INJECTION WELL FRACTURE COMMUNICATION REMEDIATION WITH FOAMED POZZOLAN SLURRY

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ABSTRACT

An operator was experiencing a fast decline in hydrocarbon production in one of their Clearfork Formation CO_2 WAG flood patterns due to fracture communications between injectors and offset producers near Littlefield, Texas. In identified wells giving very poor sweep performance, injected Carbon Dioxide (CO_2) freely communicated and broke through into offset producers. Following performing diagnostics to determine the extent and magnitude of the existing problem, designs and simulation analysis were developed on an identified well displaying a dominant fracture communication. A foamed Pozzolan slurry squeeze treatment was performed and monitored for purposes of drastically reducing if not completely eliminating the major injected flow entry in the well's openhole interval and communicating via the reservoir to the offset producer. Elimination and or reduction in CO_2 cycling through this eroded communicating fracture conduit has significantly benefited the sweep on hydrocarbon and improved the economics in this section of the WAG Unit.

INTRODUCTION

The Permian Basin Cement operations of a service provider has successfully executed CO_2 shut off and injection profile modification treatments incorporating foamed Pozzolan slurry, using a diagnostics program to design simulation, and a stepped process incorporating its logical principles.

An operator was experiencing a fast decline in hydrocarbon production in one of their West Texas WAG (CO_2 flood) patterns due to the influx of injected CO_2 into offset producers communicated through fractures within the reservoir. The intent of the treatment was to drastically reduce, if not completely eliminate the major injected flow entry in the openhole interval of the injection well and into the interwell fracture communication pathway communicating to an offset producer well. The flow from this extended communication conduit developed an increasing transmission of CO_2 over time and is a critical component in the excessive cycling of CO_2 from the injector to the producer. Elimination and or reduction in CO_2 cycling through this conduit could significantly improve the economics for this section of the field.

The service company provider developed a solution using the high rate of success proven with a step process and equipment specific technique used to perform energized cement squeezing jobs.[1, 4, 5, 6, 7, 10, & 11] Multiple energized cement squeeze conformance treatments have been performed in the operator's units through the years (1980-2004).[13, 16] Based on tracer surveys and comparison of fluids injected to those produced in the production reporting cycle, estimates of the needed volume to sufficiently fill the massive eroded communication channel between the injector and producer developing an effective diversion and blockage became an issue, especially with large volume treatment cost. An energized foamed fluid was the most suitable solution, but the cost of an energized cement squeeze job was not considered to be a cost-effective treatment.

To shut off the conduit created by the years of injected water and CO_2, an expansive fluid was desired that would fill the void spaces that existed. High compressive strengths achieved by foamed API cement was not a desired and needed requirement – a low strength and low permeable solid within the structure of communication were the desired properties and attributes of the placed solution.[2, 13] Placing the treatment out into the fracture system away from the wellbore was desired since the casing was already providing structural support and external casing zonal isolation was analyzed to exist near wellbore. The vision of the solution idea was to find a material that was inexpensive, could be foamed (energized), and was readily available. Pozmix-A was considered to be a possibility; Pozmix-A is a pozzolanic material (fly ash) derived by burning coal, which in itself possess little cementitious material.

PERFORMING DIAGNOSTICS TO DETERMINE THE PROBLEM(S)

An analysis in diagnostic techniques that has proven capable in improving successes is associated with investigating the placements of sealants or cements in fractures or extremely high permeabilities. Understanding where the treatments will be placed and what controls are needed to ensure this control can be evaluated with multi-rate injectivities utilizing tracer profiles. The conditions and monitoring mechanisms used while injecting in wells to determine placement or restrictions that may vary placement are related to the pressure changes associated with different injection rates.[9] Most multi-rate analyses are conducted with a logging tool in the hole and equipped with a release device capable of placing a specified amount of radioactive material into the flow stream above the logging tools. A base gamma analysis, to determine variations is normally suggested. Normally the testing is performed with both intensity releases of isotopes placed in segments up through the wellbore and followed with a large shot of isotope placed above the entry zone as a velocity shot. The process is normally started at a reduced rate that is generally enough to establish entry only into the interval where a desired placement of chemicals or cement is desired. By releasing the intensity shots and a velocity shot, the injectivity of the tag can be traced to determine its path and where it has gone. When both intensity and velocity shots are used, comparison analysis gives a better understanding of the injectivity. Combining these with a temperature analysis also leads to a better understanding of injectivities and possible near-wellbore voids and lack of integrity. The subsequent following log runs for multi-rates are usually taken at incremented increased rates once given enough time for clearance of the prior shot isotopes and stabilization of fluid entry. The focus is to determine if there is a variation in entries at the different rates and accompanying changes in bottomhole injection pressure (BHIP) if any.[4, 8, 9]

