

## Packer Isolation in Hurricane-Damaged Well Sealed Using Innovative Resin Application

Jorge Leal, David Brown, Jeff Watters, and Chris McDaniel, CSI Technologies LLC; Cliff Meade, Wild Well Control, Inc

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### Abstract

Permanent abandonment of wells on a hurricane-damaged platform in Gulf of Mexico (210ft water depth) presented an unusual challenge. Casings sheared below the mudline requiring a large scale open excavation to 38ft below mudline. Liftboat use was impractical due to extents of excavation, and safe diver access was not possible. Traditional plug and abandonment methods utilizing coiled tubing were unfeasible. This situation mandated innovative methods to abandon the wells safely and reliably. One challenging requirement existed on three wells: per BSEE regulations an annular barrier was necessary in the 2-7/8" by 7" annulus above the production packers. These secondary barriers needed to be placed before further plugging operations could be initiated. The inability to connect to the well by conventional methods required the use of novel resin sealant and development of a unique placement method.

Gravity placement by displacing sealant into the annulus and allowing it to freefall to the packer depth was the only method available for spotting fluids. The sealant must be a fluid with density greater than the brine in the annulus. It must remain fluid for the time required to freefall to the top of the packer and then solidify. To accomplish this, the sealant must remain cohesive and not undergo dilution by the brine. A resin sealant fitting all requirements was pumped for this purpose.

This paper describes the successful application of a resin sealant by gravity displacement. A total of three barriers were created via this method allowing appropriate Plug and Abandonment operations to be completed.

### Introduction

Development of innovative Plug and Abandonment (P&A) processes, procedures and materials commonly results from merging challenging environments with industry experts and cost saving efforts. This paper details such cases where the challenges encountered after a platform was overturned by Hurricane Katrina in 2005 led to the unique deployment of resin by gravity displacement.

This novel application of resin technology allowed for the placement of a Bureau of Safety and Environmental Enforcement (BSEE) required secondary barrier in the A-annulus above the production packer in three out of the eleven

downed wells. The annuli in these wells would have otherwise been inaccessible due to numerous safety concerns associated with such an extensive excavation and wellbore limitations, such as shallow holes in the production tubing.

Extensive dialogue and collaboration between the service provider and operator provided a clear understanding of the limiting well conditions that would require special field considerations. The decision was made to circumvent the inability to inject or circulate through tubing into the A-annulus above the production packer, reduce the high risks posed to abandonment operations with lift boat use and bypass the inability to use coiled tubing during operations, by allowing a densified, stable and cohesive sealant with optimal bonding properties to free-fall down to the top of the packer. The search for a fluid capable of placement directly in the A-annulus, and gravity displacing through greater than 4300 ft of 8.6 lb/gal field salt water (FSW) with 3% KCL, and that could come back together to form a plug narrowed the list of options to an epoxy resin sealant.

As a result, the unique challenges and extensive research led to the use of a multi-functional/adaptable resin in combination with a progressive placement method. The innovative applications proposed would require the careful and timely deployment of mixing equipment and newly developed procedures. The proper selection of equipment and the availability of detailed procedures would ensure the adaptability of the field personnel to the unconventional placement technique and sealant.

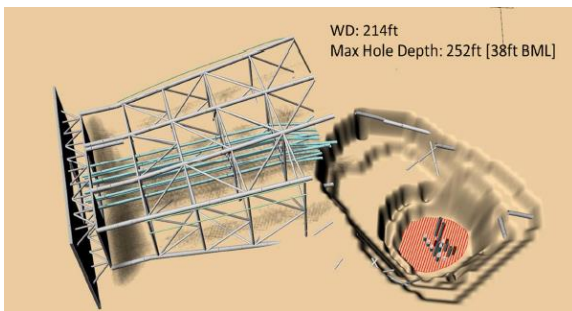
This paper demonstrates, through the review of the case history, the successful placement of balanced plugs for packer isolation by gravity displacement of resin sealant. The objective is to make evident the benefits that can be realized by resolving unusual decommissioning challenges with innovative placement techniques and emerging resin technology.

