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Field Study on the Use of Cement Pulsation to Control Gas Migration

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Abstract

Gas flow into cement is a serious problem that results in surface vent leaks and poor zonal isolation in many wells throughout Western Canada. This paper discusses the field testing and application of a new technique called cement pulsation to control this problem. Cement pulsation involves applying short, frequent 700 kPa pulses to the annulus following cement placement. These pulses reduce the gel strength of the slurry, which allows full hydrostatic pressure to be transmitted downhole across the gas zone, thus preventing gas from entering the annulus. This paper also discusses background theory, examines research on the depth to which pulses travel in the annulus, and presents a field study in which pulsation was used to control gas migration in Western Canada.

Introduction

Gas migration through cement has been an industry problem for a number of years, resulting in poor zonal isolation in some wells and surface vent leaks in others. It is not only a Canadian problem, but a worldwide problem. A 1995 study by Westport Technology revealed that 15% of primary cement jobs in the U.S. fail, costing at that time, $470 million annually.(1) Approximately one-third of those failures were due to gas or fluid migration into the cement.(1) In Canada, we continue to have surface vent flows that cost anywhere from $30,000 to $50,000 to repair. When these vent blows are combined with poorly isolated zones due to gas contamination, the costs become staggering.

Gas or fluid flow into cement after it has been placed is caused primarily by the loss of hydrostatic pressure at the gas zone prior to the cement having developed sufficient strength to prevent gas influx. The time period between these two events is called the transition time. Industry efforts over the past several years have centered on reducing the transition time of cements to prevent gas migration. Most research has been focused on increasing the gel strength of the cement, which allows the cement to inhibit gas influx. This has resulted in numerous types of thixotropic cements. Other techniques such as varying the particle sizes of cements(2) have also been evaluated. This particular technique uses low permeability cement to prevent gas from entering the slurry. Although it has been successful, it has not worked universally in all areas.

The technique discussed in this paper also examines the effects of reducing the transition time. Rather than focusing on increasing gel strength, however, it investigates delaying the loss of hydrostatic pressure until the cement has developed enough strength to repel the gas.

Background

Several authors have demonstrated that cement starts to lose hydrostatic pressure immediately after pumping stops.(3,4,5,6) This loss is primarily due to particles in the slurry forming an attraction to each other, which creates a fragile gel strength that forms quickly after pumping has stopped. This gel strength allows the cement to support itself, causing a loss of hydrostatic pressure downhole.

It has also been established that the attractive forces between the cement particles can be easily broken by vibration or pulsation of the slurry after it becomes static.(1,3,4,7,8,9,10,11) This vibration keeps the cement liquid in the annulus and ensures that it maintains a full hydrostatic head on the formation during setting. In almost all areas of Western Canada, this hydrostatic head is high enough to prevent gas from flowing into the slurry.

Pulsation Technique

The technique that has been developed to eliminate gel strength development involves applying small (approximately 550 kPa – 1,000 kPa) pressure pulses to the annulus with frequencies of 30 to 60 seconds. Immediately after pumping stops, the BOP's are closed and a specially designed cement pulsation unit begins to apply pulses through the surface casing vent to the annulus. This cement pulsation unit consists of an air compressor, air tank, water tank and hoses to connect to the surface vent. The pulse is applied to the annulus by surging water to the well with pressure from the air tank.

This pulsation technique was originally designed and patented by Texaco in the mid 90's.[8,11] Variations of the technique, such as casing vibration, were explored by others such as Cooke et al in 1988.[10] Texaco field tested a number of medium depth wells (4,700 feet) in Texas and demonstrated that pulses could be transmitted through the slurry in the lab and that the bond logs of pulsed wells were superior to those that were not pulsed. Cooke field tested a shallow well (200 feet) and showed that vibrating the casing reduced the hydrostatic loss in the annulus and also improved the cement to pipe bond on a bond log. The vibration of the casing was intended to reduce the gel strength development of the cement as a similar method to annular pulsation.

Casing vibration, however, was found to be operationally cumbersome and was not pursued to any great length. Texaco's cement pulsation technique developed slowly as many people were uncertain as to whether the annular pulses would reach bottom on actual wells. In addition, bond logs represented the only concrete evidence that the pulsation technique prevented gas from entering the slurry.