Differential pressure responses may give understanding of the tortuosity aspects of fluid entry into specific portions of the reservoir, casing leaks, annular filling and flowing intervals, or other geometries. The emphasis of placing a treatment where it develops a blocking or squeezing effect without entering other undesired portions of a formation or annular interval may be determined with this analysis. If investigations show that at a specific pressure developed from varying injectivity would cause undesired entry, this information may be used to limit the treatment pressure. The chosen solutions that can be placed under the criteria established in a multi-rate injection analysis are established with this analysis.[3, 4, 12, 14]

LABORATORY ANALYSIS

Lab testing analysis determinations for (1) foam generation capability, (2) rheology determination, (3) fluid loss measures, (4) thickening time tests, (5) free fluid loss analysis, and (6) compressive strength developments were performed. The results were acceptable in meeting the desired attributes and capabilities of the desired solution. The slurry density at surface was designed to be 13 ppg and was injected with nitrogen to achieve an average downhole density of 11 ppg.

No two jobs are alike, because cements, muds, and mix water can change from job to job and location to location. No single preflush, spacer, or cement formulation can fit all well situations. The specific material used on every job should be tested to achieve the following objectives: [15, 16]

- Appropriate material testing to help ensure compatibility, foam stability, and optimal material selection for each job
- Laboratory testing based on well conditions and parameters that evaluate fracture gradients, pore pressures, and equivalent circulating density (ECD) to help achieve optimum slurry placement and developments
- Verification of pumping and mixing characteristics

TREATMENT DESIGN – JOB PLACEMENT

The energized cement placement process does not consist of simply adding nitrogen to the cement slurry, which in itself does not ensure that all the advantages of using energized foamed cement will be achieved. Ideally, nitrogen bubbles being isolated within the cement and not displaying cohesion can be achieved through the sheer energy applied and the chemical surfactant-stabilizer system utilized. If the bubbles touch, or if there is "breakthrough," the foamed cement characteristics are compromised. The energized cement development process helps maintain these characteristics through a fully integrated system including (1) proper laboratory testing of specialized slurries and (2) incorporating a single-component foamer/stabilizer. The process is a system—not just a procedure—that consists of six elements: design, software, laboratory testing, cement blends, equipment mobilization, automation, and data acquisition.[3, 4, 7, 8, 15, 16]

Software simulation design programs were used to determine final nitrogen concentrations and predict placement pressure limitations.

The process begins with program design by a simulation design program, which can allow engineers to design and simulate an optimum cement job [primary or remedial]. The software can calculate the impact of complex well conditions and changes in the slurry during dynamic placement. Engineers can use these calculations to analyze the potential for the cementing design to help provide long-term zonal isolation; further, the designer can identify problems and design cementing parameters before cementing begins. The software can perform the following functions in the process:[3, 4, 8, 11]

- Predict and optimize displacement, even in eccentric annuli or complex tortuous pathways, by modeling the effects of changes in flow rate, rheology, or eccentricity.
- Predict and model removal of variable viscosity fluids.
- Predict frictional expansion and contraction of compressible fluids.
- At any time during the job and any well depth, predict equivalent circulating density (ECD), flow rates, pressure, density, viscosity, foam quality, nitrogen concentration, and downhole rheology.

The job was performed under tremendous operational challenges. Injection test prior to the job showed that an injection rate between 0.5 bpm and 1.5 bpm would prevent the treatment in exceeding the fracture gradient of the formation. Equipment adjustments were made to help ensure the viability of the operation.