### History of Platform and Background

To achieve the operator's goal of safely, efficiently, and cost effectively plugging and abandoning these wells, the history of the wells and plug placement challenges had to be thoroughly discussed during the design and development stage of the project. A thorough evaluation of existing data and the carrying out of well diagnostics work were critical steps in

designing a project-specific well abandonment program. The findings from the lengthy planning process and well analysis detailed the conditions of each of the damaged wells and revealed the distinct conditions and limitations of the three wells requiring the deployment of the resin method by gravity displacement.

The eleven well, eight-pile production platform set in 214 ft of water in the late-1960's was toppled over during Hurricane Katrina causing all casing to either deform or shear below the mudline. The wells on this platform were primarily single or dual strings gravel pack completions. Figure 1 illustrates the scale of the extensive excavation required. All stakeholders found lift boat operations would introduce an unacceptable risk of hole collapse from placement of the lift boat leg's near the excavation.



**Figure 1: CAD Drawing Showing Rendering of Excavation**

Early in the development of the abandonment program, a verdict was made to avoid liftboat use for the downed platform P&A activities. The potential for cave-ins due to the liftboat's legs effect on the adjacent excavation was determined to be unacceptable. The walls of the excavation were angled such as to produce stable slopes under static conditions and their stability would be compromised by the introduction of adjacent structures. Instead, operations were to occur from a derrick barge, a large anchored floating vessel equipped with a dynamic positioning system. The derrick barge would provide the required deck space needed for saturation diving and intervention equipment without affecting the excavation area. An additional benefit provided through the use of an anchored floating vessel is that existing archeological and sensitive biological areas near the downed platforms would be minimally disturbed. Additionally, the involved parties determined the angle of the remediation wellheads would make coil tubing operations unfeasible. As a result, operations were to be completed unconventionally via wireline deployed from a derrick barge.

Over the course of several months, the P&A plan and procedures were developed and submitted for approval. In early 2014, the Application for Permit to Modify (APM) was approved by BSEE, initiating the start of P&A activities. On initial site inspection, a pneumo-fathometer survey was performed approximately 200' away from center of the platform location to establish a water depth datum to which final cut depths on tubulars would be referenced. Table 1 and

2 details the tubular information pertaining to the three unusual well cases.

**Table 1: Tubular Information**

Dimensions and Strengths				
Casing/Tubing	OD (in)	WT (lb)	Grade	Depth (ft)
Drive Pipe	30	196.08	-	435 - 439
Surface	10-3/4	40.5/ 45.5	J-55	3133 - 3181
Production	7	26/29	N-80 Butt	11691 - 13375
Tubing	2-7/8	6.5	N-80 ABC Mod	7422 - 11348

**Table 2: Tubular Information (continued)**

Dimensions and Strengths					
Casing/Tubing	Drift	Burst	Collapse	ID Cap bbl/ft	Ann Cap bbl/ft
Drive Pipe	-	-	-	-	.69070
Surface	9.794 9.894	3580 3130	2090 1580	.09612 .09812	.04857 .05052
Production	6.151	7240	5410	.03826	.03023
Tubing	2.347	10570	11160	.00579	

The proposed abandonment plan contained the following steps:

1. Survey entire damaged platform and identify/mark all wells from wellhead to mudline.
2. Perform kill/bleed operations via existing wellheads until all tubing and annuli has no pressure.
3. Remove jacket structure in way of planned excavation area. Remaining jacket structure would be left as a reef in place.
4. Excavate site until straight and round conductors are accessible.
5. Dress surface casing, production casing and tubing as needed for installation of fresh 2 stage wellhead and tree.

Subsequent to the above operations, diagnostic work was performed. The following details the steps and results of the diagnostic work completed on 3 of 11 P&A campaign wells.

