/psi	C_s	=	0.05	RB/psi
r_e	=	16,500	ft(2)	r_e	=	16,000	ft(3)

(1) The uniform flux vertical fracture model is not available for the numerical reservoir model.

(2) Also used infinite-acting reservoir model (*i.e.*, $r_e \rightarrow$ infinity case).

(3) *Estimated* from radial pressure distribution from numerical simulations

EPA Requirements for Pressure Fall Off and Transient Analysis for a Disposal Well

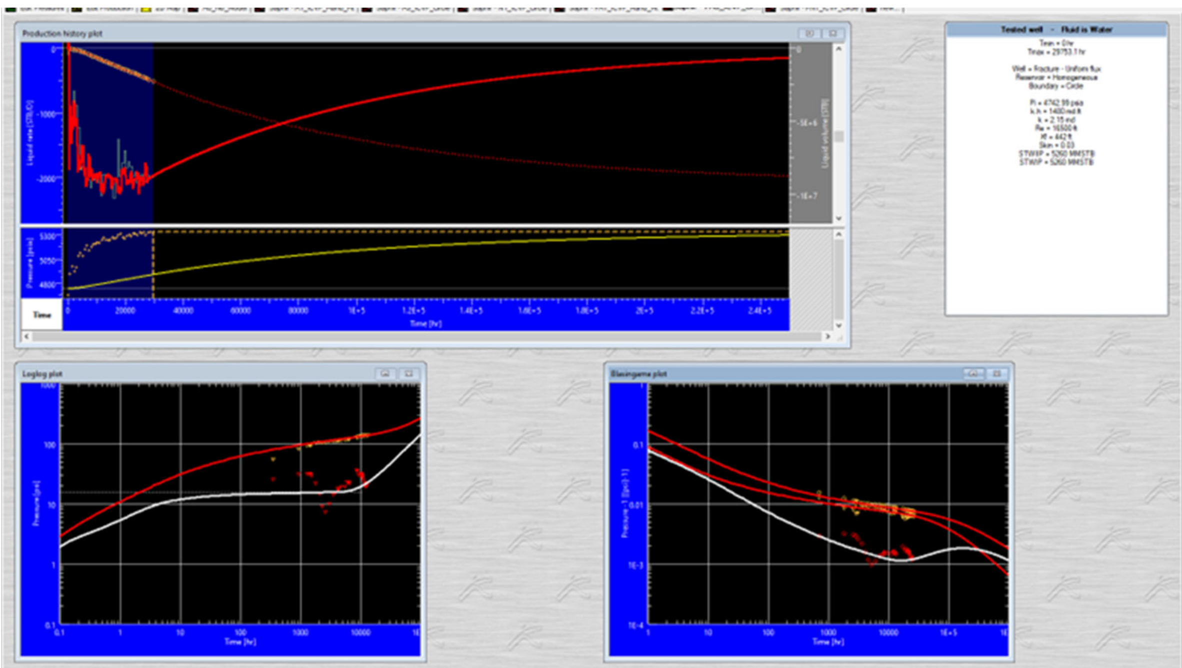
EPA Needs To Know: The injection zone pressure build up over time.

The analysis determines that there is approximately 150 psi pressure buildup in the injection zone within the area of review (AOR), when compared to estimated initial reservoir pressure at the start of injection. The maximum injection pressure is approximately 5330 *psia and occurred at the start of the pressure falloff test on* 21 *November* 2022 (17:00 *clock time*). *According to the reservoir model matches, the average reservoir pressure at this time was between* 4887 *psia* (*analytical reservoir model*) *and* 4893 *psia* (*numerical reservoir model*). *The average reservoir pressure at the start of injection was estimated to be* 4741 *psia* (*from the reservoir model matches of the injection history*), *indicating a pressure rise in the "area of review" of about* 150 *psia*. The numerical model confirms the analytical and visual data. The full report provided to the EPA illustrate the comparison in detail. For a much more detailed look, a link to your e mail can be provided for uploading Eagle Reservoir Services capabilities, case studies and report examples.

EPA Requirements for Pressure Fall Off and Transient Analysis for a Disposal Well

EPA Needs To Know: .The adequacy of assuming a fixed radius “area of review” (*i.e.*, the distance around the injection wellbore in the injection zone within which other wellbores might serve as a fluid conduit for unwanted fluid flow into aquifers protected under the federal UIC (injection well) program).