Some of the highlights of the first job results are as follows:

- Liquid Pozmix-C slurry was “batch - mixed” to help ensure a constant downhole density.
- Chemical foamer/stabilizer was diluted in water in a 1:2 ratio to be delivered at designed concentration of 2% by volume of the mixing water in the slurry (% BVOMW).
- Nitrogen delivery was automated through the entire job to help ensure the desired final foamed density.
- 400 sk [75 lb/cf] of foamed Pozmix-C Slurry were mixed and pumped downhole through a string of 2 ¾ in. tubing. Towards the end of the job, when 4 bbl of displacement (out of 25 bbl) were in the tubing, the treating pressure reached the maximum allowable value and the job was shut down.
- The well was then reversed out following pulling up off the cement retainer, closing its two-way valve, and excess foamed Pozmix-C Slurry was returned via staked and anchored lines to the pit.
- Post-drilling operations through the retainer encountered solid foamed Pozmix-C Slurry inside the casing left there during the pulling above the retainer while reversing and down to the zone of entry (due to the cementitious properties of the Pozzolan materials utilized).
- When drilling out the treatment, the operator was concerned because the process was accomplished faster than the normal drillout of conventional cement. The operator started to consider the treatment a failure until questions were asked about this feature. Energized slurries drillout much faster with the trapped energy within the solid body of the slurry.[2, 15]
- Was the treatment a success? Before the job, the well would flow gas and produced water. It also had a pressure build-up if closed in. After the drill-out, there was not any pressure at the surface and no fluid flow exhibited. A determination of success in shutting off the vast communication channel within the reservoir was reached at this occurrence.

RESULTS OF CONTROLLED PLACEMENT METHODS

The initial results have shown a marked reduction in CO_2 production. Consequently, the main target of the operation was accomplished. Post-job analysis and meetings with the operator have been held to discuss future modifications and improvements desired. Some of the discussions addressed:

- The desire to investigate a determination process that gives a better estimate of the volumes to be pumped
- How to better correlate with past performances
- Fine-tune friction pressures and their correlations
- Utilization of tail-in slurries
- Several other lessons have been learned.

DESIGN CRITERIA AND CONSIDERATIONS FOR CASE PROBLEMS

Develop laboratory testing to match needs

Determination of rheologies and rates – their correlations

Pump times and reactions under variable conditions and input techniques

Pressure responses and limitation facets – a tool for analysis

COMPARATIVE ANALYSIS DURING TREATMENTS (ACTUAL VS. DESIGN)

Onsite analysis has proven invaluable in determining the control over placement without damaging other portions of the well's reservoir. Various onsite determinations are displayed in the accompanying tables and plots given.

CONCLUSION

The operator is convinced that performing this process is beneficial and that it has proven to be very cost effective compared to the benefits received from the treatment results.

An additional four conformance treatments have been pumped in injector and production wells as designed. All of the energized Pozzolan squeezes have been successful in meeting the pre-job goals.

Once again, providers of solutions in cementing methods and techniques were challenged with a task and provided the best solution to the operator. Post-job results on production patterns surrounding two of the wells treated have demonstrated improvements in reductions of breakthrough cycled water and CO_2. The first treated pattern following 6 months has developed a net increase of 71 BOPD since the squeeze. The second pattern following a week has shown initially a net decrease of 13 BOPD, but also a dramatic decrease in cycled injectant. Performance will be recorded and evaluated as more treatments are applied to problem wells in the operators unit.

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Treatment Summaries and Tables on 2nd Treatment:

Table 1
Descriptive Well Parameters

Fracture Zone Measured Depth	4,800.0	ft
Fracture Zone Gradient	0.792	psi/ft
Fracture Zone Density	15.24	lb/gal
Fracture Zone Pressure	3,800	psi
Reservoir Measured Depth	4,800.0	ft
Reservoir Pore Pressure	2,077	psi
Reservoir Zone Gradient	0.433	psi/ft
Reservoir Zone Density	8.33	lb/gal
Back Pressure	0	psi
Simulator Volume Increment	42	gal
Surface Iron Length	500.0	ft
Surface Iron Diameter	2.000	in.
Pump to RKB Height	30.0	ft
Surface Iron Displacement	82	gal
Additional Pressure to Seat Plug	500	psi