First, wireline BOP's and pump-in sub on tree were rigged up to the 2-3/8" tubing. Then, after surface lines and 250 ft of FSW flexible hose was rigged up to the casing inlet valve and pressure tested, the B-annulus was pressure tested for 15 min. At that time, a pressure test performed on the A-annulus verified tubing and casing communication existed via possible shallow tubing holes due to the simultaneous pressure rise in the tubing and A-annulus. Communication between tubing and casing was further confirmed by pumping a dye pill and monitoring displacement volumes and returns. The highest shallow tubing hole location was then estimated based on displacement volume. Next, an injection test via the 2-3/8" tubing was performed yielding no injection into the sand perforations at approximately 7600 - 8600 ft RKB. As a result of the inability to inject into the sand perforations and the confirmed tubing holes located above the upper gravel pack

production packer for each of these 3 wells, a variance to the 30 Code of Federal Regulation 250.1715 would have to be requested. Without exploring unconventional options, dump bailer runs would be the only available placement method for meeting the permanent well plugging requirements.

In these cases, dump bailing 50' of cement on top of a bridge plug set in tubing 50 to 100 ft above the top of the open perforations satisfies the plugging requirements for isolating open perforations. However, a second independent barrier is required in the A-annulus directly above the production packer. Though the tubing can be perforated above the production packer via wireline, the shallow tubing holes inhibit the circulation of a balanced cement plug and the large volumes necessary make dump bailing cement impractical. Therefore, these three wells required a novel solution for secondary barrier placement.

The resin detailed in this case history is a two-part system consisting of an epoxy resin and chemical hardener specialized for use in well remediation operations. Each resin design is formulated and optimized to meet well-specific parameters and can be easily mixed and placed with conventional cementing equipment. Epoxy resin exhibits superior cohesive, mechanical, chemical and rheological properties that result in a product that not only outperforms cement as a barrier but was ideal for the unique difficulties encountered on this project.

In recent times, resin systems have found great utility in every stage of a well's life from drilling to abandonment. Three of the most typical resins deployed are epoxy, phenolic, and furan resins<sup>2</sup>. Common applications for oilfield resins include fluid shut off treatments, consolidation of weak permeable formations, remedial squeeze jobs, and as lost circulation material in near-wellbore thief zones. Although the three types of resin previously listed have a number of features in common, such as improved resistivity to degradation from conventional acid treatments than cement and the ability to penetrate small flow channels due to the availability of solids free formulations, epoxy resin was selected due to the unique wellbore challenges encountered in these wells.

The following section stipulates the special field considerations that led to the BSEE approval to deploy resin sealant by method of gravity displacement in the first of three cases.

### Special Field Considerations

The unconventional abandonment via wireline of a hurricane damaged well introduced sealant placement limitations that affected the final sealant placement procedures selected for this well. Diagnostic data acquired after the installation of the new wellhead confirmed the inability to inject into the sand perforations and to circulate through new perforations above the production packer due to suspected shallow tubing holes. These limitations led to the development of a novel placement protocol that utilized innovative resin technology to create a packer isolating balanced plug.

After much deliberation, it was determined that to solve the specific difficulties encountered in this well, a sealant would

have to be placed directly in the annulus and allowed to gravity displace through greater than 4030 ft of 8.6 lb/gal field salt water with 3% KCL and then coalesce on top of the production packer to form a solid secondary barrier. To achieve this, a detailed placement procedure would have to be developed to ensure field personnel of all levels adapt to this unconventional placement method. Moreover, the sealant must have strong cohesive properties to withstand the harsh fluid flow environments and be minimally susceptible to dilution by the brine.

A review of commonly-used oilfield sealants narrowed the list of materials capable of withstanding the unforgiving proposed placement process to epoxy resin. The conventional cement systems typically used during P&A operations were inadequate due to the ease in which the cement slurries disperse in water-based environments leading to particulate separation and hindered in-situ mechanical properties. On the other hand, epoxy resins optimized for water-base environments, demonstrated a strong cohesive nature which minimized dilution while gravity displacing<sup>1</sup>. Moreover, the epoxy resins capability of reforming into a uniform fluid plug after propagating through seawater and then curing into a solid barrier was optimal for this well. Also, the low viscosity epoxy allowed for the addition of inert solids for adjustment of the sealant density and remained stable. This feature allowed for the prerequisite density hierarchy to be achieved. In addition, adjusting diluent and hardener components of the epoxy resin system permitted for customization of the resins fluid time. This capability was important since a prematurely setting resin would hinder the gravity displacement process and the sealant's ability to reform in a uniform solid plug.

