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Cement Pulsation: Confirming Surface Pulses Reach Total Depth and Can Improve Gas Well Cementing

Ongoing research has shown that application of the cement pulsation technique immediately after cementing will help maintain the hydrostatic pressure of the cement column and prevent potential fluid influx during the cement transition period.

The following is a summary of a full-length article that appeared in World Oil, July 2001. Results discussed in this article verify that the applied pressure pulse can be transmitted to significant well depths, that hydrostatic pressure is maintained while the cement is setting and can reduce gas migration problems.

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A 1995 study by Westport Technology revealed that 15% of primary cement jobs fail, and that these cementing problems cost oil and gas-producing companies about $470 million annually. Approximately one-third of these problems are attributable to gas migration or formation water flow after placement and during the cement transition period. In the 1990s, Texaco E&P proposed the concept of applying pressure pulses to the casing annulus above the cement to shear the cement gel strength of the unset cement. This gel strength shearing of the unset cement prevents the cement from supporting itself and thus maintains the hydrostatic pressure of the cement column. If the hydrostatic pressure is maintained, formation fluid influx during the cement transition period can be prevented. Gas Technology Institute and Texaco jointly supported development of this product to improve gas well cementing results.

CEMENT PULSATION PROCESS

The *Cement Pulsation Schematic* in Figure 1 is a simplified diagram of the cement pulsation (CP) system. As soon as possible after the plug is bumped, the annular BOP is closed around the casing to seal the casing annulus. Then, a mobile CP unit begins applying pressure pulses of approximately 100 psi to the annulus, Figure 2.

