



Preventing Annular Flow After Cementing: Pulse It!

John Aslakson, W&T Offshore; Dale Doherty, BJ Services and Ed Smalley, CTES, L.P.

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Abstract

The first cement pulsation operation to prevent annular flow/pressure after cementing in an offshore environment was successfully performed in the Gulf of Mexico (GoM). Cement pulsation helps to prevent annular flow after cementing by retaining the hydrostatic pressure of the cement column as it sets, until such time as the cement has developed sufficient static gel strength to resist fluid influx.

This paper provides a summary of the key challenges associated with adapting the cement pulsation process from its historical application (production casing cemented in hardrock formations on land) to the shallow marine sediments commonly present when cementing conductor or surface casing strings in the GoM. The paper also provides an overview of the equipment and cement pulsation pre-job design considerations. Four shallow offshore GoM casing strings were pulsed, and the results from those wells are reported.

Introduction

The offshore exploration and production industry has been plagued for years by annular flow after cementing of shallow conductor/surface pipe in the offshore Gulf of Mexico. The issue has been studied, potential solutions have been explored, but cost-effective mitigation of annular flow after cementing continues to be a significant, ongoing problem. At best, GoM Operators are incurring significant additional well costs to avoid or remedy this issue - - while at the other end of the spectrum, annular flow can potentially result in loss of human life and the entire rig.

MMS Safety Alert No. 216, issued in October, 2003 noted that "annular flow related to cementing surface casing has been identified as one of the most frequent causes of loss of control incidents in the Gulf of Mexico." Past studies have determined the root cause of this problem is due to the loss of hydrostatic pressure of the cement column during the cement setting process. A cost-effective solution to this problem could result in a significant positive impact on offshore safety. It could also help stimulate additional offshore leasing, drilling, and production of the U.S. offshore GoM hydrocarbon resource base.

Hydrostatic pressure loss of the cement column immediately after cementing was documented in the

early 1980's as the root cause of the fluid migration problem¹, which is commonly associated with annular flow after cementing. The sequence of events associated with failure of the cement begins after the liquid slurry is put in place. The cement, through its bond to the casing and formation, begins to develop initial strength and support its own weight. Since the result of this action is cumulative over the length of the cement column, a significant reduction in hydrostatic pressure may be experienced in deeper sections of the cement column as the slurry moves through the transition phase.

If certain field conditions are encountered, the resulting underbalanced condition can allow gas migration into the unset cement column. The end result may include creation of a channel to surface and flow or pressure on the annulus.

A patented cement pulsation technique² was developed to help maintain the original hydrostatic pressure of the cement column during this transition period, until such time as the cement develops sufficient strength to resist fluid influx. The cement pulsation technique entails application of low frequency, small amplitude water pressure pulses on the annulus immediately after cementing.

In addition to improving the cement quality, a patented analysis technique³ of data acquired during the cement pulsation process provides a direct indication of the downhole cement setting process. The analysis provides validation of the slurry set times recorded in the lab (under simulated downhole conditions) and can be used to refine future cement slurry designs. For offshore applications, this indication of the downhole cement setting progress could help eliminate unnecessary waiting-on-cement (WOC) time and reduce costs.

Initial application of the cement pulsation technique focused on improving cement quality for production casing strings cemented on land. This approach was utilized in order to refine the pulsation equipment operating technique and to ensure the equipment was robust prior to initial applications in the higher-cost offshore operating environment.

The objective of this paper is to report the current status of the cement pulsation technology as it has been adapted for prevention of annular flow after cementing in offshore environments, and to report the field results

from the initial offshore application.

Cement Pulsation Technique

Following cement slurry placement, the annulus is sealed at the surface and the cement pulsation equipment applies low-pressure water pulses to the wellhead annulus. The annulus is pulsed with a pre-determined pressure that is specifically tailored to the individual wellbore conditions. The pulse pressure is held on the annulus for a short period of time, and the water pulse is subsequently allowed to flow back from the wellbore into the pulsation unit water tank. A complete pulse cycle takes 30-45 seconds to complete. This pulsing action is applied in a continuous fashion until the compressible volume of the cement column declines to a stable value, or until the slurry has reached approximately 500 lbs./100 sq. ft. Routine cement pulsation operations typically last for 4-6 hrs., depending on slurry design.

With a typical cement slurry design that sets from the bottom to the top of the well, the pressure pulses act to shear the gel strength of the unset portion of the column, so hydrostatic pressure is maintained along the length of the unset column. This action prevents fluid influx and annular flow after cementing.

The compressible volume of the unset cement column is defined as the volume of water required to pressurize the annulus to the pre-determined pulse pressure. The largest magnitude of compressible volume typically occurs at the onset of the pulsation operation, as none of the column is set and the entire cement column is experiencing some amount of movement. Compressible volume will decrease over time (rate dependent on slurry design), as the cement column develops sufficient static gel strength to preclude the cement pulsation shearing action at the cement to formation/casing interfaces.

Pulse Pressure Attenuation with Depth

A key enabling factor of the cement pulsation technique is the ability to effectively transmit small surface-applied pressure pulses through thousands of feet of cement slurry with very low pressure attenuation. Prior work indicates that the pulse transmission mechanism for the cement pulsation pressure pulse behaves as plug flow, since the energy required to pulse the slurry is much less than that required to shear the entire bulk slurry⁴.