Table 2
Wellbore Geometry

MD	Hole Ex.	Hole Dia.	Casing OD	Casing ID	Casing Weight
ft	%	In.	In.	In.	lb/ft
4,700.0	0.00	8.000	2.875	2.441	6.400
4,815.0	0.00	8.000	7.000	6.456	20.000
4,850.0	0.00	88.000	7.000	6.456	20.000

Table 3
Pumping Schedule

No.	Description	Density	Rate	Volume	Duration
		lb/gal	bpm	gal	min
1	Brine	14.79	7.00	0	0.00
2	Fresh Water	8.33	1.20	334	6.62
3	Pozmix C 1.5% ZS	13.00	1.20	8,071	160.15
	Top Plug				
4	Fresh Water	8.33	1.50	1,398	22.19
	Total			9,803	188.96

Table 4
Fracture Gradient/Pore Pressure Profile

Measured Depth	True Vertical Depth	Pore Pressure	Reservoir Gradient	Reservoir Density	Fracture Gradient	Fracture Density	Fracture Pressure
ft	ft	psi	psi/ft	lb/gal	psi/ft	lb/gal	psi
4,800.0	4,800.0	2,077	0.433	8.33	0.792	15.24	3,800

Table 5
Foam Design Parameters

Constant Density Calculation Method		
Foaming Agents in Mix Water (volume based)		
Surfactant	0.75	%
Stabilizer	0.75	%
Fracture Zone		
Measured Depth	4,800.0	ft
Fracture Pressure	3,800	psi
Fracture Gradient	0.792	psi/ft
Fracture Density	15.24	lb/gal
Calculated Hydrostatic Pressure	3,703	psi
Calculated Hydrostatic Pressure Gradient	0.771	psi/ft
Calculated Hydrostatic Density	14.85	lb/gal
Reservoir Zone		
Measured Depth	4,800.0	ft
Pore Pressure	2,077	psi
Reservoir Gradient	0.433	psi/ft
Reservoir Density	8.33	lb/gal
Calculated Hydrostatic Pressure	3703	psi
Calculated Hydrostatic Pressure Gradient	0.771	psi/ft
Calculated Hydrostatic Density	14.85	lb/gal

Table 6
Foam Pumping Schedule for Liquids

Stg.	Start Time	Pump Rate	Base Slurry Vol.	Cum. Base Slurry Vol.	Cem. Mix Water Vol.	Cum. Cem. Mix Water Vol.	Foam Agents Rate	Foam Agents Vol.	Foaming Agents Cum. Job Volume
	min	bpm	gal	gal	gal	gal	gpm	gal	gal
1	0.00	7.00	0	0	0	0		0.0	0.0
2	0.00	1.20	334	334	0	0	0.8	5.0	5.0
3	6.62	1.20	8,071	8,405	5166	5,166	0.5	77.5	82.5
4	166.8	1.50	1,398	9,803	0	5,166	0.0	0.0	82.5

Table 7
Foam Pumping Schedule for Gas

Stg.	Start Time	Pump Rate	Starting Gas Conc.	Ending Gas Conc.	Starting Gas Rate	Ending Gas Rate	Cum. Job Gas Vol.	Exp. Factor
	min	bpm	scf/bbl	scf/bbl	scfm	scfm	scf	
1	0.00	7.00	0.000	0.000	0	0	0	1.00
2	0.00	1.20	275.000	275.000	330	330	2,186	1.26
3	6.62	1.20	275.000	275.000	330	330	55,034	1.23
4	166.8	1.50	0.000	0.000	0	0	55,034	1.00

Table 8
Foam Slurry Data

No.	Description	Pump Rate	Base Slurry Vol.	Foam Slurry Vol.	Bulk Cem.	Water Req.	Yield
		bpm	gal	gal	lb	gal/lb	gal/lb
1	Brine	7.00	0	0			
2	Fresh Water	1.20	334	420			
3	Pozmix C 1.5% ZS	1.20	8,071	9,915	76,837	0.06723	0.1051
4	Fresh Water	1.50	1,398	1,398			