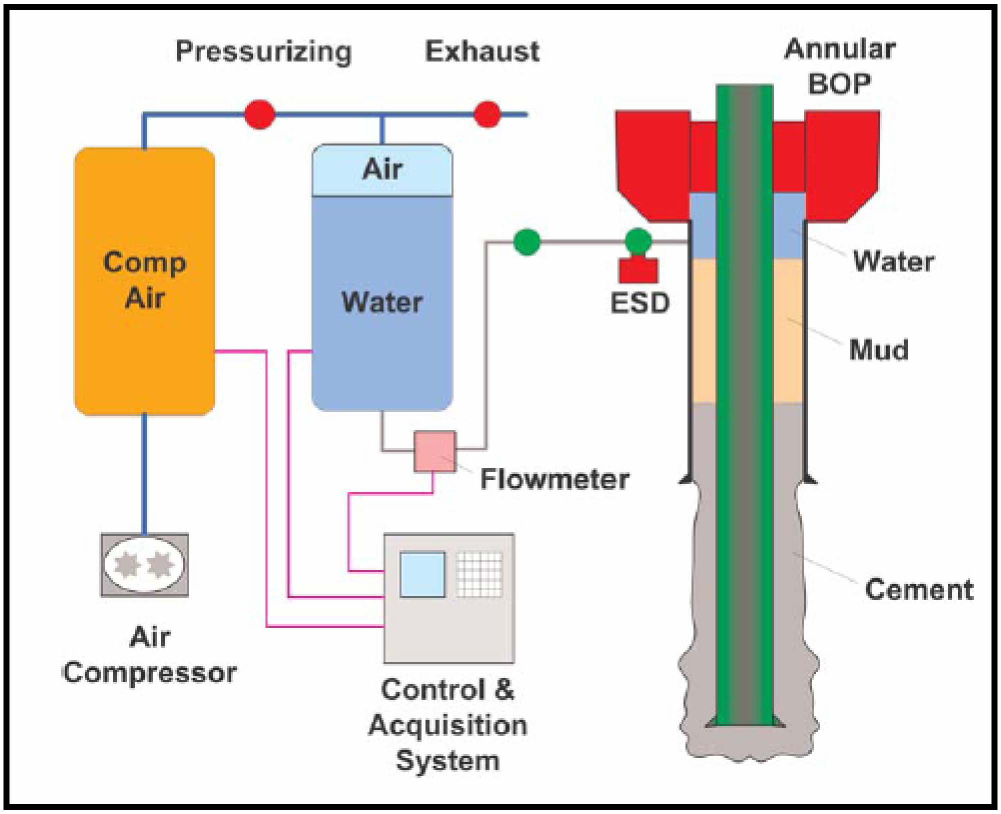

Figure 1: Cement Pulsation Schematic

Figure 2: Skid-Mounted Cement Pulsation Unit Operating on Location

To pressurize the casing annulus, the control system opens a valve between the CP air tank and water supply tank. The air pressure forces the water into the annulus and pressurizes it to a pre-set pulse pressure. An air compressor continuously pressurizes the supply air tank to provide the water pulse energy. To release pressure, the control system closes the pressurization valve and opens an exhaust valve. As pressure is released, water returns from the casing annulus to the water tank. Once pressure is fully released, water is added to the water tank as needed, to keep it full. The pulsation process is typically continued for 4 to 6 hours, depending on the cement slurry setting times.

The pulses are applied in a slow fashion, typically on the order of two pulses per minute with a built-in delay time. Pressure is applied and held for a period of 10 to 25 seconds. After the pressure is exhausted, there is another hold period of 10 to 25 seconds at zero pressure. Thus, a single pulse cycle lasts from 30 seconds to 1 minute. The volume of water displaced to and returning from the well for each pulse is determined by measuring the water level in the tank. This measured water volume is the "compressible volume" of the casing annulus (i.e. unset cement column). Initially, the entire unset cement column is compressible. As the cement column sets from bottom to top, the compressible volume of the casing annulus will decrease and the measured compressible volume will also decrease. This decrease in compressible volume during the cement pulsation operation is monitored and can provide a surface indication of the downhole cement setting process.

PURPOSE

The purpose of the CP process is to shear the gel strength of the unset portion of the cement column, preventing a significant decrease in hydrostatic pressure in the cement. If hydrostatic pressure is maintained, fluid influx from the formation during the critical time between placement and setting of cement (sometimes called the transition period) should be reduced or eliminated.

As the pressure pulses travel down the casing annulus, one would expect the magnitude of the pulse to decrease due to pressure attenuation. Three key objectives of the field test for this project was to confirm that small pressure pulses can be transmitted to significant wellbore depths, determine the amount of pressure pulse attenuation with depth, and verify that the pulsation action serves to help maintain the hydrostatic pressure of the cement column. Instrumented wellbores were used to satisfy these three objectives.

INSTRUMENTED WELLBORE TESTS

Tests were performed on two very similar wells (wells A and B) about 8,600 ft. deep, with 5 1/2-in. casing inside a 7 7/8-in hole. The lower 1,700 ft of each casing string were cemented. Instrumentation for both wells was accomplished by attaching three pressure and temperature gauges to the outside of the casing string. A 1/4 –in. OD, "disposable" pressure/temperature gauge developed by CTES for this field test is shown in Figure 3. In Figure 4, the three wireline cables from the three gauges can be seen being clamped to the casing, at a casing collar. As the casing and cables were run in the hole, clamps were attached to every third joint to support the cables.