Measurement of Pressure Pulses in the Annulus

The research presented in this paper is the result of a joint effort by The Gas Technology Institute, Coiled Tubing Engineering Services, Louisiana State University in the United States and Trican Well Service in Canada. The research was undertaken to further the Texaco work and to complete a comprehensive study on whether pulsation prevented gas migration into the annulus.

The first step of this research was to prove that annular pulses could be transmitted to a significant depth downhole. Pulsation tests were performed on deep wells to determine if pressure pulses would transmit to depths in excess of 2,650 meters and if the hydrostatic pressure in the annulus could be maintained by pulsing the slurry. The tests were carried out by running pressure gauges on the outside of casing at three intervals in the well. Pulses were applied at the surface and pressure was measured downhole at intervals of 1,951 meters, 2,325 meters, and 2,641 meters.

This work demonstrated that the pulses could be transmitted as deep as 2,650 meters and that hydrostatic pressure could be maintained during the pulsation process. These results are illustrated in Figure 1. Of interest is that the hydrostatic pressure fell rapidly once pulsation was stopped for two to three minutes. When pulsation re-commenced, the pressure was restored after two or three pulses. The pulses were dampened as the depth increased and they lagged behind the original pulse by three to five seconds. Additional details of the tests can be found in Newman et al.[1]

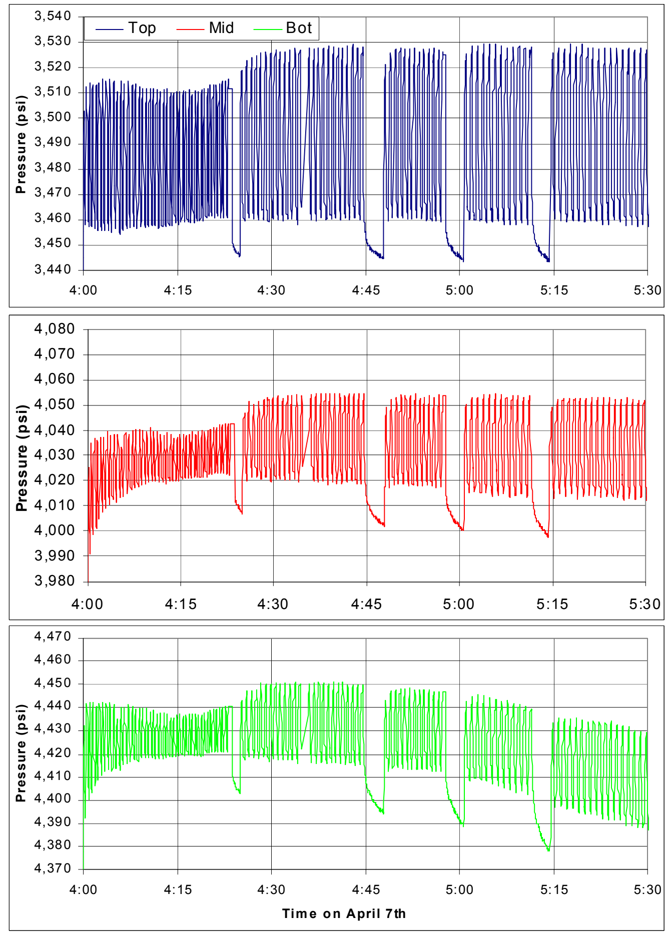

Figure 1 – Pressure Transducer Data
2,650 m well
Top Transducer at 1,951 m, Middle at 2,325 m, Bottom at 2,641 m

Effects of Pulsation on Cement

Another issue that needed to be addressed was what effect the annular pulses would have on cement. In 1988, Chow et al[9] demonstrated that the gel structure of a slurry is easily broken by vibration or shear and that this gel structure reforms rapidly once the shear ceases. The cement then hydrates normally with no ill effects on slurry or set properties. This evidence was also supported by field tests performed by Cooke[10], Haberman[8] and in the new tests carried out by Newman[1]. The construction industry has also used cement vibration for many years with no adverse effects on set properties.

In conjunction with this project, researchers at Louisiana State University tested the effects of pressure pulses on the shear bond of the cement to pipe and compressive strength of the cement. Cement slurries were pulsed in the laboratory past their maximum gel strength and compressive strength initial set. The testing concluded that pulsation had no effect on the final strength or shear bond of the cement [12]. Details are outlined in Table 1.