An exemption to BSEE's plug length requirement of 300 ft of fill was granted allowing 8 bbl of resin sealant to be balanced across the A-annulus and tubing directly above the production packer. The limited annular volume to the shallow tubing holes was the reason for the reduced fill volume. The approved plug volume called for the use of a 10 bbl blender equipped with a centrifugal pump for recirculation. A triplex pump with appropriately sized plungers and sufficient hydraulic horsepower would be used to displace the resin into the annulus through a 1-1/2" flexible pump hose rated to 5,000 psi and inserted through the A-annulus casing valve. The volumes required in this application and the associated exothermic chemical reaction that occurs during curing was not viewed as a concern due to the use of a high temperature activating aromatic amine hardener that exhibits a slow, delayed cure at surface temperatures.

With the proper placement protocol in place and the development of an optimized, cohesive epoxy resin, the limitations of this well would be circumvented. Upon proper execution of pumping operations and a specified wait on resin cure time, a trip in hole to tag the top of the balanced resin plug inside the tubing would determine success. The possibility of unknown condition preventing the placement of a balanced plug above the packer and leading to resin not being tagged inside the tubing existed. In the event resin was not tagged in the tubing, a successful pressure test of the

annulus would be used for determination of successful plug creation.

### Placement Method Development

With an understanding of the unique wellbore conditions encountered on this well a novel sealant placement procedure was developed that took into account the following concerns and issues:

- Resin design for this application would incorporate a high temperature hardener that would take weeks to solidify if spilled on the seafloor.
- Concerns for personnel and equipment if significant change in sealant temperature detected while mixing.
- Circulation rates and pressures.
- High annular velocity of sealant if placed through workstring inserted into the tubing.
- Contamination risk of saturation diver/s if pump rates exceeds fall rate of the resin sealant.
- Shallow tubing holes and gas lift mandrels (GLM) limit resin displacement volumes due to risk of circulating back up tubing.
- Blender and pump sizing requirements.
- Potential for pressure increase during exothermic chemical reaction of resin due to increased well temperature.
- Blender, lines, and pump clean-up efficiency and waste disposal.

Each outlined issue and/or concern was fully deliberated between the Operator, Service Company, equipment providers and resin sealant experts. As a result, the decision was made to pump resin directly into the A-annulus through a high pressure hose inserted through the casing valve. Sufficient hose was inserted in the annulus so that no risk in circulating resin out of the casing valve existed when pumping between ½ to ¾ bpm. These pump rates were used to calculate the annular velocity in ft/min and then compared to the resin sealants estimated fall rate of 25 ft/min. At a ¾ bpm resin pump rate, the annular velocity equaled 24.8 ft/min. This confirms there would be no risk in circulating sealant back up the annulus. In addition, the measured depth of the hose inserted in the A-annulus was sufficiently deep to prevent the tail end of the sealant from obstructing placement of a future intermediate plug.

In this case, no pressure was to be held on the sealant while it cured. Due to this fact, concerns with exceeding the 5,000 psi wellhead pressure limit were alleviated. Furthermore, instruction for cleanup and disposal of waste was clearly communicated to pump and blender technicians so proper precautions would be taken while cleaning equipment. The resulting waste from cleanup operations is to be pumped back into the stainless steel IBC totes that transported the resin material to location. The totes were then sent off for waste disposal and cleaning.