In order to prove this theory, conventional wellbores were instrumented with downhole pressure and temperature gauges. These gauges were banded to the casing, and the well was cemented and pulsed. The real-time pressure readings recorded during this test documented that small pressure pulses can be effectively transmitted to significant wellbore depths⁵. For example, this instrumented wellbore test documented that a surface pulse pressure of 114 PSI

resulted in a 32 PSI pressure pulse being recorded at the bottom of the cement slurry in an 8,600 ft. well. In addition, the cement pulsation surface pulse pressure amplitude can be increased as needed for deeper well depths or longer cement columns, so long as the resulting ECD of the column, with the additional pulse pressure, is maintained below that of the formation breakdown pressure.

Offshore Cement Pulsation Job Design

Initially, one of the biggest questions surrounding the cement pulsation technique was that of surface pulse magnitude vs. transmission distance. Potential users of the technique were concerned that the small surface-applied pressure pulses would be unable to reach total well depth. As a result, numerous experiments were conducted and a software model was developed to design the required surface pulse pressure for a given wellbore⁴. The model was then validated on full-scale instrumented wellbore tests⁵.

Application of the cement pulsation technique to prevent annular flow after cementing offshore GoM conductor or surface casing strings brought a new potential concern to the forefront. It's not uncommon for the shallow openhole section being cemented to contain a zone with a narrow operating window between the fracture pressure and pore pressure gradient. For normal openhole treating depths greater than about 2,000 ft., the low-pressure pulses applied during the cement pulsation operation are typically negligible in relation to the hydrostatic pressure experienced at deeper depths in the wellbore.

However, if a 100 PSI pulse for example were applied via the annulus to a shallow sand at a depth of 800 ft., it would add more than 2 PPG to the hydrostatic pressure profile. This additional ECD could possibly exceed the fracture pressure of an openhole zone at this shallow depth. To avoid breaking down formations when pulsing with shallow openhole zones, it is imperative to utilize a proprietary pulse pressure design model to accurately predict the downhole transmission and attenuation of the surface-applied pulse. The pulse pressure must be designed such that it is large enough to shear the gel strength of the entire cement column to total well depth, while at the same time remaining below the critical fracture pressure of the weakest openhole zone in the interval being cemented.

Cement Pulsation Equipment

The key components of the skid-mounted cement pulsation equipment consist of an air tank, water pulse tank, valve controller, and data acquisition system. The pulsation unit utilizes an air-over-water approach to apply the pulses on the annulus. A large steel-reinforced hose is connected between the cement pulsation unit and the annulus to transmit the pulses to the wellbore. See equipment schematic in Figure 1.

The wellbore is initially filled with fluid to the surface (cement, mud or water) to enable provide a pulse transmission pathway. Compressed air from the rig or from a dedicated source is used to fill the cement pulsation unit air tank, and this air tank applies a pre-set pulse pressure to the water tank for a specific period of time. This action forces a water pulse to the annulus. After the water pulse is held on the annulus for a pre-determined period, air pressure on the water tank is exhausted to the atmosphere. This action allows water to flow back from the annulus into the cement pulsation water tank, and the cycle is repeated.

The onboard cement pulsation data acquisition system is continuously recording key job parameters during this pulsing process. These parameters include surface pulse pressure and cumulative water loss to the wellbore (measured with a flowmeter) during the pulsation process. Due to cement fluid loss, shrinkage, and other factors, it's not uncommon to permanently displace a cumulative volume of 100-700 gallons of water to the wellbore during the course of a pulsation operation. The data acquisition unit also displays the change in cement column compressible volume during the operation, as an indicator of the downhole cement slurry setting progress.

Challenges for Offshore Cement Pulsation

While cement pulsation has been applied on hundreds of land wells in the U.S. and Canada, there were numerous unanswered questions and challenges regarding its adaptation for offshore GoM applications. These included the:

- Ability to successfully pulse the GoM shallow marine sediments (800 ft. to 3,200 ft.), given their rather weak rock properties.
- Ability to successfully pulse the cement column given up to an hour delay after the plug was bumped and prior to initiating the pulsation process, as a result of waiting on the grout line to be retrieved.
- Ability to design a surface pulse amplitude such that it remains below the critical fracturing pressure of weak zones, but still contain sufficient energy to shear the entire cement column to total depth.
- Ability to utilize the compressible volume change of the cement column (recorded during the pulsation operation) to provide real-time surface monitoring of the downhole cement setting progress and as a measure of adequate WOC time.
- Absence of annular flow after cementing following application of the cement pulsation process.

Teamwork and Communication

Given the above list of challenges and the initial application of a new operating procedure in an offshore setting, teamwork and good communication were identified as a cornerstone of this project. The operator, cementing service company, and cement pulsation service company conducted meetings and developed a written procedure to ensure a clear understanding of the cement pulsation process, identify the required tasks and equipment, and to define responsibility for each step in this process. Communication of the cement pulsation technique was again reviewed with the rig crew prior to initiation of the cement pulsation operation. Proper communication and planning were essential to the success of this project.

Initial Offshore Cement Pulsation Application

The initial offshore GoM application of the cement pulsation technique was situated in the Outer Continental Shelf/South Timbalier Block 229. This block is located approximately 40 miles from the Louisiana coast in about 238 ft. of water. Annular flow after cementing was a concern due to the fact that offset wells in the area had experienced pressure and/or flow within 18 hrs. following cementing of the conductor casing (at approximately 1,550 ft.) or surface casing (at approximately 3,200 ft.). These offset wells ultimately required a remedial cement job to cure the problem. Cement pulsation was selected to be applied on this well in an effort to prevent the occurrence of a similar annular flow after cementing problem.