Table 1 – Summary of Averaged Shear Bond/ Compressive Strengths of Pulsed vs. Non-Pulsed Cements [13]

	48-Hour Compressive Strength (MPa)	48-Hour Shear Bond (MPa)
Sample 1		
Pulsed	8.5	1.4
Non-Pulsed	8.2	1.1
Difference	*0.3*	*0*
Sample 2		
Pulsed	10.0	1.4
Non-Pulsed	9.2	1.4
Difference	*0.8*	*0*
Sample 3		
Pulsed	9.5	2.2
Non-Pulsed	8.7	2.0
Difference	*0.8*	*0.2*

Researchers at Louisiana State University performed tests to determine necessary mud and cement properties that would ensure that the pulses would travel through the cement and mud in the annulus.[13] This research was used to design cement properties during the field tests.

Design of Pulsation Equipment

For this project, a portable cement pulsation unit was designed, consisting of an air compressor, water tank, hoses to connect to the well, instrumentation and a recording system (Figure 2). Pulses are applied to the annulus by water that is pressurized by the air compressor. A specialized design ensures that pulses are transmitted rapidly at consistent frequencies. Pulse frequencies are normally every 60 seconds and magnitudes vary from 550 –850 kPa (80- 120 psi). After charging the well, the water is bled back to the tank. Pulse size and volume are recorded in a computer on the unit and the water volume per pulse is used to determine the compression of the cement in the annulus.

Figure 2 – Cement Pulsation Unit

Field Testing - Husky

The final phase of the research was to test the pulsation theory in the field to determine if pulses would in fact prevent gas flow into the annulus. Ideally, the initial test would involve several wells in an area with previous gas migration problems.

Eastern Alberta was chosen as an ideal area to test the technique. This area contains a number of wells that experience gas migration to surface. This migration is easy to measure by monitoring surface casing vents. Another advantage of this area is that it also has a solid history of recorded vent leaks to which the new data can be compared.

A pulsation cementing project was undertaken with Husky Energy in three fields; the Tangleflags, Wildmere and Abbey fields. All three of these fields have experienced various levels of gas migration in the past and numerous techniques have been used in an attempt to control the problems.

Tangleflags Area

A typical Tangleflags well is described in Table 2. This area has had a history of moderate gas migration problems with the percentage of leaking wells ranging from 0 to 12% depending on the year drilled and area (Table 3). A total of 24 wells were included in the study: seventeen were pulsed and two were abandonment plugs that were also pulsed.

Wildmere Area

A typical Wildmere well is also described in Table 2. It has been more difficult to control gas migration in Wildmere, which has had a history of 4 – 29% of leakers, again depending on year and area (Table 3). A total of eight wells were included in the study. All were pulsed and two were abandonment plug jobs.

Table 2 – Typical Tangleflags and Wildmere Wells

	Tangleflags	Wildmere
Location:	51-26-W3M	48-6-W4M
TD:	Approximately 600 m	Approximately 700 m
Casing:	177.8	177.8
Hole Size:	222.3	222.3
Cement Tops	Surface	Surface
BHST:	25°C	25°C
BHCT:	25°C	25°C
Surface Casing Depth	133 m	133 m
Gas Producing Zones	Up and down the hole	Up and down the hole

Table 3 – Gas Migration History

Wildmere (only those wells in 47-4):

	By Rig Release Date					
	<1980	1980-1989	1990-1997	1998	1999	2000
Total Wells	70	40	7	14	0	27
Leakers	20 29%	15 38%	0 0%	2 14%		1 4%
Non-leakers	50 71%	25 63%	7 100%	12 86%		26 96%

Tangleflags (only those wells in 50-25 and 51-25):

	By Rig Release Date					
	<1980	1980-1989	1990-1997	1998	1999	2000
Total Wells	185	59	13	9	16	24
Leakers	23 12%	6 10%	2 15%	0 0%	0 0%	1 4%
Non-leakers	162 88%	53 90%	11 85%	9 100%	16 100%	23 96%

The above test results were taken from the information available from Husky's gas migration tests database and they may not be inclusive. Not all wells drilled in the years specified may be reflected in the numbers - some wells do not have tests on file. The leaker/non-leaker status is based on the most recent test conducted.