A generic version of the developed placement method is detailed below:

1. Preparation for resin sealant treatment
  - Hold pre-job safety meeting with all involved parties.
  - Perforate two joints of tubing above packer
  - Pull GLM's and replace with dummies
  - Apply tubing patch across suspected hole location.
  - Establish circulation rates and pressures with field salt water.
  - Verify correct quantities and types of sealant components are on location.
2. Final check with dye to ensure there are no holes further down the well
3. Pumping of resin and displacement at > 0.5bpm and less than < 0.75 bpm
  - Position someone near the blender tank with infrared thermometer to ensure excessive heating does not occur (>20° F above ambient).
    - Contingency plan in place for safe transfer of material out of blender.
  - Verify mixing of resin components is performed per mixing instructions.
  - Pump 8 bbls of resin sealant through 1-1/2" flexible pump hose at prearranged rates.
  - Displace with SW to clear lines and 1-1/2" flexible pump hose.
4. After pumping resin and displacement
  - Shut in tubing and casing
  - Diver close valve on pump hose and return to surface for additional cleaning
  - Diver installs diffuser on casing. Opens casing to allow full free fall of resin in casing annulus. Approximate fall time 5 hrs.
  - Diver installs diffuser on tubing. After resin has fallen required distance to packer, tubing will be opened to allow resin to balance across tubing and casing.
  - Shut in well. Wait on resin to cure.

At this stage, it was found that proper planning of the field operations was imperative to the outcome of this project. If any of the detailed issues or concerns were overlooked, improper execution of the job may have led to costly job delays and/or failure. With the placement procedure outlined, the proper development of a resin sealant that would meet the rigorous demands of gravity displacement, through greater than 4300 ft of well fluid and down to an otherwise inaccessible production packer, could commence.

The following section discusses the process for developing a tailor-made epoxy resin sealant system designed to meet this well's specific configuration and operational challenges.

## Sealant Development

To develop a well specific resin solution, the resin design and lab testing needs to be approached systematically. A series of non-standard tests are typically performed addressing the specific conditions to be encountered during the placement of the sealant. In the ensuing sections, the conditions that exist for placing a balanced resin plug for packer isolation are addressed through the overview of selected test methods and laboratory results.

## Mixability

The un-weighted base epoxy resin component representative of the sealant systems used for this type of plug application has a relatively low viscosity ranging from 100 to 425 cP. The type of inert weighting material added to the base component and the percent loading by weight of resin (BWOR) required for a set final density affects the viscosity of the weighted base epoxy resin. The resin designs final viscosity and density is in most cases lower than the solid laden base resin component due to the introduction of relatively low viscosity hardeners, S.G ~1.02. In the field, the addition of hardener is reserved for the final stage of the blending process. Consequently, the hardeners contribution to viscosity reduction is not realized until the final moments of the blending process. For this reason, it is critical the resin sealant system is design to be mixable in its pre-hardener state. This is achieved through a mixability test designed to determine if trouble with mixing may arise on location due to the choice in weighting material and density selection.

The simple test method involves adding the designated grams of un-weighted base resin component to a clean mixing cup and placing the filled mixing cup under a IKA RW 20 digital tabletop mixer equipped with a R1382 propeller stirrer or comparable tabletop mixer setup. Then the tabletop mixer is positioned so the blades of the propeller are located  $\frac{3}{4}$  of the base component height from the bottom of the cup. The tabletop mixer is subsequently operated at 600 rpm +/- 50 rpm. After 1 min of mixing, the designated grams of weighting material are added to the mixing cup gradually over 2 minutes. After the allotted two minutes, a visual inspection of the mixture in the cup is performed. If the added weighting material is not fully dispersed and homogenous in the base resin component, usually depicted by non-wetted solid particles at the surface of the mixture, the system is labelled as difficult to mix. This type of finding would result in the adjustments to the base resin components, the weighting material type and/or density.

Findings from this investigation resulted in the further evaluation of two weighting material types and corresponding final densities.

1. 14 lb/gal system loaded with fine weighting agent #1.
2. 16.5 lb/gal system loaded with exactly ground weighting agent #2.

## Stability

The two aforementioned systems were then evaluated for stability. A static settling test was performed on the solid laden

systems to evaluate their ability to remain stable at bottom hole temperatures. Although the stability testing was not performed under dynamic conditions that would introduce constant shear, this testing was used as an initial indicator of the solids affinity to precipitate out of the solution during gravity displacement.