Table 9
Stage Summary - Liquid Volume and Density, Design Shutdown

Number	Design Volume	Actual Volume	Design Density	Average Density	Minimum Density	Maximum Density
	gal	gal	lb/gal	lb/gal	lb/gal	lb/gal
2	334	464	8.33	8.42	8.21	11.34
3	8,071	7,162	13.00	13.19	11.55	14.44
4	1,398	1,132	8.33	8.35	7.45	12.07

Table 10
Stage Summary - Pump Pressure and ECD

Number	Average Pump Pressure	Minimum Pump Pressure	Maximum Pump Pressure	Average ECD	Minimum ECD	Maximum ECD
	psi	psi	psi	lb/gal	lb/gal	lb/gal
2	1,088	882	1,222	14.79	14.79	14.82
3	1,146	877	1,472	14.80	14.79	14.81
4	1,493	1,103	1,735	14.80	14.79	14.80

Table 11
Stage Summary - Pump Rate and Nitrogen Rate

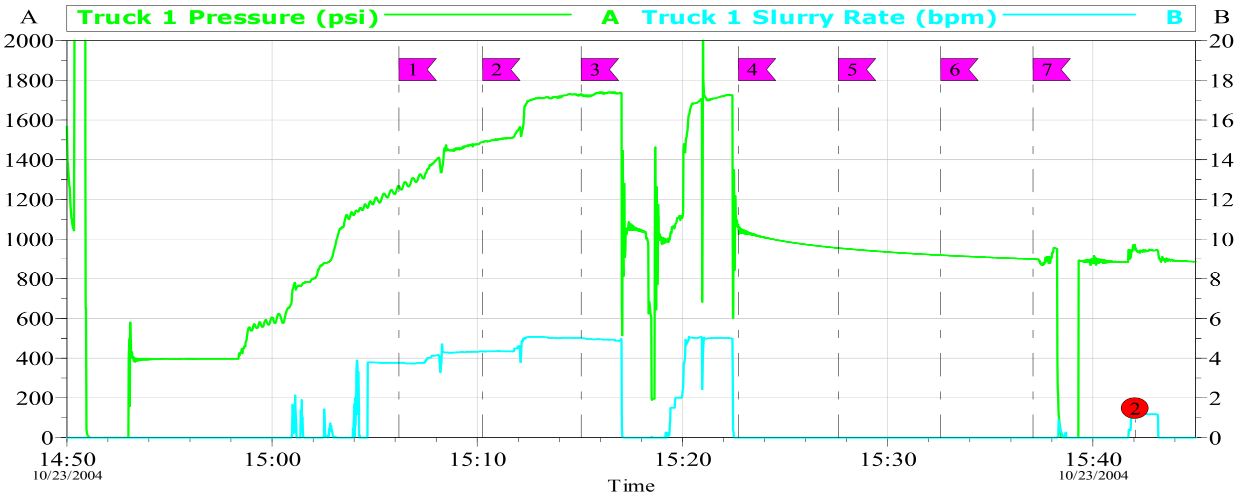
Number	Design Average Pump Rate	Average Pump Rate	Min. Pump Rate	Max. Pump Rate	Design Average Nitrogen Rate	Average Nitrogen Rate	Min. Nitrogen Rate	Max. Nitrogen Rate
	bpm	bpm	bpm	bpm	scfm	scfm	scfm	scfm
2	1.20	1.15	0.10	1.29	330	307	0	1,103
3	1.20	1.49	0.84	1.63	330	446	0	653
4	1.50	1.47	0.00	1.61		63	0	449

Table 12
Shutdown Summary

Stage Number	Elapsed Job Time	Stage Volume Pumped	Shutdown Duration
	min	gal	min
2	1.13	54	10.30
3	31.41	687	0.40
4	153.46	1,132	0.36