Wellbore Configuration and Cement Slurry Design

This paper will report the cement pulsation results of two offshore wellbores that were constructed with essentially identical wellbore configurations and cement job designs. Any significant deviations will be noted.

The wells were configured with drive pipe set to 750 ft. They were subsequently drilled to 1,550 ft. with a 17 1/2 in. bit, and under-reamed to 24 in. The well plan specified 18 5/8 in. conductor pipe to be set to T.D., with top of cement at 368 ft. The conductor pipe cement design called for placement of the materials as listed in Table 1.

The lead and tail slurry laboratory pump times were 6:00+ hrs. and 2:42 hrs., respectively. The lead slurry was designed with a fluid loss of 26 cc/30 min., and zero free water at a 45° angle.

The design of the lead slurry was focused on controlling flow after cementing, per common industry standards of less than 50 cc/30 min. fluid loss and zero free water at a 45° angle. The cement design challenge on the offshore GoM shelf with respect to annular flow after cementing, centers on the prevention of gas influx as the slurry moves through the transition period.

Slurry Transition Period and Cement Pulsation

For the purposes of this paper, we will define the transition period as that time when the cement slurry static gel strength is a value between 100 lb/100 sq. ft. and 500 lb./100 sq. ft.

In the absence of cement pulsation, at some point between these two gel strength numbers the hydrostatic pressure of the cement column drops below the pore pressure of the adjacent formation. This value is known as the critical gel strength value. The point between the critical gel strength value and 500 lb./100 sq. ft. is the point where gas or liquids may enter the slurry, and cause annular flow after cementing.

Pulse Amplitude Design Challenge for Initial Offshore Cement Pulsation Application

While the production casings of conventional land wells can be safely pulsed with 100 PSI or more of surface pressure, the pulsation design for this shallow offshore casing string presented an additional hurdle. When designing the pulse amplitude for the conductor casing to be set at 1,550 ft., we had to cognizant of a shallow sand at approximately 800 ft. (near the drive pipe shoe) that had a very narrow gradient between its pore pressure and fracture pressure. If the cement pulsation pulse amplitude was too large, there was a risk of breaking down this formation.

A proprietary software model was used to determine the minimum surface pressure required to shear the gel strength of the cement column to total depth, as well as the attenuation and ECD of the applied pulse pressure at all points in the wellbore. A minimum surface pulse pressure of 50 PSI was found to be more than adequate to effectively pulse the conductor casing. The same model was used to design the surface casing amplitude, and a pulse pressure of approximately 90 PSI was determined to adequate for this application. The actual pulse pressures utilized during the field operations were slightly in excess of the required job design, to make certain the entire cement column would be treated to total depth. As a result of the rather low pressure requirements for these two pulsation operations, the rig air supply was used to supply compressed air to the cement pulsation unit.

Pulse Volume Modeling for Offshore Applications

In addition to designing an appropriate surface pulse pressure, the model can also be used to predict the compressible volume, which is the volume of water displaced to the wellbore during each pulse as a result of a small amount of compressibility in the unset cement slurry. A potential concern with pulsing the rather weak shallow marine sediments in the GoM was the volume of water required to deliver a pulse in these soft sediments. Others have reported⁶ that these shallow sediments could exhibit Young's Modulus values in the range of 1.04×10^5 . This low value (as compared to traditional

Young's Modulus values commonly found in deeper production casing strings that are pulsed) provides for a significant increase in wellbore ballooning in the openhole section of the wellbore, requiring addition water volume to deliver each pulse. The cement pulsation unit utilized for these field operations contains a 200 gallon water tank to supply the necessary pulse volume to the annulus. Prior to modeling, and it was not known if this pulse tank volume would be sufficient to effectively pulse these shallow wellbore sections containing the lower Young's Modulus values.

Pre-job cement pulsation modeling was performed, using the lowest expected value of Young's Modulus for the openhole section of the wellbore. This was done in order to calculate the largest water pulse volume required to effectively pulse the well. Even using this worst case assumption, the modeling results indicated that initial cement pulse volume would be less than 80 gallons/pulse. This value was well below the capacity of the current 200 gallon water pulse tank, and thus the equipment did not require modification for this particular operation.

Cement Pulsation Applied to the Conductor Casing

Two wells were drilled and pulsed from the same offshore platform, and the details of the conductor casing cement pulsation operations are discussed in the following sections. The purpose of this operation was to pulse the cement column around an 18 5/8 in. conductor pipe which was set at approximately 1,550 ft. Drive pipe was previously set to 750 ft., leaving 800 ft. of 24 in. openhole section to be cemented.

Conductor Casing Pulsation Details – Well A5

The cement job was pumped as designed, and returns were observed at the surface during the cementing operation. Initiation of the cement pulsation operation was delayed by 25 minutes (following bumping of the plug) while cement was washed from the stack.

The annular was sealed and cement pulsation was initiated. The well was pulsed with 58 PSI surface pulses for 7 hrs. and 10 min. Pulses were applied and held on the annulus for 15 seconds, with a 15-second pulse relaxation period following opening of the exhaust valve. Pulse frequency remained stable at about 39 seconds for the duration of the operation. The two primary measurements recorded during the pulsation operation included compressible volume of the cement column and cumulative water loss to the wellbore.