This test method involves pouring 250 mL of a conditioned resin system into a 250 mL graduated cylinder and then cured vertically in an oven at bottom hole temperature (BHT). The conditioning process involves placing the mixed resin sealant into an atmospheric consistometer and stirred at the lesser of BHT or 190°F for 30 min. Once cured, the solidified resin is removed from the 250 mL graduated cylinder and is then sliced into 3 evenly sized, labeled sections. Using the Archimedes' Principle, the density of each section of sample is measured by totally immersing the sample in water and recording the weight while suspended and while sitting on the bottom of the container. The percent variance between the top, middle and bottom sections was then calculated. The system with the least percentage variance between the sections would be better at suspending the solids in the solution. In other words, the more stable suspension exhibited stronger adhesive forces between the liquid resin mixture and the solid particles<sup>3</sup>.

This testing resulted in the focused testing of the 14 lb/gal system loaded with the fine particles of weighting agent #1. This system had a variance of 0.4% which is within oilfield cementing best practices acceptable limits of less than 10%.

## Cohesiveness

The unique application method utilized to create a balance resin sealant plug above the otherwise inaccessible production packer demanded the use a cohesive, weighted resin system. To evaluate the resin systems cohesiveness and ability to avert dilution a gravity displacement test was performed and the sealants response was noted.

To start, a 2000 mL graduated cylinder was first filled with 1640 mL of lab mixed 8.6 lb/gal FSW with 3% KCL. Then, 360 mL of mixed resin sealant was injected directly below the water line in 60 mL batches. This was achieved by filling a 60 mL wide-tip syringe with sealant and injecting over 10, 8, 6, 4, and 2 sec period. The modified time to inject allows observation of the sealants behavior under gentle to vigorous injection. The sealants response after injection and during its gravity displacement was carefully observed and noted between each subsequent batch. Furthermore, using the 0.1825" ID of the 60 mL syringe nozzle, the nozzle velocity for the gravity displacement test was approximated to be 70, 87, 117, 175 and 350 ln.ft/min for the 10, 8, 6, 4, and 2 sec injection period, respectively. The nozzle velocity for the 1.5" high pressure hose with assumed ID of 1.2" was approximated to be 357 and 536 ln.ft/min at the  $\frac{1}{2}$  and  $\frac{3}{4}$  bpm pump rates, respectively. Comparing the syringe and hose nozzle velocities, it is evident that the  $\frac{1}{2}$  bpm pump rate is best represented by the vigorous 2 sec injection test due to the near matching nozzle velocities. The  $\frac{3}{4}$  bpm pump rate would introduce a higher amount of shear than that evaluated in the

gravity displacement test yet is expected to be in the same order of magnitude.

The sealant demonstrated superb cohesion when gently to vigorously introduced into the lab made 8.6 lb/gal salt water with 3% KCL well fluid and allowed to gravity displace to the bottom of the graduated cylinder. The system was described to string, or “rope”, out of the syringe and/or form droplets that propagate to the bottom of the graduated cylinder. The resin sealant demonstrated it would reform into a homogenous plug upon finding the bottom. When vigorously injected the amount of droplet formation was noted to increase indicating sensitivity to the shearing forces caused by high rate injection. Regardless of the amount of individual droplet formation the mixed resin sealant demonstrated it would matriculate through the well fluid and coalesce into a plug at bottom. This droplet behavior is attributed to the strong adhesive forces that binds the weighting material with the liquid resin mixture and prevents the separation of the solids even when vigorously sheared. The epoxy resin’s immiscibility in water-based fluids consequently allows for the unique application of resin by gravity displacement.

### Fluid Time/Set Time

In this application the planned ‘fall-to’ depth was 8400 ft RKB. At an average fall rate of 25 ft/min, the sealant needed to stay liquid and be able to re-coalesce after approximately 06:00 hr:mn. A modified penetrometer test was performed at the application temperature to evaluate the curing process and obtain the fluid and set time properties.

