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Implementing Manufacturing-Style Workflow to Resin Sealant Squeeze Applications Reduces Cost and NPT

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Abstract

Resin sealants offer more reliable alternatives to Portland cement for remedial well sealing. Liquid resin squeezed into small channels or formation permeability hardens to create a durable seal, and small resin volumes placed selectively function better than large quantities of cement. In the past, resin jobs involved a significant design customization, volume tailored to well geometry, special mixing equipment, specially trained operators, and extra wait time.

Fundamentally developing the resin squeeze design and application process using manufacturing-style workflow principles achieved significant streamlining for resin squeeze application. Choosing four barrels as normal resin treatment volume allowed pre-packaging of components in standard volumes. Standardized resin formulae achieved through clever exploitation of resin material choice allowed packaging of standard components in these standardized containers that can be mixed and matched to cover application temperatures from 65ºF to 230ºF with a shortened wait time. Additional formulation improvements produced reliable handling time and shortened curing time sufficiently to establish a series of standardized formulations covering the temperature range. Small resin squeeze volumes using standardized component packaging permitted batch mixing resin in standard RCM tub by skilled equipment operators.

These step changes in resin squeeze application workflow lowered inventory cost, reduced waste, shortened lead time, improved operational throughput, reduced nonproductive time (NPT), and ultimately lowered cost and risk of a resin squeeze treatment. Considering lower volumes and resin treatment cost reductions delivered with the manufacturing-style workflow changes, price of a resin squeeze is comparable to squeezing with cement. Further consideration of cement squeeze success rate (optimistically 50%) with that of resin squeeze success (>90%) results in considerable cost reduction as well as reduced NPT for resin applied the manufacturing-style. The workflow step changes and relative cost reductions are described along with examples of field application success.

Introduction

The petroleum well drilling process developed over the last century approached each well as a specific project. Drilling and completion sequence followed a linear path with each step completed in order. Little effort was devoted to conducting work concurrently or minimizing NPT. Unusual issues requiring special attention (hole problems, equipment failure, or maintenance) halted the drilling process often for long periods extended by supply issues or a contingency plan. Result of this one-off drilling process approach was increased time and cost to construct a commercial well.

Manufacturing-Style Drilling

This drilling workflow method has shifted incrementally over the last 20 years driven by need to minimize drilling cost and NPT. Also motivating this shift was desire to avoid preventable or unplanned problems, while minimizing environmental, social, and governance (ESG) concerns. The result of implementation of these workflow modifications has been termed manufacturing drilling, a philosophy and workflow protocol focusing on delivery of final product (a commercial well) of highest possible value through optimizing workflow efficiency, removing NPT, and minimizing waste and cost. Manufacturing Drilling has been adapted from the work originally conducted by Toyota in the 1950's through 1970's to produce the Toyota Production System (de Wardt, 2012). This system was based on Lean Manufacturing, the product of a thorough understanding of the entire manufacturing process, establishing a new workflow to optimize productivity and reduce waste and cost, and continuously evaluating and improving the workflow process after implementation.

As importance of minimizing well construction cost and maximizing ultimate recovery grew, driven by increasing demand and commodity pricing, manufacturing drilling has been applied to provide wells at a cost that supports commercial development. Emphasis on coalbed methane and shale wells accelerated this adaptation. Rexillus (2015) reported that implementation of this protocol had resulted in reduction of drilling time and cost for shale wells by ± 50% compared to conventional drilling methods. Rexillus further describes balance of speed and efficiency with flexibility and innovation focused on reservoir to optimize ultimate recovery and cost effectiveness.

A typical manufacturing-style drilling program for shale wells incorporates (Cantwell and Devraj, 2014):

- Integrated planning-batch drilling and completion of multiple wells minimizes rig moves, NPT, and waste. Uniform design and operation procedures speed progress and reduce cost.
- Logistics-material movement and storage optimized to reduce material transport and use close, accessible storage and staging.
- Collaborative communication and management with contractors- ensures financial control, risk management, ESG focus, and achievement of operational and financial goals.

While multiple operators have employed some form of manufacturing-style for drilling large numbers of wells in shale formations, few attempts to apply manufacturing style to individual completion aspects are documented. Basset *et al* (2012) applied manufacturing-style primary cementing practices successfully in the Haynesville and Marcellus shales. Fracturing fluids and proppants are strategically acquired and stored to deliver reliable supply during extended shale well fracture stimulation.