The initial compressible volume measurement was slightly in excess of 30 gallons/pulse, and decreased to approximately 23 gallons/pulse after the first hour of pulsing. The compressible volume measurement then remained quite stable, declining only slightly to 21 gallons/pulse at the conclusion of hour 5 of the operation. At this point the compressible volume started declining at a much faster rate, reaching a minimum

value of approximately 6 gallons/pulse at the conclusion of hour 7 of the operation, where it stabilized. See Figure 2.

A total of 890 gallons of water were permanently displaced to the wellbore during this pulsation operation. Approximately 420 gallons of water was displaced in the initial 65 minutes of pulsing, with an average water loss of nearly 6.5 gallons/minute.

Water loss to the wellbore then decreased dramatically, with an additional 390 gallons lost during the next 235 minute period. The water loss during this period was approximately 1.7 gallons per minute. By this juncture, the well had been pulsed for a total of 5 hrs., and the cumulative water loss to the wellbore was 810 gallons.

The water loss to the wellbore for the final 130 minute pulsation period decreased to only 80 gallons, or less than 0.4 gallons/pulse. This time period also corresponds with the decrease in compressible volume from 21 gallons/pulse to 6 gallons/pulse.

Conductor Casing Pulsation Details – Well A6

The A6 well was drilled from the same platform as the A5 well, and thus the conductor and surface casing wellbores were in close proximity to each other. In addition, the same reservoir properties were expected to be encountered on this well.

The cement job on the conductor casing of this second well was pumped as designed, and returns were observed at the surface during the cementing operation. Initiation of the cement pulsation operation was delayed by 65 minutes (following bumping of the plug) while cement was washed from the stack.

The annular was sealed and cement pulsation was initiated. The well was initially pulsed with 55 PSI surface pulses for just over an hour, at which time the surface pulse pressure was increased to 62 PSI, where it remained until conclusion of the pulsation operation. Pulse pressure was increased to determine if the compressible volume of the column would also increase. There was no appreciable change in compressible volume as a result of this surface pulse pressure increase. The well was pulsed for a total of 6 hrs. and 55 min.

Pulses were applied and held on the annulus for 15 seconds, with a 15-second pulse relaxation period following opening of the exhaust valve. Pulse frequency remained stable at about 38 seconds for the duration of the operation. The two primary measurements recorded during the pulsation operation included compressible volume of the cement column and cumulative water loss to the wellbore.

The compressible volume measurement was slightly in excess of 13.5 gallons/pulse after 35 minutes of pulsing. Earlier compressible volume measurements were not possible, as no water returned from the wellbore due to excessive water loss to the wellbore.

This water loss could be the result of hole filling, air in the rig lines used to transmit the pulse to the annulus, downhole cement slurry movement into a void space as a result of the pulse pressure, or other factors.

Compressible volume decreased to 11.25 gallons/pulse after 140 minutes of pulsing activity. During the final 275 minutes of the pulsation operation, the compressible volume decreased only slightly, to 10.50 gallons/pulse. Water loss during this same period was also minimal at only 99 gallons, or less than 0.3 gallons/pulse. See Figure 2.

A total of 454 gallons of water were permanently displaced to the wellbore during this conductor casing pulsation operation on the A6 well. Approximately 160 gallons of water was displaced during the first two pulses.

After the second pulse, the pulsing operation was paused for approximately 10 minutes to replenish the water supply tank with 60 gallons of water. Pulsing was reinitiated, and the entire 60 gallons of water was again lost to the wellbore. Pulsing was paused for a second time for approximately 35 minutes, refilling the pulsation water supply tank to a level of 180 gallons prior to reinitiating pulsing. The rig water supply was sufficient to maintain an adequate level in the water supply tank for the remainder of the pulsing operation, which was approximately 100 minutes after the plug was pumped. It should be noted that 227 gallons of water were lost to the wellbore in the initial 4 pulses.

Results of Conductor Casing Cement Pulsation

Both wells were pulsed for approximately 7 hours. The A6 well was tested for annular flow immediately after completion of the cement pulsation operation, while the A5 well incurred an additional 6 hours of WOC time prior to testing for annular flow. Both wells were tested for annular flow by opening the diverter and checking for the presence of any flow. Both wells remained static after the diverter was opened, and thus neither of the pulsed wells exhibited annular flow after cementing.

Cement Pulsation Applied to the Surface Casing

The purpose of this operation was to pulse the cement column around a 13 3/8 in. surface pipe that was set to 3,220 ft. for two wellbores drilled from the same offshore platform. Conductor pipe was previously set to 1,550 ft., leaving 1,670 ft. of 17 1/2 in. openhole section to be cemented. Table 2 summarizes the cement slurry design used in this section of the wellbore.

Surface Casing Pulsation Details – Well A5

The cementing operation went as planned during the surface casing cementing operation of the A5 well with one notable exception. Cement returns were observed at surface during the cementing operation, while the cement top was designed to be at approximately 1,350 ft. These returns during the cementing operation

provided an early indication of a potential problem, such as incomplete mud displacement. Any drilling mud remaining in the wellbore during the cementing process could increase the probability of channeling and annular flow/pressure after cementing, regardless of the application of cement pulsation.

Following completion of the cementing operation, the rig washed the stack and retrieved the grout line. As a result, the cement pulsation process was not initiated until 75 minutes after the cement plug was bumped.