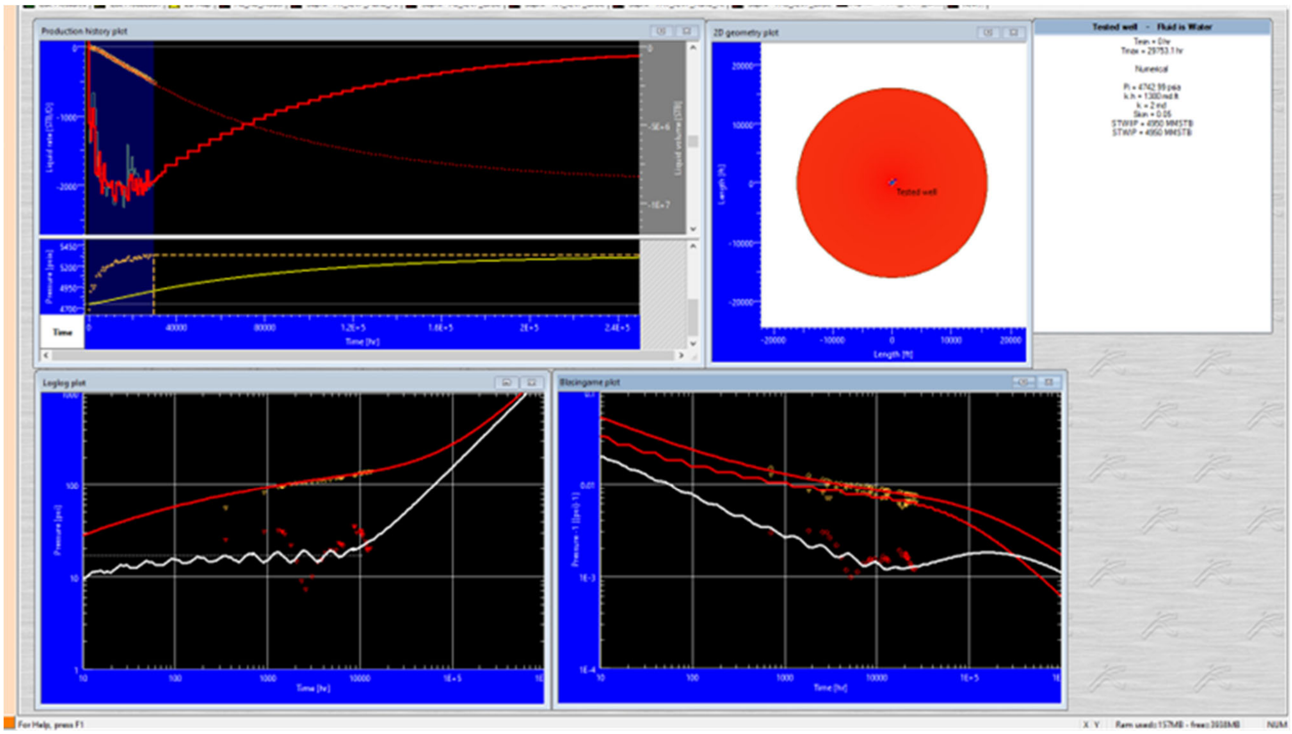
The report analysis indicates that pressure transient did not detect pressure effects from other wellbores completed in the same area or from “pinch outs”, or other stratigraphic or structural geological effects. More importantly, there is NO EVIDENCE of any pressure interference features in diagnostics of either the injection phase (29,753.1 hr) [*pressure and rate* (*injectivity index*) *function and derivative diagnostics*] *or the shut-in* (*fall-off*) *phase* (72.1319 hours) [*pressure derivative diagnostics*]. A full suite of plots are included in report that can be downloaded from a provided link to Eagle Reservoir Services ftp site.



Injection history data presented with a match of a vertical well with a uniform-flux vertical fracture in a bounded circular reservoir (analytical model) — realistic match of injection history data

Figure 2

EPA Requirements for Pressure Fall Off and Transient Analysis for a Disposal Well



Injection history data presented with a match of a vertical well with a uniform-flux vertical fracture in a bounded circular reservoir (numerical model) — realistic match of injection history data

EPA Requirements for Pressure Fall Off and Transient Analysis for a Disposal Well

Conclusions:

The following conclusions were derived from the diagnostic interpretation and model-based analyses of the injection history and the pressure falloff test data provided for this study (see full report via Eagle Reservoir Services ftp site):