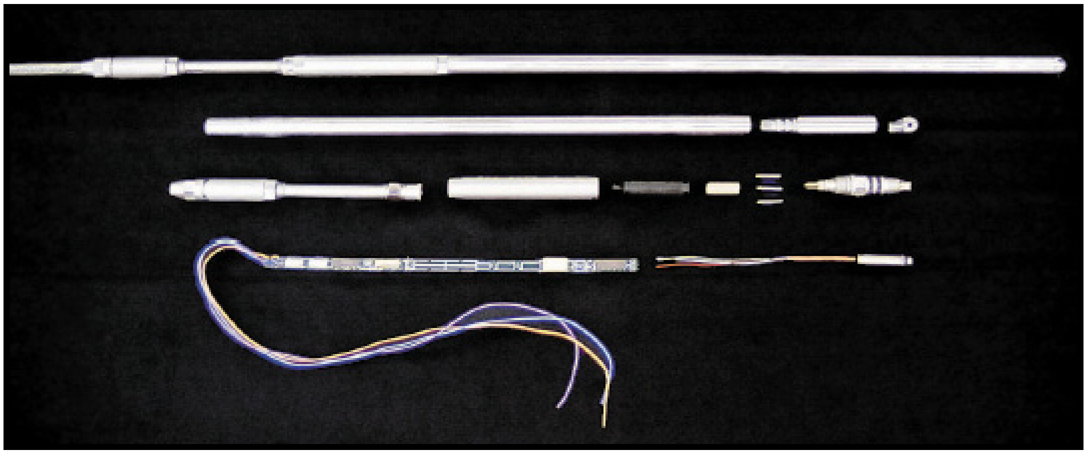

Figure 3: Downhole Pressure/Temperature Gauges for Instrumented Wellbores

One gauge was placed near the bottom of the cement column, one gauge in the middle and one gauge at the top. In well A, the top gauge was just above the top of cement, in the drilling fluid. In well B, the top gauge was just below the top of the cement.

In both tests, the clamps used to attach the pressure and temperature gauges to the casing caused errors in the pressure calibration. The pressure data were adjusted for this calibration error, based upon the known hydrostatic pressure of the drilling fluid column at various depths.

Figure 4: Clamping Wireline on Exterior of the Casing

RESULTS FROM INSTRUMENTED WELLBORES

The results from wells A and B were similar. For brevity, only the results from B are presented in this article. Figure 4 through Figure 6 summarize the results from well B. The following paragraphs contain highlights of the field test results.

Initially, pulses were begun with a 10-second "hold" period (pressure remains constant during this time, either at the surface pulse pressure or vented to atmospheric pressure), with 107-psi pulses introduced at the surface, Figure 5. Four times during the process, pulsation was paused for a period of 2 to 3 minutes. Each time the pulses were paused, there was a significant decrease in downhole hydrostatic pressure. This measured downhole pressure decrease (in the absence of pulsation) verified gel strength development as a naturally occurring phenomena of the cement setting process. At this point in the process, the cement is strong enough to start supporting itself, which decreases the hydrostatic pressure transmitted to the bottom of the cement column. Unfortunately, while the cement may be able to start supporting itself, it may not have enough strength to prevent the influx of gas under certain conditions. Gas influx is a direct result of the decreased downhole pressure that occurs during gel strength development. Note that within two or three pulses after pulsation was resumed, downhole hydrostatic pressure of the cement column was restored to its original value.

After the first pause in the pulsation process, pressure hold periods were changed to 20 seconds. This hold period allowed the CP system to supply slightly higher pressure, so that the pressure pulse amplitude at the surface became 114 psi.

The compressible volume is shown in the middle plot of Figure 5 (light blue line). It decreased significantly during the first 30 minutes of pulsation and then declined only slightly for the rest of the period. The significant decrease observed during the early time period could be indicative of a cement setting event, i.e. the lead or tail slurry has progressed through the transition phase and is no longer being compressed by the cement pulsation pulses.