Squeeze cementing, a remedial operation with low rate of success and significant NPT seemed to be an ideal candidate for improvement through application of manufacturing-style processes.

Squeeze Cementing Effectiveness

Squeeze cementing is a broad category of remedial operations in which well leaks are sealed by placing Portland cement slurry across the leak and applying pressure to the cement to force water from the slurry ("squeeze") to create cement filter cake at the leak site creating a flow barrier (Jones and Watters, 1998). Jones and Watters estimate squeeze cementing success potential at 50% or less. Historically, squeeze cementing operations have a high failure rate. Cowan (2007) analyzed results from a large squeeze cement data base to find a squeeze success rate for first attempted squeeze of 34%. The majority of wells in the study required 2+ attempts to seal the leak. A percentage of wells in the data base were still leaking after 5 squeeze attempts. In general, multiple cement squeeze applications are required to seal a leak. Table 1 summarizes squeeze cementing success reported by Cowan for squeeze work performed in the Permian Basin field. Wells in this study were 30 to 50 years old, and some of the wells had undergone CO_2 flooding.

Table 1: Summary of Squeeze Cementing Success in a Permian Basin Field Study (Cowan, 2007)

Total Wells	137
Repaired with 1 squeeze	47 (34%)
Repaired with repeated squeeze treatments (up to 5 total)	54 (40%)
Repair with multiple squeeze cementing unsuccessful	36 (26%)

Cowan's analysis emphasizes a crucial fact: over time, the industry has simply accepted that squeeze cementing has a low probability of success and assimilated these odds into the operational culture and cost requirements. Squeeze cementing's low probability of success significantly increases the cost of repairing a well barrier; an average of 2 or 3 times the cost of a single cement squeeze due to the multiple squeeze attempts necessary to seal the barrier. This revelation is eye-opening in terms of cost and NPT investment in this remedial process.

Numerous operational issues contribute to squeeze cementing's low success potential, but a primary factor in Portland cement's ineffectiveness as a squeeze sealant is the cement itself. The first issue is that cement particles are the basis for formation of a solid barrier. The flow path that cement must penetrate to effectively squeeze a leak is often too small for the cement grains to enter. So, in a conventional squeeze, the cement bridges at the surface of the leak path as water is squeezed from the slurry. A cement filter cake is deposited to form the barrier seal at the mouth of the leak path. This limits accessibility of cement slurry to the leak path and is a major source of cement squeeze failure. Secondly, cement squeezes are typically performed with aqueous fluids in the well. Cement slurry readily mixes with and is diluted by these fluids. Excess cement slurry volume is usually applied to overcome this intermixing and dilution.

Resin sealant properties offered the potential to improve squeeze success. With a different sealant as the basis for improvement, implementation of manufacturing-style principles to the process began. First, a time and cost analysis of a typical Permian basin squeeze operation was assessed. This assessment, presented in Table 2, is a general breakdown of operator cost and time for a squeeze operation. Costs and times are relative to allow a more universal comparison to other squeeze methods. Cost of this general squeeze application is set as 100% with total time requirement specified as 100%. Relative costs for other squeeze methods or sealants will be normalized as a percentage of this general cement squeeze assessment. Actual costs and times for a routine squeeze operation in the Permian Basin is estimated to range between \$20,000 and \$30,000 and from 70 to 90 hours

Table 2: Cost and Time Estimate for an Average Permian Basin Cement Squeeze

Category	Subcategory	Cement Job	
1st Job		Hrs	Cost %
Pre-Job	Design Time	1	0.32
	Manufacturing Time	0	0.00
	Pre-Job Logistics	1	0.41
	Lab Testing Time	24	7.29
Job Execution	Loading/Handling Time	4	5.67
	Cement (100 sk)	1	10.13
	Pumping Equipment	8	24.31
	Pumping Personnel	8	2.27
	Bulk Equipment	8	8.10
	Bulk Personnel	8	0.97
Post-Job	Workover Rig Spread Rate	8	16.21
	Cleanup & Disposal	0	0.00
	WOC & Testing/Evaluation	12	24.31
	Total	83	100

The Resin Sealant Application Process

Resin sealants have been successfully used as well sealants since the 1940's (Sonnier, 2018). Benefits of resin sealants include improved bonding to pipe and formation, lower volumes required due to cohesion, barrier resiliency (Sonnier, 2018), chemical resistance (Sabins *et al*, 2021) and permeation (Alkhamisetal, 2020). Resin stability in aqueous environments containing dissolved CO_2 is reported by Sabins *et al*. Illustrative data from that reference appears in Table 3.