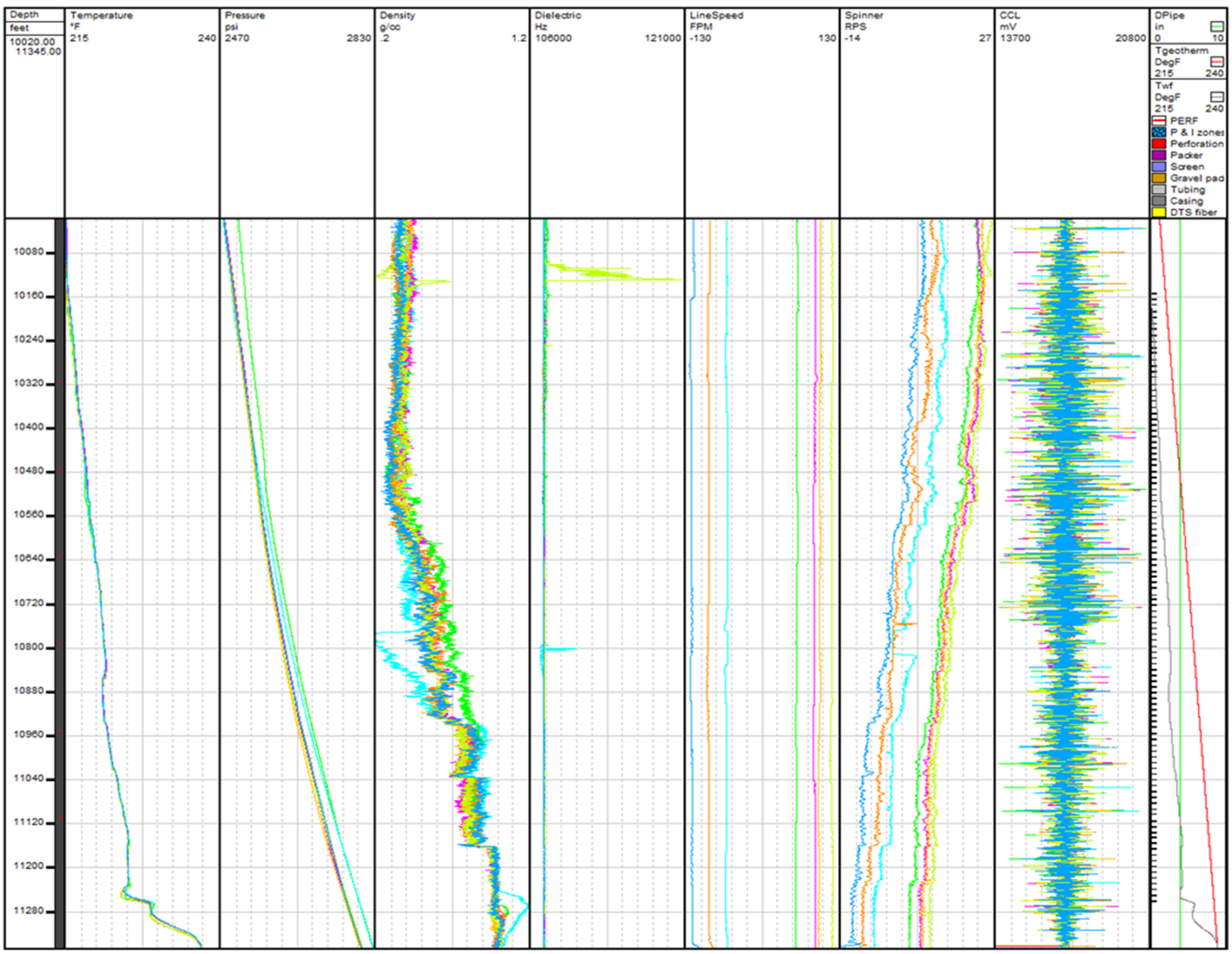
- There are no indications of out-of-zone injection.
- There are no indications of reservoir boundaries or offset well interference.
- Based on the diagnostic plot :
- — There are minimal wellbore storage effects (0.0055 to 0.02 hr) [*pressure drop/derivative*]
  - — Linear Flow exists (*i.e.*, the 1/2 slope trend) (0.02 to 7 hr)[*pressure drop/derivative/β-derivative*]
  - — Infinite-Acting Radial Flow exists (*i.e.*, constant derivative) (7 to 72 hr)[*derivative*]
- From model simulations :
  - — The average reservoir pressure at start of injection (01 July 2019) was approximately 4741 psia.
  - — The maximum injection pressure was approximately 5330 psia (at 17:00 on 21 November 2022).
  - — The average reservoir pressure at the end of the PFOT was between 4887 and 4893 psia.
  - — The total pressure increase in the "area of review" during injection is about 150 psia.
  - — The total extent of the pressure distribution was about 16,000-17,000 ft.
- From the calculations of the radius of investigation, we conclude that:
  - — 20,520 ft for the historical injection period (29,753.1 hr)
  - — 1,010 ft for at the end of the pressure fall-off test (72.1319 hr)
  - — We note that these estimates may be high, doubling the compressibility yields a 30% reduction.
- Additional comments:
  - — The PFOT data yielded exceptional diagnostic results, and an outstanding model match.
  - — The historical injection data gave realistic diagnostics/good model match, confirming data quality

High Perforation Count Production Logging

Eagle utilizes the most precise instrumentation for vertical production logging, injection profiling, and very complicated deviated and horizontal well production logging. Any conveyance method can be used from wireline, wireline tractor, slickline memory, coil tubing memory and e coil. Many complicated completions have been logged, including downhole pumps and valve entry in the LA Basin

Fiber (DTS/DAS) and production logging together are a powerful service that Eagle has run and analyzed many times over the evolution of combining the services.