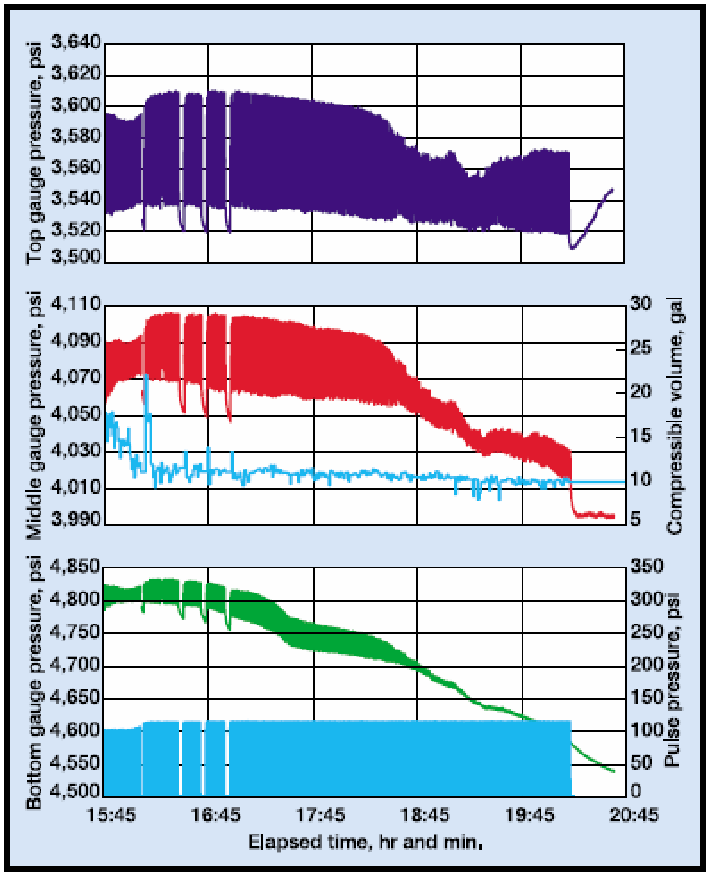

Figure 5: Downhole Pressure Measurements vs. Time

Five minutes of pulsing, including the first pause, are displayed on an expanded time scale in Figure 6. The pulses at the downhole pressure gauges lag behind the surface pulse as a result of the time required for the pulse to travel through the cement column. Since data were being acquired only once per second, a highly accurate measurement of lag time cannot be made. But within a 1-second accuracy, the lag times of the three gauges are as follows:

- Top gauge 3 second lag
- Middle gauge 4 second lag
- Bottom gauge 5 second lag

From Figure 6, the pressure amplitudes with the 10-second and 20-second pressure hold periods can be compared. For the 10-second hold period, surface pressure amplitude was 107 PSI. For the 20-second hold period (starting at time 16:08), surface pressure amplitude was 114 PSI.

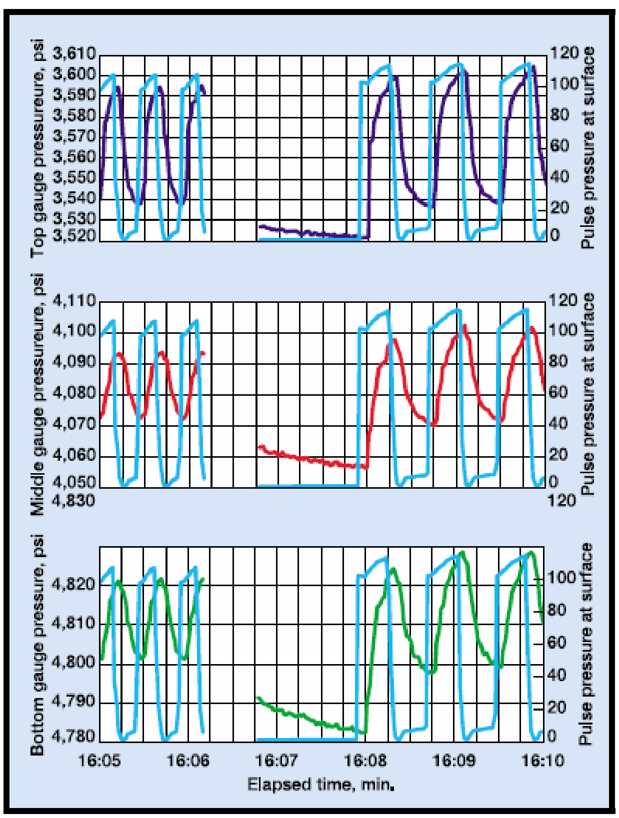

Figure 6: Effects of Varying Surface Pulse Amplitude and Frequency

The measured downhole pressure (amplitude) for two of the gauges are shown below. It is interesting, that a 7-PSI increase in pressure pulse amplitude at surface caused a 9-to10-PSI increase at the downhole gauges:

	Downhole Pressure Measured with 10-Second Pulse Hold Period (PSI)	Downhole Pressure Measured with 20-Second Pulse Hold Period (PSI)
Top Gauge	57	66
Bottom Gauge	21	31

At the third pause in the pulsation process, the pressure hold time was again increased, this time to 25 seconds. Before this change, the surface pulse pressure had increased slightly, to 115 PSI. After this change, the surface pressure increased to 116 PSI. Pressure amplitude downhole increased 1 or 2 PSI.