Table 3: Resistance of Resin to CO2 Degradation (Sabins *et al*, 2021)

Curing Medium	Resin Density (lb/gal)	Weighting Material (Vol%)	Cure Temp	Tensile Strengths 1, 2, 3 4 weeks (psi)
Aqueous CO_2 220ºF	9.1	0	170ºF	3500, 3400, 3300, 3450
Aqueous CO_2 220ºF	12.7	20	170ºF	2500, 2450, 2510, 2530

A significant number of successful squeeze applications of resin are documented (Perez *et al*, 2017, Blank and Brunherotto, 2019, Arroyave *et al*, 2021, Wang *et al*, 2021, Guna *et al*, 2021). Resin sealant's mechanical properties penetration, and chemical resistance produce more resilient barriers than those of Portland cement. Barrier leaks repaired with resin result in more durable deals resistant to mechanical stresses as well as chemical degradation. These resin attributes are especially beneficial in repairing casing leaks. Casing leak squeeze is the most difficult barrier repair usually requiring penetration of sealant through small holes in the casing which is not feasible with cement slurry or even microfine cement slurry. Additionally, casing leaks are often a result of corrosive fluids that degrade Portland cement but do not affect resin illustrated by Table 3. Therefore, resin barrier repairs in these corrosive environments which are often encountered in Permian Basin wells, will be more successful and more durable. Chemical durability of resin sealant is also important to consider when preparing wells for CO_2 storage.

However, resin sealant usage has been considered a specialty application requiring considerable planning, special-order materials, dedicated mixing equipment, trained personnel, and extra time to implement. A sealant application was normally handled as a special project from beginning to end. Resin design was often a unique formula based on designer's preferences. Extensive laboratory design testing was always required to fine tune and confirm the required performance properties of the unique formulation. Resin components were special ordered and custom packaged for the treatment. Rush for application necessitated hot-shot shipment to service site. Relatively small resin volumes typically called for specially sized, third-party blender units to be rented and shipped to location. Often, resins were designed to be very viscous and therefore were difficult to mix. Specially trained blender operators and extra crew to handle the manually added components were required. Finally, resin is tremendously more expensive than cement. All these complicating operational factors of resin for squeeze application are summarized in Table 4.

Table 4: Epoxy Resin Attributes Supporting of and Detrimental to Widespread use as Squeeze Sealant

Pros	
Penetrates	Penetrates and sets in small flow channels or permeability
Less volume	Cohesive, will not dilute.
More durable seal	Better mechanical properties, chemical resistance, higher bond
Cons	
Design	Multiple compositions can be tailored for squeeze application Unique design requires specific volumes of specialty components
Design time	Long and arbitrary. Requires lab testing to fine tune
Cost	Epoxy component costs much higher than Portland cement components.
Manufacturing	Special blending and custom packaging of components
Logistics	Shipped from manufacturing site. No local warehouse. Rush shipping.
Mixing and Placement	Special blender requires extra time and expense. Trained personnel. Extra handling of component packages and unique mixing procedure. Extra pumps.
Waiting on Resin	Designs often require extra time to seal.

Cost and time requirement of a resin squeeze treatment calculated by the same method as that used to calculate the cement squeeze cost presented in Table 1 is presented in Table 5.

Table 5: Cost and Time Estimates for an Average Permian Basin One-Off Resin Squeeze Treatment

Category	Subcategory	Old Process Resin Job	
1st Job		% Hour(s)	Total %
Pre-Job	Design Time	2.4	0.65
	Manufacturing Time	28.9	9.72
	Pre-Job Logistics	28.9	9.72
	Lab Testing Time	57.8	14.59
Job Execution	Loading Handling Time	1.2	0.16
	Resin (4 bbl)	1.2	81.04
	Pumping Equipment	9.6	24.31
	Pumping Personnel	9.6	2.27
	Bulk Equipment	0	0.00
	Bulk Personnel	0	0.00
Post-Job	Workover Rig Spread Rate	9.6	16.21
	Cleanup & Disposal	1.2	2.03
	WOC & Testing/Evaluation	28.9	48.62
Total	1st Job Total	180	209.32
	Savings per 1st Job	-80	-109%