Abbey

Table 4 outlines a typical Abbey well. Abbey is in a river valley and wells in this area have serious gas migration problems. The wells are shallower here due to the lower surface elevations. Gas migration is believed to generate from the Milk River zone at 360 m and 3,800 kPa. This depth reduction, in conjunction with higher pressure gas zones has resulted in more than 80% of the wells leaking in this field. Four wells were included in this study. Both an intermediate and production string was pulsed in each well for a total of eight pulsed jobs.

Table 4 – Typical Abbey Well

Location:	22-17-W3M
Surface	244.5 m casing at 70 m
Intermediate:	177.8 mm casing at 130 m 222.3 mm hole size BHST = 90°C; BHCT = 23°C Potential gas zones along interval
Production:	114.3 casing to 500 m 158.8 mm hole size BHST = 26°C; BHCT = 23°C
Potential Gas Zones	Milk River at 360 m BHP of 3,800 kPa

Additional Field Testing

Additional wells were pulsed in other areas of the province after the Husky project was completed. The location of these wells varied from Red Deer to Whitecourt. The depths were as deep as 1,305 meters.

Cement Treatment Design

The blend chosen for the test was a non-thixotropic Gastight low permeability cement. This cement blend utilizes multiple particle sizes to reduce the permeability of the blend. The cement has a fluid loss below 30 ml/30 minutes, a thickening time of approximately three hours, a low static gel strength of 35 lbs/100 ft^2 and is expanding. This blend was selected because of its low static gel strength combined with its other gas migration control properties, which are described by Dusterhoft et al.[2] Additional blend details are found in Table 5 and Figure 3.

Table 5 – Gastight 1850 Cement Properties

Density:	1,850 kg/m3
Yield:	0.795 m3/t
Water Req.	0.471 m3/t
Thickening Time:	2 – 3 hours at 25°C
24 Hr Compressive Strength:	12 mPa at 5°C
Free Water	0%
Fluid Loss	30 ml/30 minutes
Rheology	Plug Flow Rate – 0.3 m3/minute
	Turb Flow Rate – 1.0 m3/minute
Static Gel Strength	35 lbs/100 ft^2

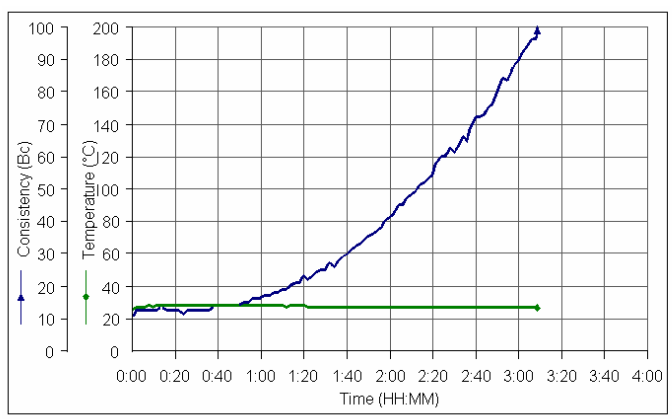

Figure 3 – Gastight Cement Thickening Timeline

Good cementing practices ensured that mud removal was not an issue. Mud properties were reduced to a minimum, the wells were adequately centralized and pre-flush volumes between 5 – 6 m^3 were utilized. The wells were cemented to surface with one blend with slurry volumes varying from 12 –

20 m^3. Cement returns were seen at surface after displacement. Displacement rates averaged 1.2 m^3/minute.

Pulsation

Immediately after the plug was bumped, the BOPs were shut in and pulsation began. In most cases, pulsation was initiated within 5 minutes of plug down. Pulse sizes varied between 685 – 850 kPa while pulse frequency was maintained at 40 – 60 second intervals. A typical pulsation chart can be seen in Figure 4. The pulse unit electronically recorded pulse pressure, frequency and the volume of the pulse. Pulse volume was used to determine the compression of the slurry in the annulus and when plotted versus time, compression volume acted as a measure of whether the pulses were having an effect on the slurry. The compression versus time curve would often exhibit characteristics similar to a thickening time curve in that compression volume was high immediately after the beginning of pulsation and then declined as the cement began to set. A typical curve is illustrated in Figure 5. At the start of the project the wells were pulsed for the thickening time of the cement (approximately three hours). As the project evolved the wells were pulsed until the cement became incompressible.