Cement pulsation was initiated with a pulse pressure of approximately 95 PSI, as determined by the pre-job design model. The surface casing was pulsed for a total of 6 hrs., and 20 minutes. Pulses were applied and held on the annulus for 15 seconds, with a 15 second pulse relaxation period following opening of the pulse pressure exhaust valve. Pulse frequency varied between 39 and 50 seconds on this operation, as a result of fluctuations in the amount of available compressed air volume, as supplied by the rig. The two primary measurements recorded during the pulsation operation again included compressible volume of the cement column and cumulative water loss to the wellbore.

The compressible volume measurement of the column was in the range of 30 gallons/pulse initially, and decreased to approximately 22 gallons/pulse after 110 minutes of pulsing. However, no further reduction in compressible volume was observed for the remainder of the cement pulsation operation. In fact, just the opposite occurred. Compressible volume of the column increased slightly to 24 gallons/pulse during the last 3 hours of the pulsation process, as shown in Figure 4.

A cumulative water loss to the wellbore of 330 gallons was observed during pulsing of the surface casing. Of this total, approximately 100 gallons of displacement to the well occurred during the initial 3 pulses.

Surface Casing Pulsation Details – Well A6

The cementing operation went as planned during the surface casing cementing operation for the A6 well. Approximately 30 Bbls of cement returns were observed at surface at the conclusion of the cementing operation. Following completion of the cementing operation, the rig washed the stack and retrieved the grout line. As a result, the cement pulsation process was not initiated until 135 minutes after the cement plug was bumped.

Cement pulsation was initiated with a pulse pressure of approximately 90 PSI, which appeared to be the near the upper volumetric limit of the rig air supply. The surface casing was pulsed for a total of 4 hrs. Pulses were applied and held on the annulus for 15 seconds, with a 15 second pulse relaxation period following opening of the pulse pressure exhaust valve. Pulse frequency was constant at about 44 seconds/pulse for the duration of the operation. The two primary measurements recorded during the pulsation operation

again were compressible volume of the cement column and cumulative water loss to the wellbore.

The initial compressible volume measurement of the column was slightly more than 43 gallons/pulse. However, no further reduction in compressible volume was observed for the remainder of the 4 hr. cement pulsation operation, as shown in Figure 5

A total of 154 gallons of water was lost to the wellbore during the entire pulsation period. Of this total, approximately 20 gallons was lost by the end of the second pulse, after which time the rate of water loss to the wellbore was essentially constant at approximately 0.4 gallons/pulse.

Results of Surface Casing Cement Pulsation

The A5 well was pulsed for 6 1/4 hours, while the A6 well was pulsed for 4 hours. The decision to terminate pulsation of the A6 well at this reduced time interval was due to the absence of a reduction in the compressible volume measurement and the fact that we were beyond the slurry set time provided by the cementing service company. Both wells were tested for the presence of annular flow immediately following the pulsation period, with no additional WOC time. The wells were tested by opening the diverter and checking for the presence of flow.

No annular flow was observed on the A6 well. However, the A5 well exhibited annular flow after the diverter was opened. The flow subsequently stopped for a time after the wellbore was filled with seawater. Later, the well began to flow for a second time, and 400 PSI was observed at the wellhead. The well was treated with a cement squeeze through the casing head valve, and no further flow or pressure was observed.

Recall that the A5 surface casing string (the single casing string exhibiting annular flow after cementing) was the only situation where cement returns were observed prematurely during the cementing operation. Post-job analysis of this casing string also indicated that wellbore deviation was higher than originally designed for. The 12° wellbore deviation measured on the A5 casing string was at the upper deviation limit for the amount of casing centralization used on this string. In addition, this increased amount of wellbore deviation could have enhanced the probability of developing a rugose wellbore. No caliper measurements were made to confirm hole rugosity. The root cause of annular flow on this well can only be speculated. However, the early cement returns point to a mud displacement issue, which cement pulsation is unable to overcome. Casing centralization and/or hole rugosity could have contributed to this problem.

Successful Cementing Practices Important

While cement pulsation and utilization of slurries designed to control flow after cementing were utilized in

this operation, it is important to note that all industry-accepted cementing successful practices must still be followed in order to obtain positive results. Cement pulsation is not a panacea for substandard field cementing technique.

When working to obtain good cementing results in areas prone to shallow gas, successful cementing practices help insure positive cementing results. These practices include, but are not limited to:

- Proper hole cleaning prior to running casing.
- Proper mud conditioning prior to the cement job.
- Proper spacer type and amount.
- Adequate centralization.
- Pipe movement during the pre-job circulation and cement job.
- Adequate displacement rates for cement and spacer.

Utilization of a technically advanced and proven primary job cement simulation software is strongly recommended when performing cement slurry job designs. This software will determine the most efficient drilling mud displacement rate without exceeding the wellbore fracture gradient. The model also provides a centralizer placement recommendation to achieve a minimum standoff value of 67% for properly centralized pipe.

Recommended outputs from a leading cement simulation model were utilized on this project to obtain optimum mud removal, centralization and proper cement placement. This enabled the cement pulsation process to be applied on an uncontaminated cement column.

It should be noted that while this software can provide solutions to challenging cementing situations (based on mathematical calculations from input data), the model does not account for the effects of hole rugosity or pipe movement. Hole rugosity is rarely measured on these shallow casing strings. An extremely rugose hole could account for a substantial amount of channeling, negating normalized model predictions for optimum mud removal. A rugose hole could develop in a deviated wellbore such as the one that existed on the A-5 well.