Previous NewsLetters have demonstrated Horizontal Well Production Logging with Array instrumentation (including gas lift through a sub above the logging tools) The following is a vertical completion with over 110 individual interval perforations

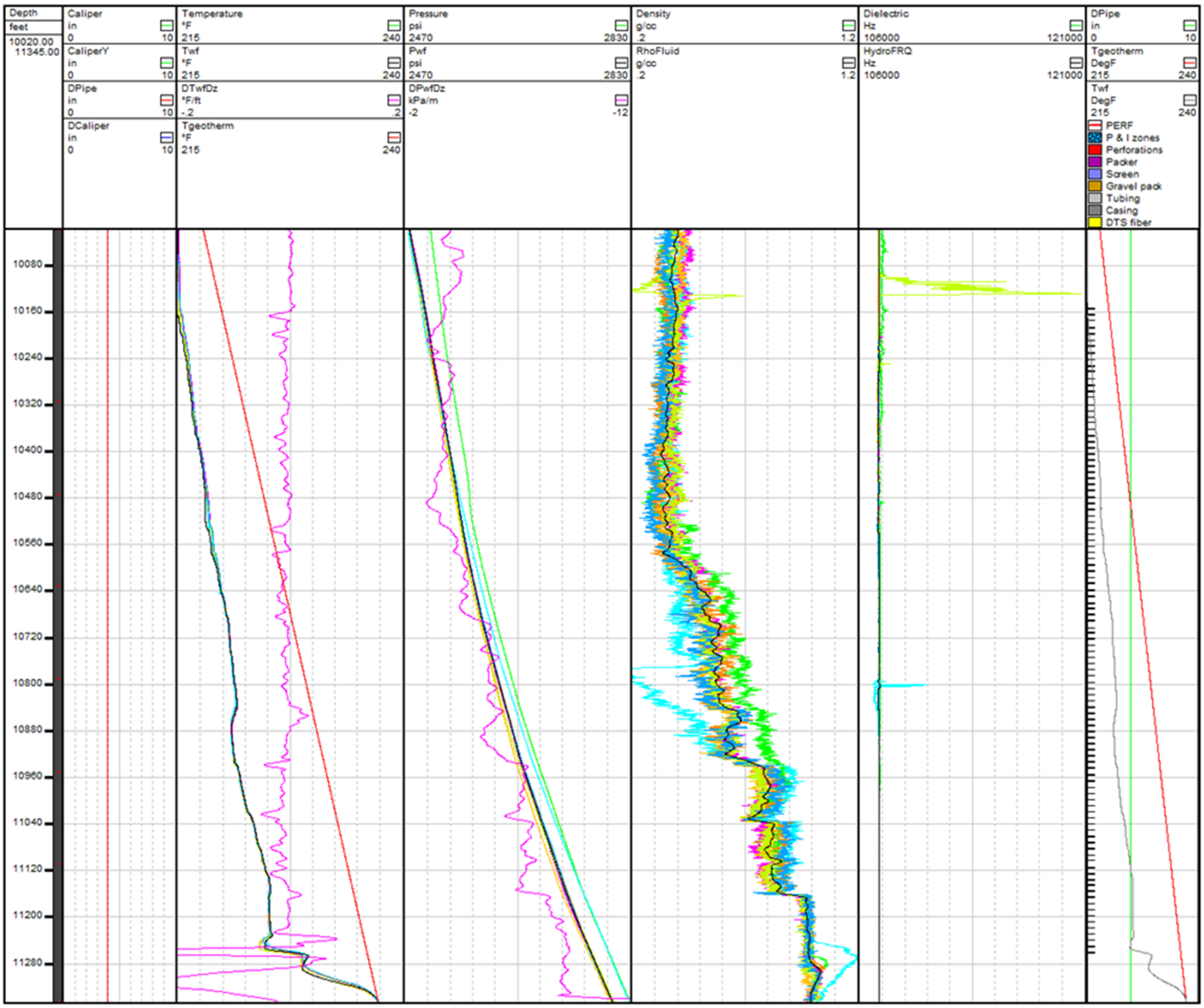


Raw data (temperature, pressure, phase density, capacitance, speed, spinner, and CCL.

Far right track contains the temperature geothermal, pipe diameter, average temperature and perforations