The modified penetrometer test involves the monitoring of the sealants level of gelation. After mixing the epoxy resin system at room temperature, 2” by 2” molds are filled with the sealant and placed in a water bath at BHT. Lab personnel use a small 3/16” diameter rod to measure the level of gelation hourly for the first 12 hrs and every 4 hrs, thereafter. A value from 1 to 6 is assigned to each measurement. A 1 denotes the system is a viscous liquid while a 6 represents the resin is fully cured and does not indent. As a result, a resin system was designed with an appropriate loading concentration and type of diluent and hardener to achieve an 8 hr fluid time. In addition, the final design demonstrated to be suitably hard-set for pressure testing after 48 hrs.

### Bonding Properties

Historically cement has been the material of choice to create barriers in wells being permanently abandoned. However, various properties of cement such as shrinkage, gas migration during setting, and fracturing after setting, are not well suited for creating a long-term impermeable seals. In addition, cement systems disperse easily when contact is made with water-based fluids leading to separation and dilution of the particulates in the system. The high-cost associated with decommissioning operations requires a secondary barrier specifically formulated to create a long-term impermeable seal after gravity displacing thousands of feet.

The first bonding property assessed for each material was the hydraulic bond strength, which provides insight into the

materials ability to withhold hydraulic pressure. In this case, the packer was simply being isolated with a balanced resin plug due to BSEE requirements but serves as a hydraulic pressure barrier if a production packer seal failure occurred in the future.

The second bonding property assessed for each material was the shear bond strength, which determines how well the material can support the casing. Later plans to cut and pull the tubing string will result in some level of load distribution among the A-annulus barriers from the weight of the remaining tubing. This requires the resin system exhibit good shear bonding properties.

Findings showed that not only would the resin sealant gravity displace through seawater without diluting, which is uncharacteristic of cement, but that the resin sealant offered far superior mechanical and bonding properties than the conventionally used barrier material. Figure 2 and 3, below, demonstrate the benefit to mechanical seal integrity that a superior epoxy resin sealant can provide.

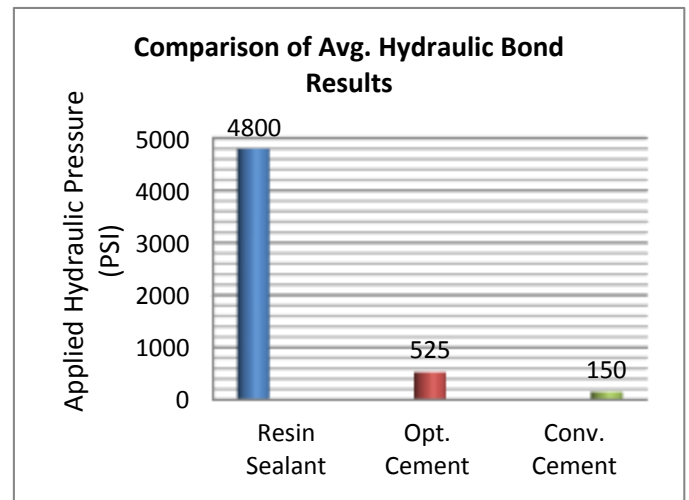


Figure 2: Comparison of the hydraulic bond results for the resin sealant, optimized cement and conventional cement.

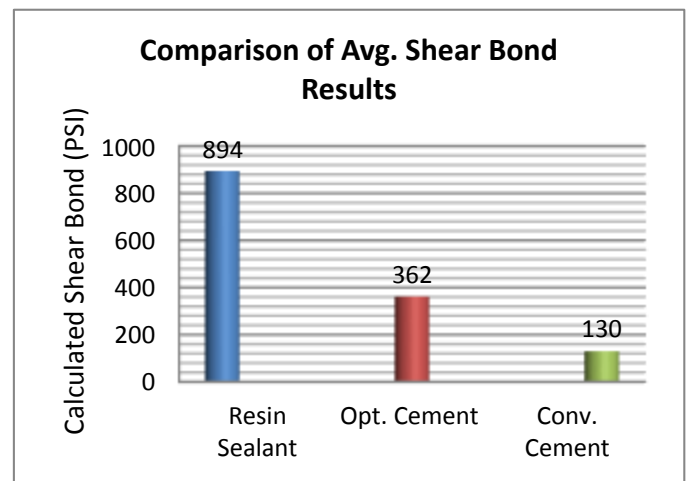


Figure 3: Comparison of the shear bond results for the resin sealant, optimized cement and conventional cement.