The cost and time for the one-off resin squeeze is more time consuming and costly. Overall cost and time are roughly double that estimated for the cement squeeze treatment in Table 1. However, success of epoxy resin squeeze applications is well documented as noted above. Anecdotal reports cited note squeeze success in one attempt. One hundred percent success is too good to be true considering all the uncontrollable ancillary variables surrounding repair of a leaking wellbore. The authors' review of personal experience from 60+ resin squeeze operations performed over a 5-year period indicated a success rate of 95% for the first resin squeeze. Performance of resins as well sealants is well documented. Resin sealants generally produce more durable seals than Portland cement does due to more effective mechanical properties, strong adhesion, and ability to penetrate. However, cost, supply chain, and application issues prohibit widespread resin sealant application. Implementation of manufacturing style resin sealant workflow was undertaken to reduce these application and acceptance barriers.

Development of Manufacturing-Style Workflow for Epoxy Resin

A manufacturing style squeeze process requires standardization over a broad application range: uniform design, standard component packaging, reliable supply chain, documented procedures with normally available equipment and personnel, short and consistent wait times, and minimum cost. Epoxy resin's wide-ranging capabilities and available components, it is sometimes difficult for job designers to narrow down to a specific formula necessary for a specific job type. Narrowing design criteria to unweighted squeeze application from 65ºF to 230ºF in pipe sizes to 7 inch or less focused the performance boundaries of resin so that development of a standardized kit to target the majority of squeeze jobs encountered in U. S. land operations. The standardized kit concept encompasses components, formulas, lab testing, manufacturing times, packaging, warehousing, shipping, operational procedures, cleanup, and disposal. Cost and NPT would be minimized with a manufacturing-style approach using an epoxy resin kit.

Formulation Design

First, shortening the lengthy list of possible resin components including base resins, diluents, hardeners, set control additives, and bonding aids, and weighting materials. For ease of use in the field and speed to manufacture, it was decided to focus only three components to meet the demands of the wide temperature range (in 10-degree increments). Solids were eliminated as density control was not important for most squeeze operations. A base resin was formulated with a single hardener and set control additives elected from a large pool of possible candidates from countless lab tests. The beauty of three component system is that the three components can be easily arranged in varying amounts to achieve a fit-for-purpose design that aligns with almost any set of well conditions within the specified squeeze application temperature range. Formulaic recipes are now standard issued equipment with kits.

Standardized squeeze application formulation

From the BHCT, and BHST, a specific formula (comprised of just the three components mentioned above) can now be taken from the Formula Matrix (more to come on this later). The recipe will have viable performance data supporting its use including fluid time to ensure safe placement at temperature and shortened initial set and drill out times. Through numerous tests, it was discovered that this could be accomplished for the temperature range of 65ºF to 230ºF by manipulating component ratios of the three-component system.

Minimal Design Confirmation Testing

Generally, epoxy resin components are manufactured more uniformly and with better quality control than materials used in Portland cement blends. More uniform component composition translates to predictable performance thereby eliminating the need for design testing. The data matrix provides what most would consider a finalized recipe. However, if confirmation testing is desired or required, it can be performed with minimal changes to the already curated matrix designs and confirm what is already in the matrix. This “pre-designed” system definitely addresses the last minute, urgent job requests that occur for squeeze repairs.

Reduced Waiting-on-Resin Time with Hardener Combinations

Older versions of resin were plagued with long wait times primarily added to manage extreme temperature increases driven by the resin’s highly exothermic crosslinking reaction. Sonnier (2018) noted exothermic crosslinking reaction as epoxy and hardener react can produce temperature increases of over 250ºF depending on hardener chemistry and resin volume. One approach to mitigating this temperature increase is to reduce hardener reactivity, but this results in extended wait time for the resin to harden. Clever manipulation of hardener chemistry and concentration along with set control additive concentration resulted in development of the standard resin formulations applicable in 4-barrel volumes over the design range with manageable temperature increases. With these revised squeeze formulations and application limited to 7-inch casing and below, wait times have been greatly reduced; especially those 100ºF and below. The combinations witnessed through testing have evolved to include diluent, hardener and set control additive to shorten wait times and decrease operator spread costs.