Table 13
Job Event Log

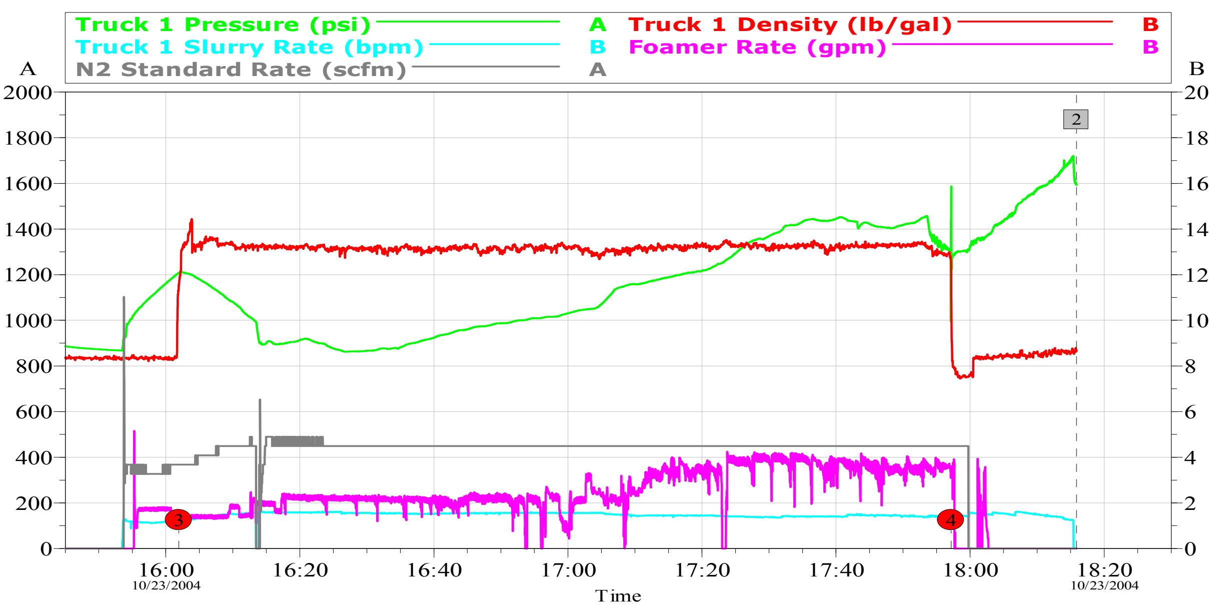
Time	Description	Comment	Truck 1 Dens	Truck 1 Slry Rt	Truck 1 Pr	N_2 Gas Rate	Foamer Rt
			lb/gal	bpm	psi	ft³/min	gpm
14:42:17	Start Job	Starting Job	8.54	0.00	396	0	0.00
15:42:03	Next Stage	Fresh Water	8.47	1.24	956	0	0.00
16:01:56	Next Stage	Pozmix C 1.5% ZS	11.55	1.19	1,208	330	1.39
17:57:09	Next Stage	Fresh Water	12.07	1.01	1,088	0	3.60
18:15:52	End Job	Ending Job	8.70	0.00	1,593	0	0.00



Local Event Log

	Intersection		T1P		Intersection		T1P
1	Injection Rate @ 1200 Psi	15:06:11	1267	2	Injection Rate @ 1400 Psi	15:10:16	1489
3	Injection Rate @ 1800 Psi	15:15:04	1725	4	ISIP	15:22:43	1065
5	5 Min SIP	15:27:36	954.9	6	10 Min SIP	15:32:35	919.0
7	15 Min SIP	15:37:05	899.4				