Conclusions

From an operational standpoint, 100% success was achieved, as there was no equipment malfunctions or downtime. Our technical goal was to cement 4 shallow casing strings with no annular flow/pressure after cementing. We achieved our goal on 3 out of the 4 cement pulsation operations.

The single casing string that exhibited pressure after cementing also exhibited symptoms of a mud displacement problem during the cementing operation – cement returns were observed during the job, when the cement top had been designed for 1,350 ft.

Overall results of the initial offshore applications of

cement pulsation to prevent annular flow/pressure after cementing, have enabled the following conclusions to be made:

- The operational efficiency of the equipment indicates it is sufficiently robust for offshore use.
- The rather weak shallow marine sediments in the GoM, with their correspondingly low Young's Modulus values, are able to be successfully pulsed with the existing cement pulsation equipment.
- While it's preferable to initiate pulsation immediately after the plug is bumped, it appears that the surface pulse pressure is able to effectively treat the cement column for some reasonable amount of time following bumping of the plug.
- The cement pulsation modeling software enabled a surface pulse pressure to be successfully designed, such that the cement column was treated to total depth while staying below the fracture pressure of shallow, openhole zones.
- The change in compressible volume of the cement column during the job can, in some instances, provide a surface indication of downhole setting progress and appropriate WOC time.
- A lack of compressible volume decrease of the cement column during the job is not necessarily indicative of a potential annular flow after cementing problem. However, no annular flow occurrences have been observed on casing strings where a compressible volume decrease was recorded during the pulsing operation.
- None of the casing strings that were pulsed and where the cementing operation matched the original cement job design expectations exhibited annular flow/pressure after cementing.

Future Recommendations

The results of these initial offshore applications of cement pulsation to prevent annular flow/pressure after cementing are encouraging, but numerous unanswered questions remain. A significantly larger database of offshore field applications will be necessary in order to confirm cement pulsation as a highly effective method of preventing annular flow/pressure.

Additional laboratory and field work would also be beneficial to better understand:

- Maximum amount of acceptable delay time following completion of the cementing operation and prior to initiation of cement pulsation operations. This value would be dependent on slurry composition.
- The downhole disposition of the pressure pulse for those situations where the compressible

volume is large, and no decrease is observed during the cement pulsation operation.

- Ability of wells treated with cement pulsation to exhibit less tendency for sustained casing pressure development over a substantial time period.

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Nomenclature

<i>ECD</i>	=	<i>equivalent circulation density</i>
<i>ft.</i>	=	<i>feet</i>
<i>gal.</i>	=	<i>gallons</i>
<i>hrs.</i>	=	<i>hours</i>
<i>in.</i>	=	<i>inches</i>
<i>lb.</i>	=	<i>pounds</i>
<i>min.</i>	=	<i>minutes</i>
<i>PSI</i>	=	<i>pounds per square inch</i>
<i>PPG</i>	=	<i>pounds per gallon</i>
<i>sec.</i>	=	<i>seconds</i>
<i>sq.</i>	=	<i>square</i>
<i>T.D.</i>	=	<i>total depth</i>

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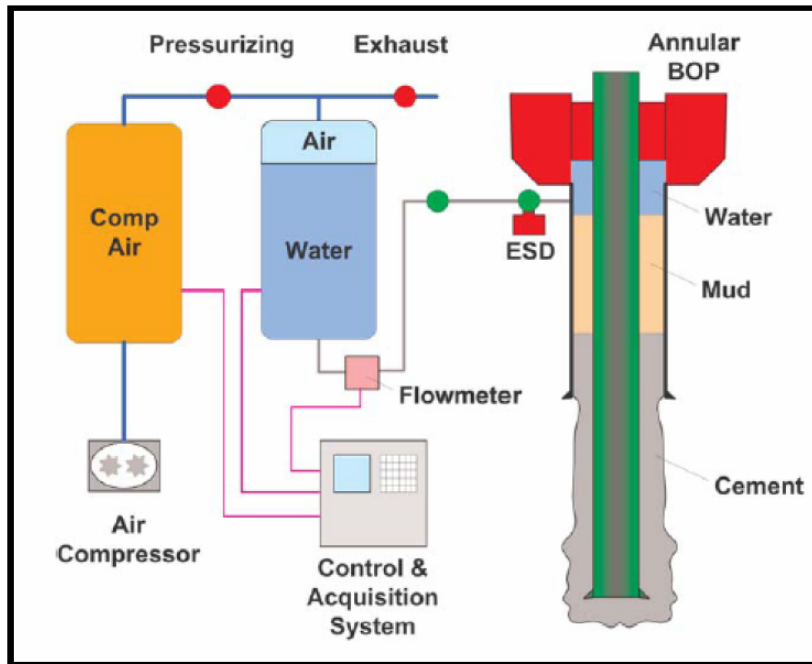