Standardized Product Packaging

Considering resin’s cohesiveness permeation ability and mechanical properties, it was determined that a four-barrel kit volume was optimum for mixing, pumping, and barrier formation. The four-barrel kit also includes cleanup fluid and two types of operational procedures; a traditional procedure for the resin to be mixed with a pump truck or a procedure for the resin to be mixed in the tote with a portable paddle mixer.

The kit is assembled for ease of mixing and handling by field personnel. Resin can be easily transferred by pump to a mixer. Other materials are contained in pails easily handled by personnel mixing the resin. The kit can be utilized in a myriad of different scenarios, even without a pump truck, when well conditions and well sites can accommodate. The tote that the cleanup fluid comes in can also be utilized for wash up and waste collection allowing the operator to dispose of the diluted fluid easily. Each component has its own sized container, as to reduce the possibility of inputting the wrong product at the wrong time into the mixture. The simplified packaging also allows warehouse personnel to count each item easily and ensure that all parts of the kit are accounted for and make it to location. Once on location, the three different sized containers are easily discernable and easy to handle.

Standardized packaging increases efficiency of resin delivery to the customer. Resin squeeze operations are low volume, and therefore packaging the product in specified volume increments allows the service provider to easily measure the product for the job site. The packaging also allows for appropriate amounts hardener and or accelerator to be added to the formulation for any application within the product’s temperature range. With resin being a relatively unfamiliar operation to most service companies and operators, the standardized packaging and formulation of the product will curb the burden of extensive material planning and design.

Warehousing and Availability

The pre-packaged kit allows for mobility, easy shipping, and placement. The package can be easily counted and shipped to anywhere with a flatbed or box truck. With the of goal of getting product where the work is quickly, a supply of pre-manufactured kits was placed close to the service company field facility. This reduced both manufacturing time and shipping from the previous one-off method.

Temperature range dictates standard hardener concentration

The three-component system was constructed and tested from 65ºF to 230ºF and in holes smaller than or equal to seven inches. A particular base resin, hardener, and accelerator were used in varying percentages to make a matrix (Table 6) of easily understood recipes for quick use.

Table 6: Resin Design for the 4 bbl Manufactory Style Resin

	Pails/4 bbl Mix			Add 20°F to BHST for <7"		Add 35°F from BHST for 7"	
BHCT (°F)	Add 1, # 4 gal	Add 2, # 1 gal	Fluid Time (hr)	Initial Set (hr)	Drill Out Time (hr)	Initial Set (hr)	Drill Out Time (hr)
65-75	9	5	4.5	12	20	8	12
76-90	9	3	4.0	10	18	8	12
76-90	9	5	3.0	10	18	8	12
91-110	9	2	4.5	12	20	8	12
9-110	9	3	3.5	10	18	8	12
111-130	9	2	4.5	12	20	8	12
111-130	9	3	3.0	10	18	8	12
131-160	9	2	3.0	10	18	8	12
131 to 160	9	1	4.5	12	20	8	12
161 to 185	9	0	4.5	10	18	8	12
161 to 185	8	0	5.5	10	18	8	12
186 to 210	9	0	3.5	10	18	8	12
211 to 230	7 or 8	0	4.0	10	18	8	12

Note: Initial set is 100 psi, drill out time is 500 psi,
Fluid time could be + or -30%

Operation

Once the service provider and operator have formulated a design and decided on the volume of product needed for the operation the materials are easily transported from local warehouse in totes for the base resin and drums or handled buckets for the additive materials. Components are easily identified via the container and proportioning is handled through standardized design and materials supplied. The right mix is prepared by emptying all containers supplied into the mixer. Standard mixing order is specified.

The resin operation requires less equipment and personnel than a standard remedial cement job due to the simplicity of mixing and pumping. This flexibility of product handling allows for less equipment (no bulk equipment) on location and only the need of a small transfer pump to deliver the product onboard the mixing equipment. Depending on the volume of the design the resin formulation can be mixed directly into a cement mixing tub, typically 6-10 bbls for most service providers and with some sort of auger mechanism, or in a small batch mixer with a centrifugal pump to deliver the product to the triplex pump truck. The product can also be mixed directly in the tote with the hardener and accelerator, mixed up with a tote blender, and then transferred to the pump truck. There is some risk with this method as the resin and additives create an exothermic reaction and could damage the plastic tote. The preferred method is to mix the product directly on the pump truck to ensure that there is no residual fluid left behind when transferring due to the small volumes. Once the product is pumped and placed in the wellbore the service provider must clean the residual film of resin from the equipment, treating lines, and tubing. The cleanup process is simple using equal volume of cleaning solution per bbl of resin. The cleaning concentrate is diluted at a designed ratio with fresh water and then circulated in the mixing tub, pumped through the lines, and then out to the return tank. Any resin returned to surface is contained in the empty resin tote. Once all cleanup fluids and returns are contained, they can be picked up for easy disposal.