As a 5-minute expanded time slice, Figure 7 is similar to Figure 6, but it is near the end of the pulsation period, instead of at the beginning. From Figure 5, it would appear that the cement at the bottom gauge was set by this time. However, Figure 7 shows clearly, that the pressure pulses were still reaching the bottom gauge, though with very low amplitude. At that time, surface amplitude was still 116 PSI. Amplitudes at the top and bottom of the cement column were:

- Top gauge 46 PSI
- Bottom gauge 3 PSI

Once pulsation stopped, pressure at the bottom sensor continued to decrease. The pressure at the middle sensor decreased and then remained flat, and the pressure at the top sensor decreased and then increased again! This was similar to the responses from well A.

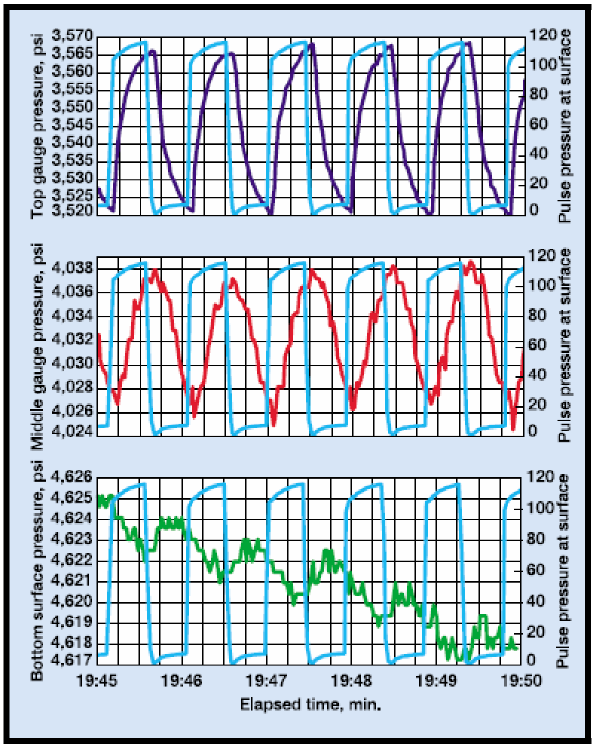

Figure 7: Reduced Downhole Pressure Measurements Near the End of Pulsing

PRE-JOB SURFACE PULSE MODELING

An LSU team working to support this project has developed a predictive software modeling tool to design the minimum required surface pulse pressure required to break the gel strength at total depth of the well. As such, the pulse pressure applied at the surface is tailored to the individual wellbore conditions (cement slurry, depth, hole size, etc.). This model was tested and refined on the CP instrumented wellbore field tests, and the predicted downhole pressure pulse amplitude was in good agreement with the measured downhole pressures.

Pre-job modeling is critical for wellbores with openhole zones that have a narrow operating window between its pore pressure and fracture (breakdown) pressure. The inputs required for the model are available from standard cementing company lab tests and knowledge of the openhole mechanical rock properties. In general, increased surface pulse pressure is used for deeper wells and/or longer cement columns, due to the attenuation of the pulse applied at surface.

Designing a CP treatment for an individual well involves determination of multiple parameters such as pressure pulse amplitude, pulse cycle duration and the maximum required depth of treatment. Interestingly, the three parameters are somewhat dependent on each other. These CP treatment parameters also would obviously relate to the well properties of cement, mud, rock and annular geometry. Hence, mathematical modeling of pulse transmission becomes a basis for the design.

During the CP operation, cement slurry is sheared at the walls as it reciprocates upwards and downwards. The displacement is caused by pressure at this depth and controlled by compressibility of the annulus below this depth. The instrumented wellbore field tests confirmed that efficient transmission of small pressure pulses over thousands of feet of non-Newtonian fluids with yield stress could be efficient, if the column yields only at the walls, while the bulk fluid is not sheared. Thus, the cement pulsation model employs the plug flow concept and formulas to describe partial attenuation of the pressure wave in the annulus. Moreover, since the slurry moves only as a plug, its reciprocating motion can be converted to an equivalently slow, continuous motion in the plug flow regime.

CONCLUSIONS

These field tests on instrumented wellbores make it clear that:

- Pressure pulses are reaching the bottom of the cement column.
- Pressure pulses in the cement are preventing hydrostatic pressure from decreasing significantly, which can help prevent fluid influx after the cement is put in place.

This research is continuing and CP will be performed on additional wells. Candidate wells in fields with significant gas migration problems are being sought.