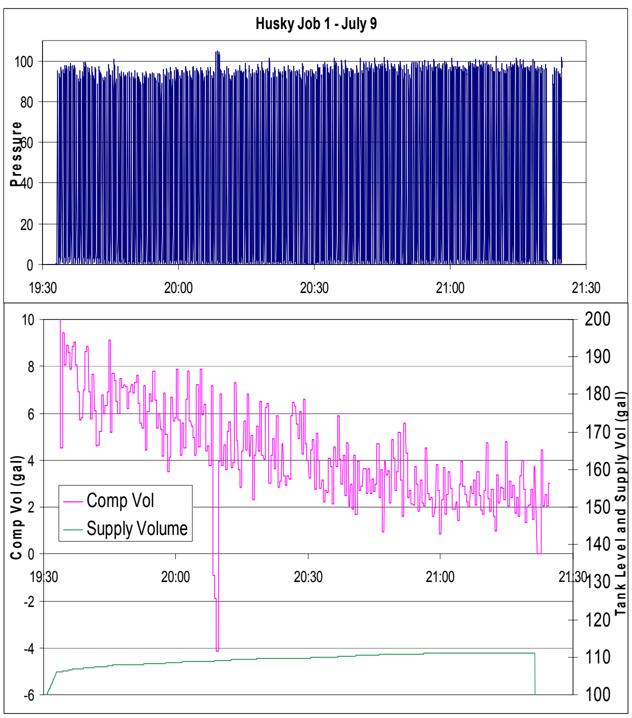

Figure 4 – Cement Pulsation Surface Pressures

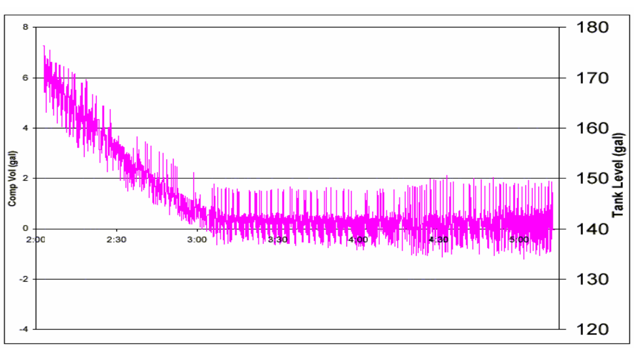

Figure 5 – Cement Pulsation Compressibility

Results

The wells were shut in for 2 – 4 weeks after cementing and vent leak tests were performed at that time. The results to date show 100% success in Wildmere and Tangleflags, 50% success in Abbey and 100% success in other areas of the province. Results are summarized in Table 6.

Table 6 – Cement Pulse Results

Date	Location	Job Type	Pulsed	Gas Leak
Jul. 7, 2001	14-21-50-25W3M	Production	Yes	None
Jul. 12, 2001	5-21-50-25W3M	Production	Yes	None
Jul. 15, 2001	3-27-50-25W3M	Production	Yes	None
Jul. 17, 2001	8-9-51-25W3M	Production	Yes	None
Jul. 21, 2001	3-7-51-25W3M	Production	No	None
Jul. 23, 2001	12-23-48-4W4M	Production	Yes	None
Jul. 23, 2001	11-32-51-25W3M	Production	No	None
Jul. 25, 2001	15-15-48-6W4M	Production	Yes	None
Jul. 26, 2001	13-33-51-25W3M	Production	No	None
Jul. 29, 2001	14-25-51-26W3M	Production	Yes	None
Jul. 30, 2001	3-15-48-6W4M	Production	Yes	None
Aug. 2,2001	4-15-48-6W4M	Plugs	Yes	None
Aug. 4, 2001	14-13-51-26W3M	Production	Yes	None
Aug. 6, 2001	7-9-48-6W4M	Production	Yes	None
Aug. 6, 2001	10-19-50-25W3M	Production	Yes	None
Aug. 9, 2001	4-7-50-25W4M	Production	Yes	None
Aug. 9, 2001	2-21-47-4W4M	Production	Yes	None
Aug. 12, 2001	5-33-48-4W4M	Plugs	Yes	None
Aug. 13, 2001	8-31-50-25W3M	Production	Yes	None
Aug. 16, 2001	9-31-50-25W3M	Production	Yes	None
Aug. 16, 2001	15-36-49-2W4M	Production	No	None
Aug. 18, 2001	15-9-51-25W3M	Production	Yes	None
Aug. 18, 2001	8-12-52-2W4M	Production	Yes	None
Aug. 20, 2001	4-14-51-25W3M	Production	Yes	None
Aug. 22, 2001	15-19-51-25W3M	Production	Yes	None
Aug. 22, 2001	8-23-53-2W4M	Plugs	No	None
Aug. 24, 2001	9-27-49-1W4M	Production	No	None
Aug. 25, 2001	1-33-51-25W3M	Production	Yes	None
Aug. 26, 2001	6-6-52-25 W3	Production	Yes	None
Aug. 30, 2001	12-10-51-27 W3	Plugs	Yes	None
Sept. 9, 2001	5-5-52-23 W3	Production	No	None
Sept. 16, 2001	11-13-20-19 W3	Intermediate	Yes	None
Sept. 19, 2001	11-13-20-19 W3	Intermediate	Yes	None
Sept. 21, 2001	11-36-20-19 W3	Intermediate	Yes	None
Sept. 24, 2001	11-36-20-19 W3	Intermediate	Yes	None
Sept. 29, 2001	11-24-21-19 W3	Production	Yes	None
Oct. 1, 2001	7-13-21-20 W3	Intermediate	Yes	None
Oct. 9, 2001	11-19-47-6 W4	Production	Yes	None
Oct. 20, 2001	6-36-37-28 W3M	Production	Yes	None
Oct. 30, 2001	8-32-35-21 W4M	Two-Stage	Yes	None
Dec.15, 2001	1-6-60-4 W5M	Production	Yes	None
Jan. 12, 2002	15-7-58-6 W5	Production	Yes	None
Jan. 18, 2002	15-7-57-7 W5	Production	Yes	None
Jan. 21, 2002	3-17-51-6 W4	Production	Yes	None
Jan. 25, 2002	8-6-52-7 W4	Production	Yes	None
Jan. 27, 2002	6-1-21-21 W3	Production	Yes	*
Jan. 28, 2002	10-17-21-18 W3	Production	Yes	*