Cost and NPT Reduction from Manufacturing -Style Process Application

Implementation of manufacturing style process to resin squeeze operations resulted in significant cost reduction from the following factors:

- Standardized formulation with no lab testing
- Routine material procurement and handling
- No special rigging or equipment
- Easier, quicker mixing
- No extra personnel
- Easy cleanup
- No special handling of waste or packaging

This reduction was realized without consideration for anticipated resin material cost reductions that are expected to follow with increased volumes that would come from increased use.

Cost and NPT are reduced with the introduction of manufacturing-style resin application into an operator's squeeze, P. & A., and remedial operations. Office, Lab, Engineering, Bulk Plant, warehousing, Logistics, and field operations all benefit from the efficiencies gained by implementing this process. The cost of a manufacturing-style resin squeeze treatment (compared to the cost of a cement squeeze) is presented in Table 7.

Table 7: Cost and NPT Reduction from Manufacturing -Style Process Application

Category	Subcategory	Manufacturing-Style Resin Job	
1st Job		% Hour(s)	Total %
Pre-Job	Design Time	2.4	0.32%
	Manufacturing Time	0	0.00%
	Pre-Job Logistics	2.4	0.41%
	Lab Testing Time	0	0.00%
Job Execution	Loading Handling Time	2.4	0.16%
	Resin (4 bbl)	2.4	81.04%
	Pumping Equipment	9.6	24.31%
	Pumping Personnel	9.6	2.27%
	Bulk Equipment	0	0.00%
	Bulk Personnel	0	0.00%
Post-Job	Workover Rig Spread Rate	9.6	16.21%
	Cleanup & Disposal	1.2	2.03%
	WOC & Testing Evaluation	16.8	28.36%
Total	Job Total	51.8	155.11%
	Savings compared to cement squeeze	48.2	-55%

Application of manufacturing-style process lowers cost of a resin squeeze by 50% compared to the one-off resin process. This is a significant reduction derived from simple process changes. However, the cost of the manufacturing-style resin squeeze is still over 50% higher than that of a single squeeze cement application.

Considering Squeeze Application Success Rates

Comparing treatment cost of the two systems does not paint a complete picture. Earlier, success rates for squeeze treatments with cement vs. resin were compared. Optimistic success rate for cement squeeze was 50%. Thus, optimistically (Jones and Watters, 1998), the average repair of a well leak by squeezing cement requires two applications. Pessimistically (Cowan, 2007), the average repair of a well leak by squeezing cement is 34% indicating the average repair of a well leak by squeezing cement requires three applications. Resin squeeze applications were conservatively estimated to be 90% successful on the first attempt. With one in ten resin squeezes requiring a second attempt, the multiplier to account for cost and NPT to achieve a successful resin squeeze is 1.1.

Cost of a single cement squeeze verses a single one-off resin squeeze or a manufacturing-style resin squeeze is presented in Table 6. Applying average success rates (2 and 3 for cement and 1.1 for resin) to the cost of a single treatment for each scenario yields actual costs also presented in Table 8. Costs are presented as percentages of cost for a single cement squeeze. Similar analysis for NPT is presented in Table 9. Bar graphs comparing single treatment cost and NPT are presented in Figure 1 while Figure 2 depicts the average cost of successfully sealing a leak by squeezing cement or resin accounting for success rates.