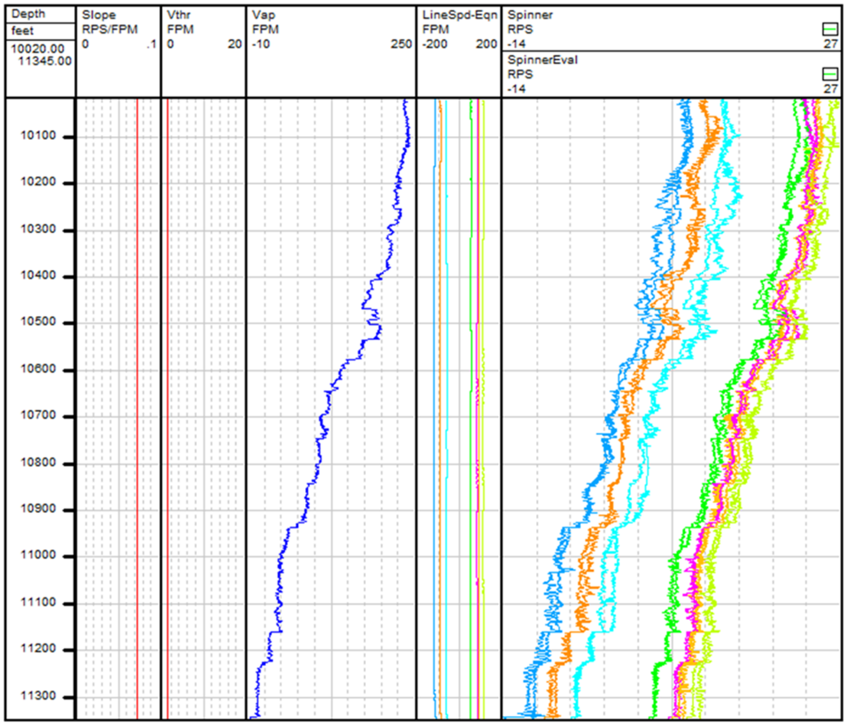
High Perforation Count Production Logging

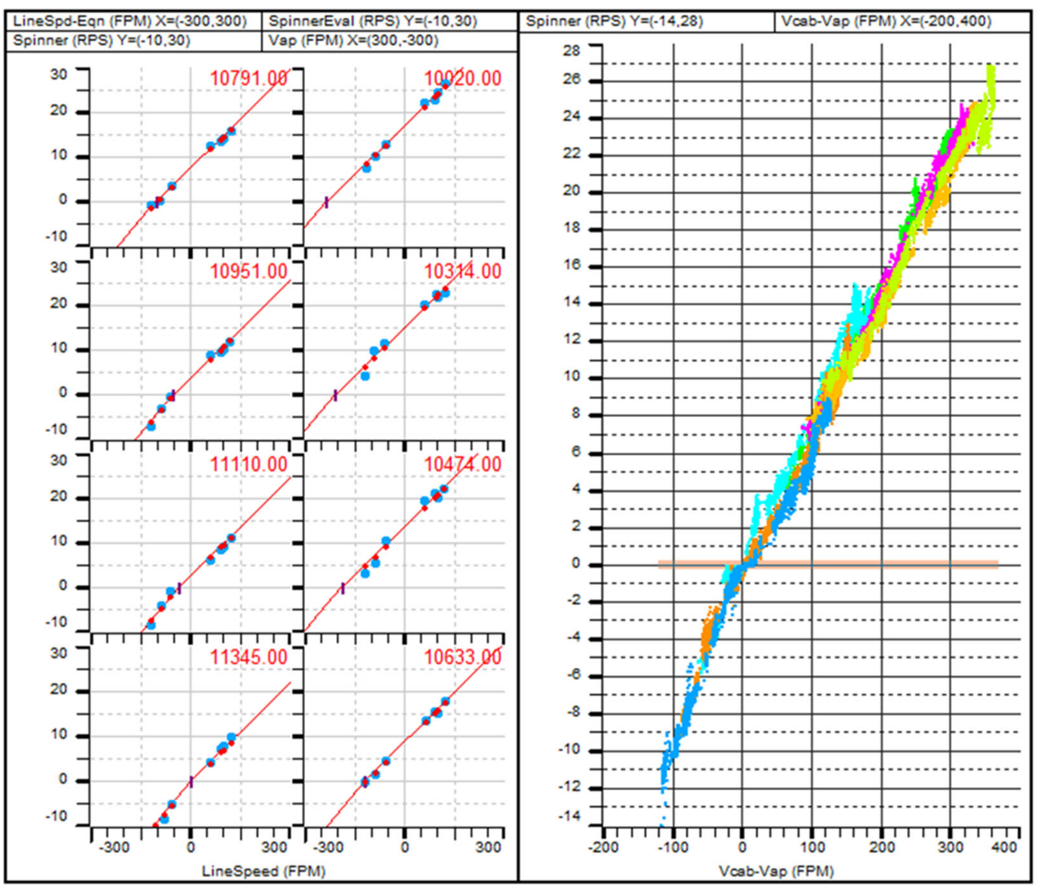
This plot is the calculated temperature and pressure derivative that is required for localized analysis of entry (phase and rate) that is complimented by the spinner data.