* *Data not available at time of publication.*

As the non-pulsed wells showed the same results as the pulsed wells in Tangleflags and Wildmere, these results are still somewhat inconclusive as to whether the pulsation technique or the cement slurry design controlled the gas migration. No leaks occurred whether the pulse technique was used or not. Also of interest is that the abandonment plugs that were pulsed did not leak. It is interesting to note that a non-thixotropic gas control cement controlled gas migration. According to the industry standard, thixotropic cements have always been run in these applications. Further research may need to be undertaken to examine this phenomenon.

The results from the Abbey area are an improvement, but are not where we would like them to be. Further work needs to be done to conclude if the gas migration is due to a hole-cleaning problem, microannulus or channeling through cement. Additional Abbey wells will be cemented in Q1 2001 which will give a larger database to analyze.

Additional Results

After completing the initial tests, additional wells have been cemented for other companies using the pulsation technique. The area of use has expanded to Western Alberta and has been used to a depth of 1,305 meters. In all cases, the wells pulsed have been offset wells that had previous gas migration problems to surface. To date, the technique has been 100% successful at preventing gas migration in these wells.

Future Work

To date, the pulsation technique appears to control gas migration into cement in most wells. A success rate of 94% was achieved in controlling gas migration in the studied wells. Additional work is being done in the following areas:

1. Determine the cause of the leaks in the two Abbey wells.
2. Expanding the use of the pulsation unit to other gas migration areas for other companies.
3. Applying pulsation to deeper wells to improve zonal isolation in areas that have gas or fluid migration into the annulus.
4. Bond log some pulsed wells to determine if zonal isolation is improved with pulsing.
5. Researchers at Louisiana State University are developing a well diagnosis model that uses pulsation volumes to determine downhole well conditions. This research is aimed at determining the location of downhole bridges, cement tops, high fluid loss areas and actual cement thickening times. Research completed to date is described in Kunju et al.[7]

Further work needs to be done on reducing the cost of cement blends in gas migration areas. If cement pulsation by itself controls gas migration, then expensive additives can be removed from cements, which will improve economics for operators in these areas.

Conclusions

1. Pressure pulses applied at surface to a cemented annulus reach the bottom of a cement column.
2. Pressure pulses in cement prevent hydrostatic loss of pressure in the annulus as cement sets.
3. Cement pulsation has proven to control gas migration in wells to a depth of 1,305 meters in Alberta.
4. Further work needs to be done to expand the research to deeper wells and to optimize blends to reduce costs using pulsation technology.

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