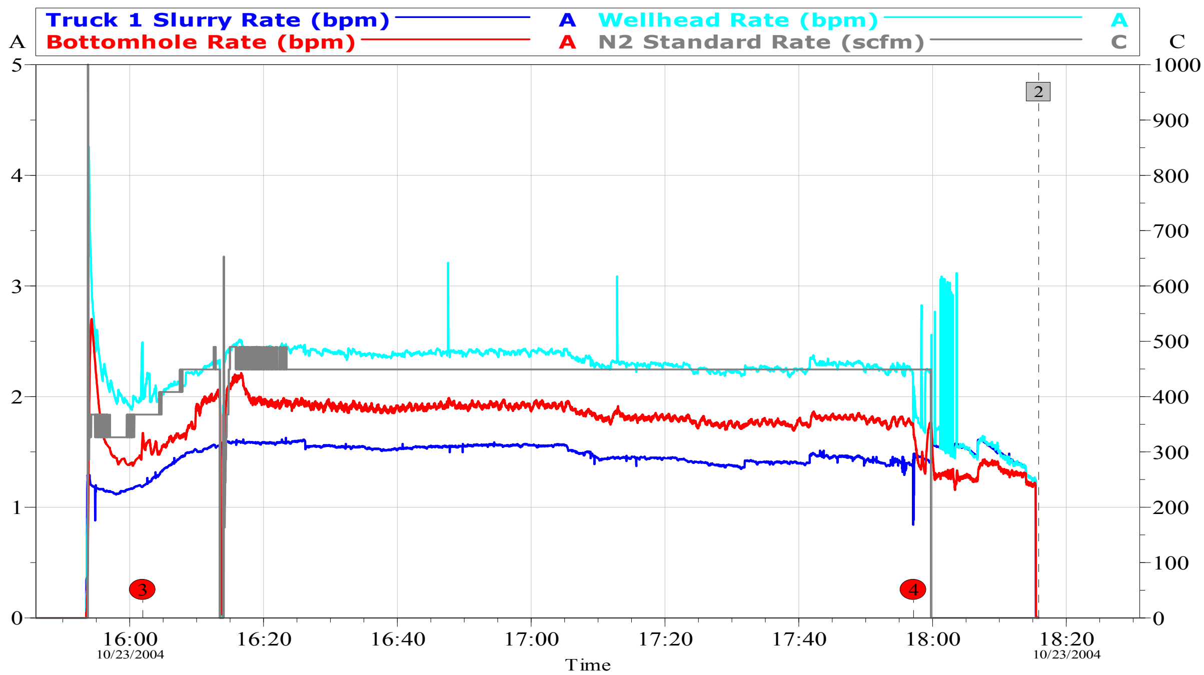
Plot 1 - Injection Test (graph) 2nd Treatment



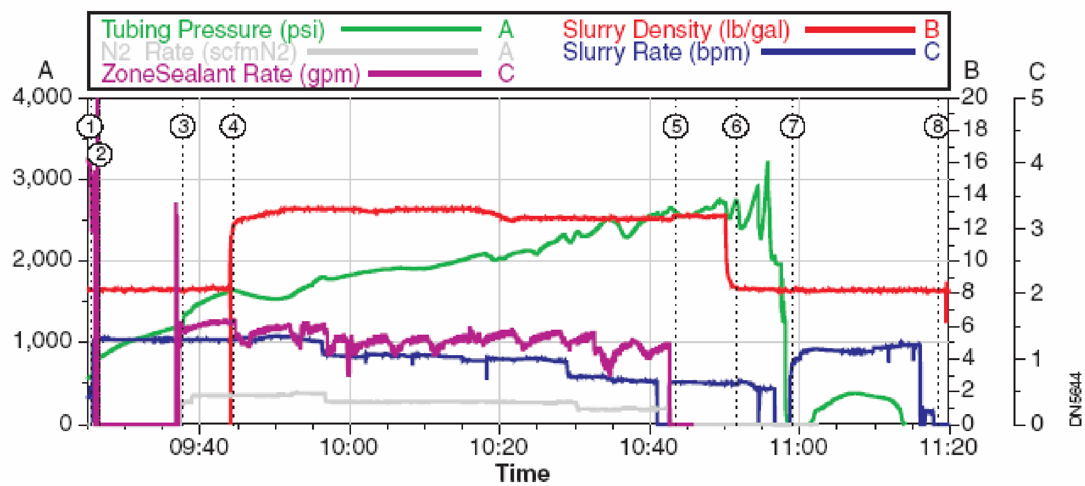
Stages

2	Fresh Water	15:42:04	3	Pozmix C 1.5% ZS	16:01:57	4	Fresh Water	17:57:10

Plot 2 - Job Summary (graph) 2nd Treatment



Plot 3 - Rate Profile (graph) 2nd Treatment



Stages

1	Start job	09:25:20	2	Pump FW tubing capacity	09:26:37
3	Pump 5 bbl foam FW	09:37:40	4	Pump 400 sk foam Pozmix	09:44:25
5	Pump unfoamed slurry	10:43:30	6	Pump displacement (4 bbl)	10:51:32
7	Reverse out	10:59:08	8	End job	11:18:22

Job chart

Plot 4 - Parameters Recorded During the First Energized Pozzolan Squeeze