High Perforation Count Production Logging

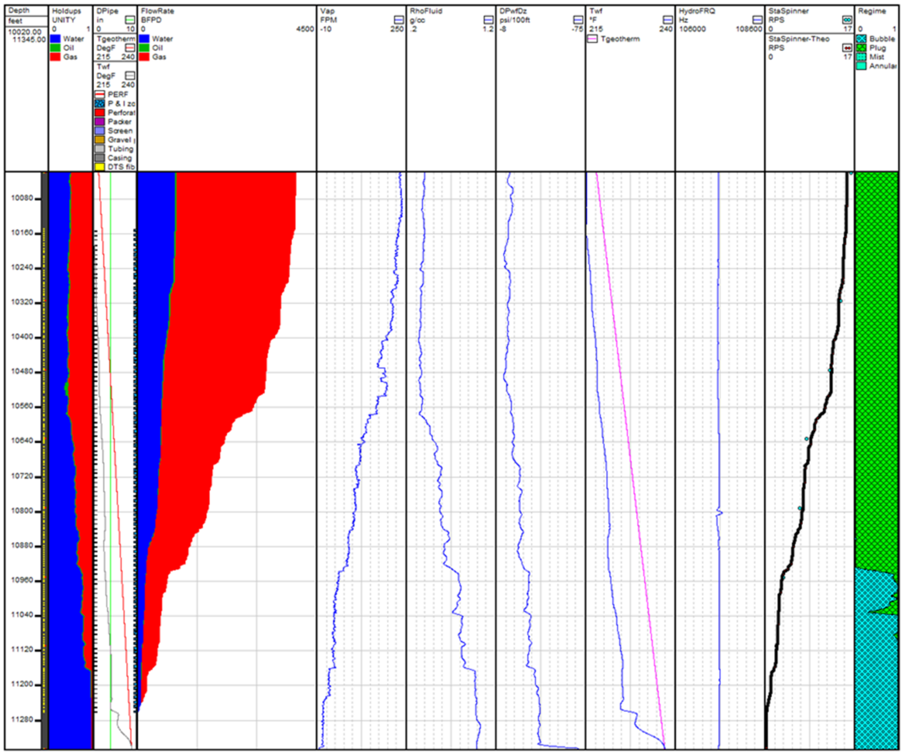
Calculated velocity from spinner data. In Array logging, seven velocities are calculated.

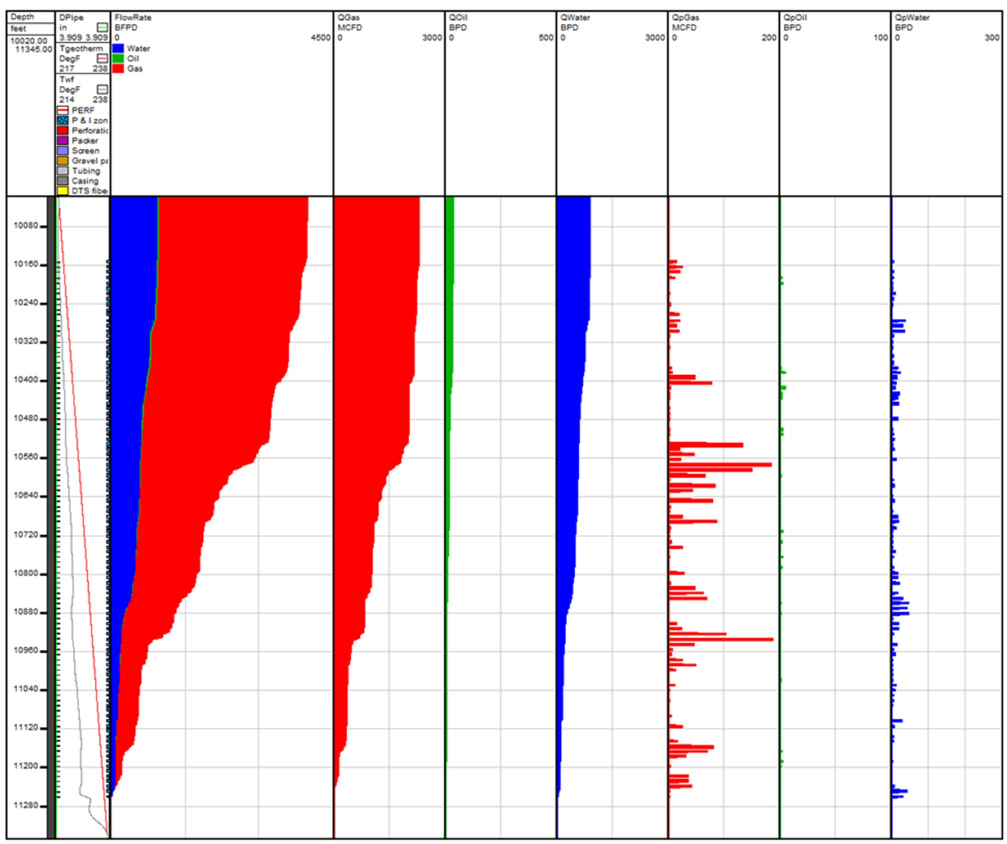




High Perforation Count Production Logging

LoProbablisitcalized phase entries with flow regime shown on the right. The next plot is macro calculated quantified entries and phases from a very robust probabilistic analysis.