Although the optimized cement system provided hydraulic bond improvements over conventional P&A cement system, the resin system created a seal vastly superior over either cement system. The optimized cement system was able to withhold 3.5 times the hydraulic pressure applied to the conventional cement system and the resin sealant held back 9 times the hydraulic pressure withheld by the optimized cement system. This indicates a resin plug would create a seal capable of withholding much higher annular well pressures than the tested cement systems.

The resin sealant demonstrated it can withhold 2.5 times the force necessary to shear the optimized cement system from the pipe. Furthermore, the optimized cement systems shear bond strength was approximately 2.7 times the calculated shear bond estimate of the conventional P&A cement system.

Factors encountered in aged wells, such as temperature induced cyclical stresses and cement bond deterioration, often compromise the mechanical seal integrity provided by cement. The laboratory investigation into the bonding characteristics demonstrate how using epoxy resin can relieve long-term mechanical seal integrity concerns due to resins superior ability to withhold hydraulic pressure and support casing. The added benefit of dilution and chemical resistance provided by the epoxy resin sealant makes for an optimal material substitute for plug creation.

## Conclusions

The unique challenges introduced by the condition of the wells in this hurricane downed platform prevented conventional plug and abandon methods from being utilized leading to the novel deployment of resin by gravity displacement. The inability to place a balanced plug above the A-annulus production packer by traditional means resulted in the combination of a novel placement method with an emerging resin product to create a BSEE approved barrier in these wells. A total of three barriers were successfully created via this method allowing for ensuing Plug and Abandonment operations to be completed. The unique properties of epoxy resin played a vital role in the safe, cost efficient abandonment of this hurricane downed platform.

1. Epoxy resin sealants with density slightly greater than the wellbore fluid will gravity displace down the annulus, coalesce and cure to form a solid seal.
2. Proper consideration of particle sizes of inert weighting material, sealant viscosity and downhole conditions, allows for stable densified systems.
3. Adjustment of hardeners and/or accelerators allows sufficient fluid time for the immiscible resin sealant to gravity displace to the zone of interest.
4. Low level of droplet dispersion noted due to high rate displacement shear levels minimally effects the droplets matriculation through the well fluid.
5. Bond properties between an epoxy resin, an optimized cement system, and a conventional cement system showed significant benefits to hydraulic and shear bond when using an epoxy resin plug.

## Acknowledgments

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## Nomenclature

<i>APM</i>	= <i>Application for Permit to Modify</i>
<i>BHT</i>	= <i>bottomhole temperature</i>
<i>BSEE</i>	= <i>Bureau of Safety and Environmental Enforcement</i>
<i>%BWOR</i>	= <i>percent by weight of resin</i>
<i>cP</i>	= <i>centipoise</i>
<i>°F</i>	= <i>degrees Fahrenheit</i>
<i>FSW</i>	= <i>field salt water</i>
<i>ft</i>	= <i>feet</i>
<i>GLM</i>	= <i>gas lift mandrel</i>
<i>in</i>	= <i>inches</i>
<i>KCL</i>	= <i>potassium chloride</i>
<i>lb</i>	= <i>pounds</i>
<i>lb/gal</i>	= <i>pounds per gallon (density)</i>
<i>ln.ft/min</i>	= <i>linear feet per min</i>
<i>mL</i>	= <i>milliliters</i>
<i>P&amp;A</i>	= <i>plug and abandon</i>
<i>RKB</i>	= <i>rotary kelly bushing</i>
<i>&gt;</i>	= <i>greater than</i>
<i>&lt;</i>	= <i>less than</i>

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