Table 8: Cost of Squeeze Treatments Accounting for Success Rates

Squeeze Type	Single Job Cost (% Cement Squeeze)	Success Multiplier	Successful Squeeze Cost
Cement	100%	2	200%
Cement	100%	3	300%
One-off Resin	210%	1.1	220%
Manufacturing-Style Resin	155%	1.1	170%

Table 9: NPT of Squeeze Treatments Accounting for Success Rates

Squeeze Type	Single Job NPT (% Cement Squeeze)	Success Multiplier	Successful Squeeze NPT (% cement Squeeze)
Cement	100%	2	200%
Cement	100%	3	300%
One-off Resin	180%	1.1	198%
Manufacturing-Style Resin	52%	1.1	58%

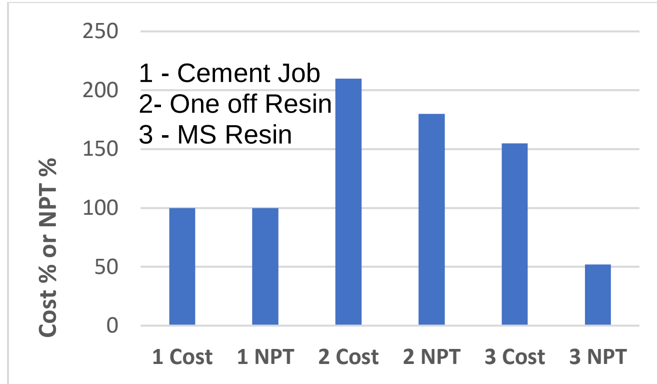

Figure 1: Comparison of Cost and NPT for a Squeeze Treatment using Portland Cement, One-off Resin, and Manufacturing-Style Resin (MS Resin)

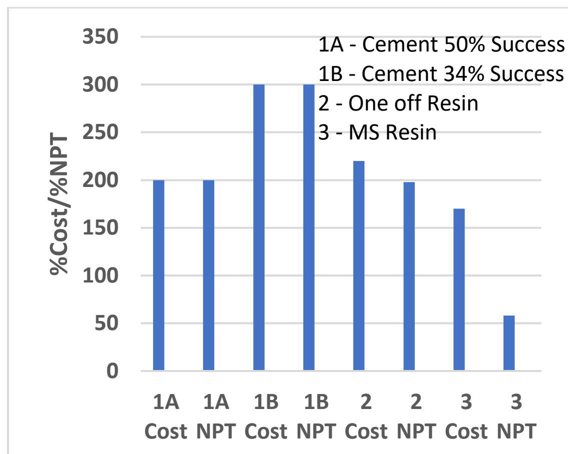

Figure 2: Comparison of Cost and NPT for Effectively Sealing a Barrier Leak using Portland Cement, One-Off Resin, and Manufacturing Style Resin (MS Resin)

Considering resin's much higher squeeze success ration, the cost of repairing a well barrier breach with resin is actually lower cost on average using the manufacturing -style process than with cement when considering remedial work on a number of wells.

Field Example

Operator in the Permian basin had a pinhole leak at 4200 ft in the production casing of a producing well. The well was identified because the backside of the production tubing could not hold 500 psi as a regulatory requirement. An injection test was performed with a maximum allowable pressure of 1000 psi to ensure there was no further damage to the wellbore or surrounding formation. The injection rate at 950 psi was a consistent 0.5 bpm. The ISIP was 700 psi and the well bled down to below 500 psi in less than 30 minutes. The minimal injection rate and pressure restrictions for this job made conventional cement squeezing a risk due to premature cement dehydration. The well was treated with a resin formulation of 3 bbls. The resin was spotted over a bridge plug and the leak interval and tubing was pulled out of the plug. Pressure was applied through the tubing with a closed annulus and a total of 0.75 bbls of resin was injected into the well before shutting in. The well was bled back to 300 psi before shutting in and waiting to harden. The resin was drilled out the next day and the leak held for the 500 psi pressure test. The well is now back online producing.

Conclusions

1. Implementation of manufacturing-style workflow for resin squeeze application improves execution, reduces cost and NPT. Considering relative success ratios for squeezing with Portland cement versed with epoxy resin, the cost and NPT are less with manufacturing-style resin than with cement. A successful manufacturing-style resin squeeze repair average cost is 25% to 50% less and is performed with 75% less NPT than a repair using Portland cement.

2. Mechanical properties, adhesion, chemical resistance (especially to CO_2), and penetration of epoxy resin deliver superior performance for squeeze seal applications. Barrier repairs using resin are more durable and resilient, and resin repairs resist chemical degradation. These attributes translate to expectation of longer-lived barrier repairs and lower chance for additional barrier repair. Barriers repaired with resin should provide more stable foundation for abandonment when the time comes. These factors improve ESG considerations for wells remediated with resin.

3. Manufacturing-style resin squeeze implementation continues with continuous review to identify additional process improvements. Identification and implementation of additional improvements will further reduce cost and NPT of squeezing with resin.

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