Probabalistic analysis with iteration (particularly temperature and pressure data), allows for a very precise and accurate analysis. Quantification of very small volumetric entries (oil here) can be found with confidence.

High Perforation Count Production Logging

Partial Example of production summary

Depth		Profile	Q-Water-STP	Qp-Water-STP	Q-Oil-STP	Qp-Oil-STP	Q-Gas-STP	Qp-Gas-STP	Total Water and Percentage	Total Oil and Percentage	Total Gas and Percentage
feet			BFPD	BFPD	BFPD	BFPD	MCFD	MCFD			
Total Well Production									900.86	36.43	2339.82
10154-10199				15.91		4.00		69.10	2%	11%	3%
10154	10155	Produce	900.86	5.13	36.43	0.00	2339.82	14.20	1%	0%	1%
10165	10166	Produce	895.73	0.00	36.43	0.00	2325.62	25.30	0%	0%	1%
10174	10175	Produce	895.73	3.93	36.43	0.00	2300.32	19.50	0%	0%	1%
10187	10188	Produce	891.80	4.57	36.43	1.70	2280.82	10.10	1%	5%	0%
10198	10199	Produce	887.23	2.28	34.73	2.30	2270.72	0.00	0%	6%	0%
10209-10243				19.38		0.00		3.63	2%	0%	0%
10209	10210	Produce	884.95	3.28	32.43	0.00	2270.72	0.00	0%	0%	0%
10218	10219	Produce	881.67	8.69	32.43	0.00	2270.72	1.18	1%	0%	0%
10231	10232	Produce	872.98	5.10	32.43	0.00	2269.54	0.00	1%	0%	0%
10242	10243	Produce	867.88	2.31	32.43	0.00	2269.54	2.45	0%	0%	0%
10253-10298				100.90		0.00		70.70	11%	0%	3%
10253	10254	Produce	865.57	0.00	32.43	0.00	2267.09	0.00	0%	0%	0%
10261	10262	Produce	865.57	0.00	32.43	0.00	2267.09	18.50	0%	0%	1%
10275	10276	Produce	865.57	37.20	32.43	0.00	2248.59	19.60	4%	0%	1%
10286	10287	Produce	828.37	29.20	32.43	0.00	2228.99	14.30	3%	0%	1%
10297	10298	Produce	799.17	34.50	32.43	0.00	2214.69	18.30	4%	0%	1%
10306-10363				18.54		0.00		3.53	2%	0%	0%
10306	10307	Produce	764.67	4.85	32.43	0.00	2196.39	2.08	1%	0%	0%
10320	10321	Produce	759.82	1.57	32.43	0.00	2194.31	0.00	0%	0%	0%
10330	10331	Produce	758.25	3.42	32.43	0.00	2194.31	1.45	0%	0%	0%
10341	10342	Produce	754.83	0.00	32.43	0.00	2192.86	0.00	0%	0%	0%
10349	10350	Produce	754.83	3.71	32.43	0.00	2192.86	0.00	0%	0%	0%
10362	10363	Produce	751.12	4.99	32.43	0.00	2192.86	0.00	1%	0%	0%

High Perforation Count Production Logging

Probabilistic Analysis is necessary for horizontal flow and more accurate and precise for vertical.

$$\partial_z T\, \Sigma_i\, Q_i\, \rho_i\, Cp_i \;=\; \partial_z P\, \Sigma_i\, Q_i\, (\varepsilon_i - 1) - g \cos\theta\, \Sigma_i\, Q_i\, \rho_i - Qr_G\, \rho_G\, hv_G$$
$$+\, U\,(T_R - T) + \Sigma_i\, Qp_i\, \rho_i\, Cp_i\, (T_R - T)$$
$$-\, \Sigma_i\, Qp_i\, (\varepsilon_i - 1)\, s\,(P_R - P) - Qpr_G\, \rho_G\, hv_G$$

Where:

z	Measured depth	**i**	Index over phases
T	Well temperature	Q_i	Flowrate of phase "i"
T_R	Geothermal temperature	Qp_i	Production rate of phase "i"
P	Well pressure	Qr_G	Gas coming out of solution
P_R	Reservoir pressure	Qpr_G	Evaporated gas from reservoir
g	Gravity factor	ρ_i	Density of phase "i"
θ	Well deviation	Cp_i	Heat capacity of phase "i"
U	Effective heat conductivity btw wellbore and reservoir	ε_i	Compressibility of phase "i"
		Hv_G	Vaporization heat of gas
s	Skin		

Total Energy on left = flow energy plus added production or subtracted injection / crossflow on the right.