Figure 1: Schematic of Cement Pulsation Unit

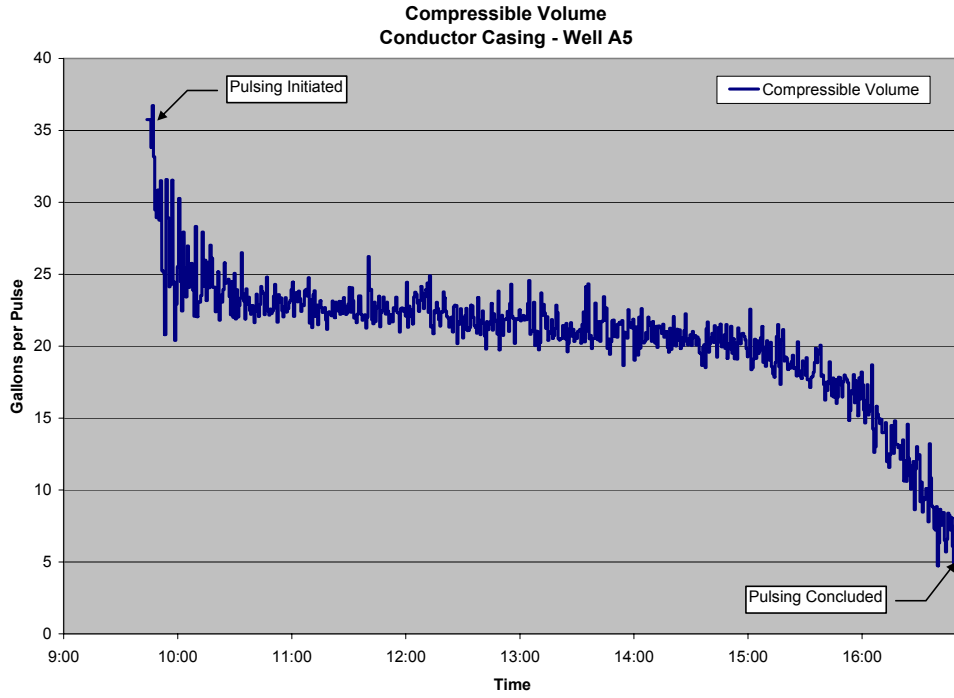


Figure 2: Compressible Volume Change while Pulsing Well A5 Conductor Casing

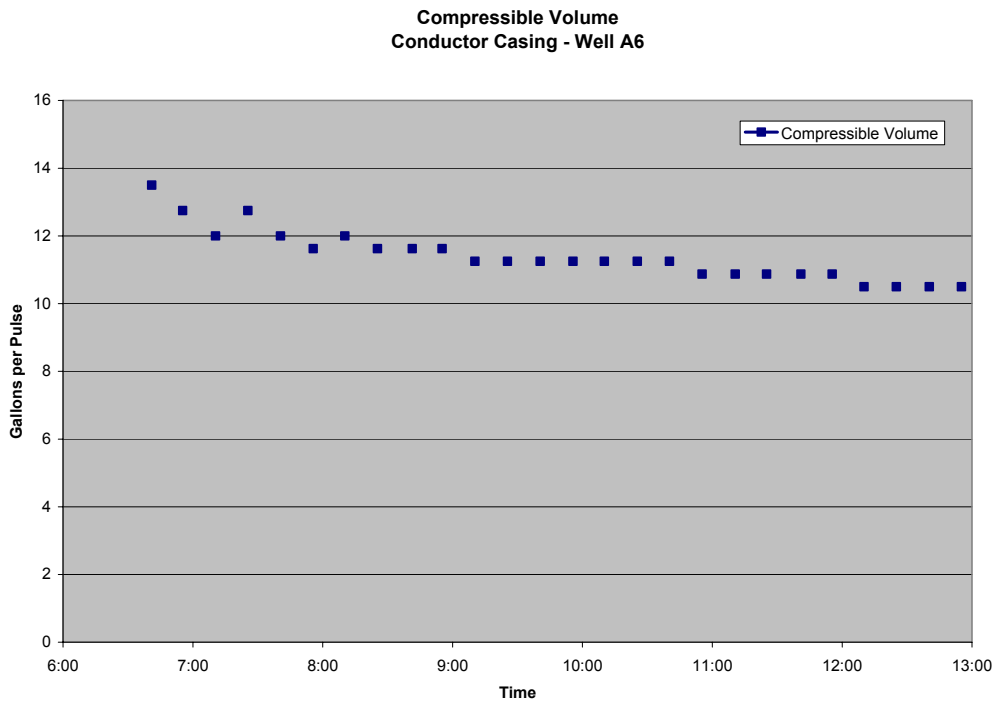


Figure 3: Compressible Volume Change while Pulsing Well A6 Conductor Casing

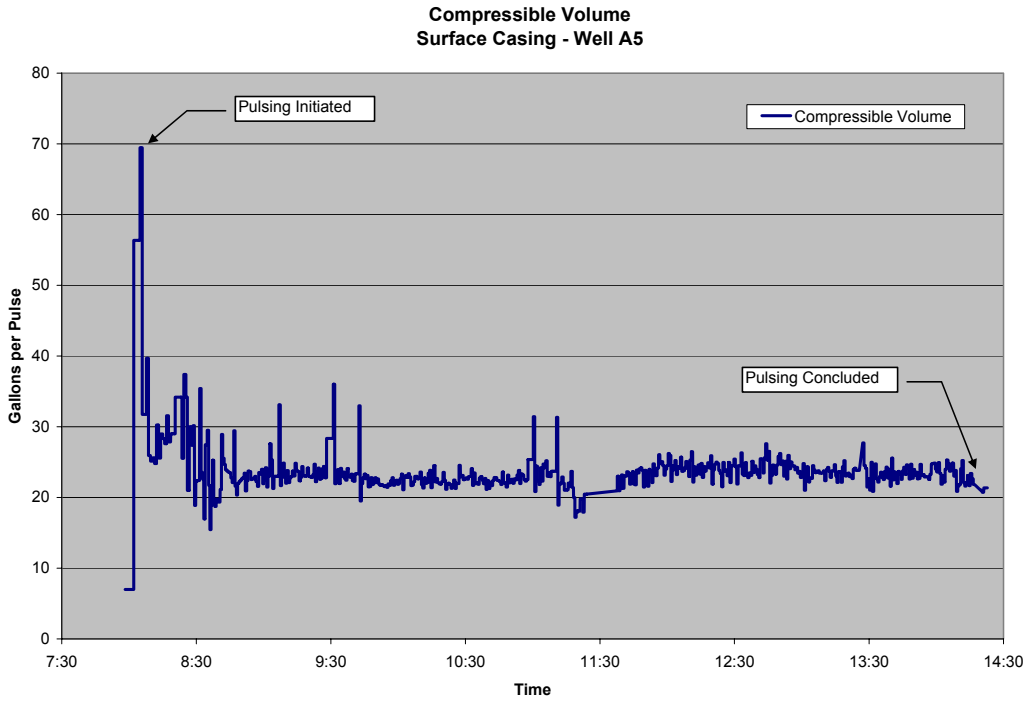


Figure 4: Compressible Volume Change while Pulsing Well A5 Surface Casing

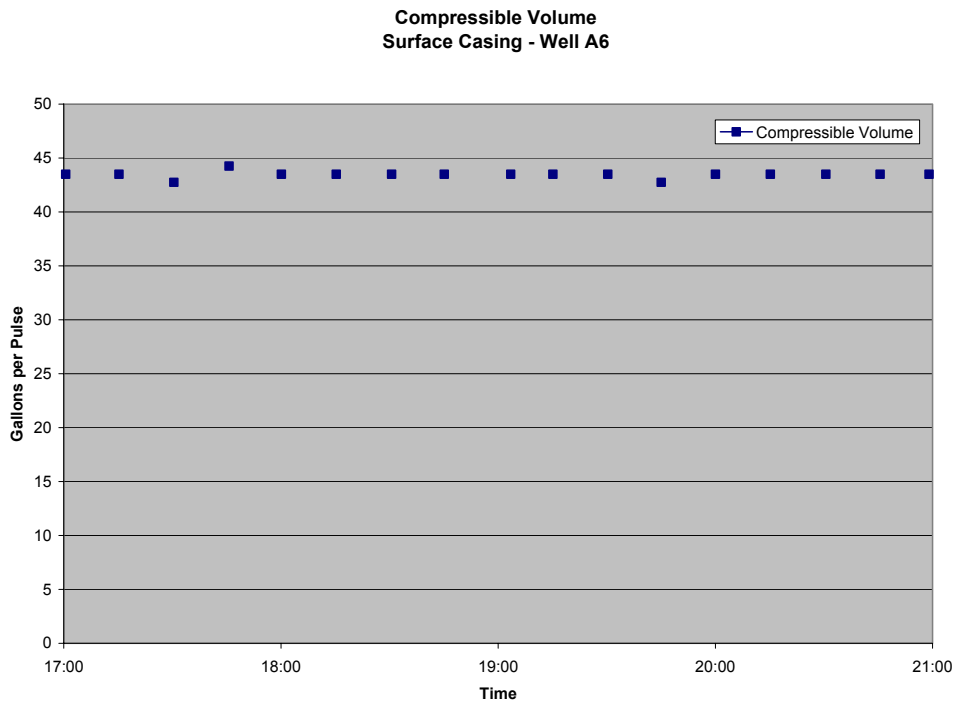


Figure 5: Compressible Volume Change while Pulsing Well A6 Surface Casing

Table 1: Conductor Casing Cement Slurry Design

Material	Density (PPG)	Bottom Depth (ft.)	Top Depth (ft.)
Sea Water	8.4	31	0
Spacer	9.8	368	31
Lead Cement Slurry	12.0	1,250	368
Tail Cement Slurry	16.4	1,550	1,250

Table 2: Surface Casing Cement Slurry Design

Material	Density (PPG)	Bottom Depth (ft.)	Top Depth (ft.)
Mud	10.7	473	0
Sea Water	8.5	872	473
Spacer	11.5	1,350	872
Lead Cement Slurry	12.0	2,600	1,350
Tail Cement Slurry	16.4	3,200	2,600

Table 3: Summary of Cement Pulsation Operations and Results

	Conductor Casing		Surface Casing	
	Well A5	Well A6	Well A5	Well A6
Delay Time Prior to Initiation of Pulsing* (min.)	25	65	75	135
Pulse Pressure (PSI)	58	55-62	95	90
Pulse Frequency (sec.)	39	38	39-50	44
Duration of Pulsation Operation (min.)	430	415	380	240
Total Water Loss During Pulsing (gal.)	890	454	330	154
Initial Compressible Volume (gallons/pulse)	30	13.5	30	43
Final Compressible Volume (gallons/pulse)	6	10.5	24	43
Compressible Volume Change (gallons/pulse)	24	3	6	0
Job Comments	None	None	Early returns during cementing	None
Presence of Annular Flow or Pressure?	No	No	Yes	No

*Delay time is the time interval after the cement plug was bumped and prior to initiation of wellbore pulsing.