Flow Component of Total Energy in red on the right

$$\partial_z T\, \Sigma_i\, Q_i\, \rho_i\, Cp_i \;=\; \partial_z P\, \Sigma_i\, Q_i\, (\varepsilon_i - 1) - g \cos\theta\, \Sigma_i\, Q_i\, \rho_i - Qr_G\, \rho_G\, hv_G$$
$$+\, U\,(T_R - T) + \Sigma_i\, Qp_i\, \rho_i\, Cp_i\, (T_R - T)$$
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s	Skin		

$$\partial_z T\, \Sigma_i\, Q_i\, \rho_i\, Cp_i \;=\; \partial_z P\, \Sigma_i\, Q_i\, (\varepsilon_i - 1) - g \cos\theta\, \Sigma_i\, Q_i\, \rho_i - Qr_G\, \rho_G\, hv_G$$
$$+\, U\,(T_R - T) + \Sigma_i\, Qp_i\, \rho_i\, Cp_i\, (T_R - T)$$
$$-\, \Sigma_i\, Qp_i\, (\varepsilon_i - 1)\, s\,(P_R - P) - Qpr_G\, \rho_G\, hv_G$$

Where:

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U	Effective heat conductivity btw wellbore and reservoir	ε_i	Compressibility of phase "i"
		Hv_G	Vaporization heat of gas
s	Skin		

Added Production Component of Total Energy in red on the right

Lagniappe!

Join us in supporting the Youth of Texas by advertising in the Houston Livestock Show and Rodeo Souvenir Program or making a charitable contribution to the Houston Livestock Show and Rodeo Scholarship Fund.

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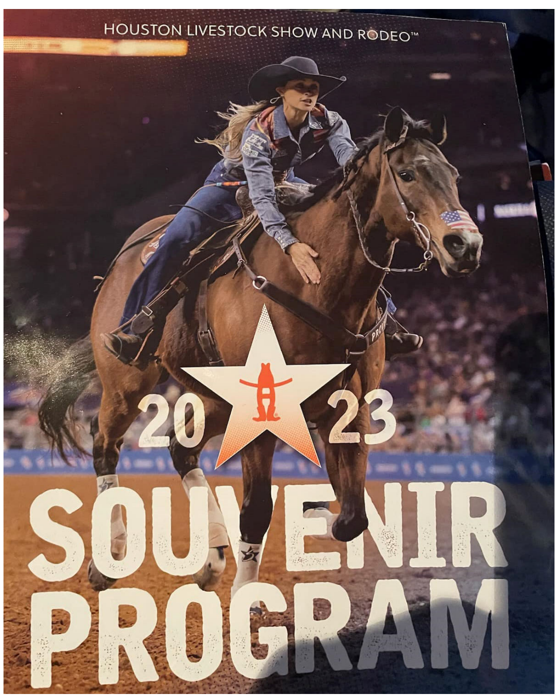

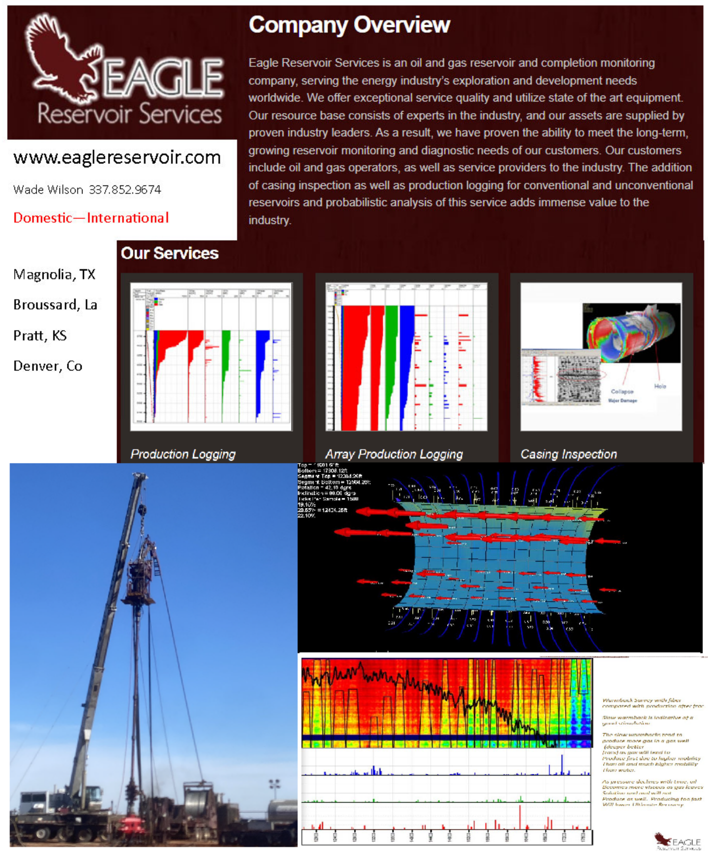

Eagle Reservoir Services ad in Houston Livestock Show and Rodeo Souvenir Program—2024