FOAM CEMENT FOR LOW-PRESSURE SQUEEZE APPLICATIONS

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ABSTRACT

Foam cement's ultra-light density and high compressive strength characteristics have been employed in the Permian Basin to protect low-fracture gradient formations. In addition to standard casing jobs, squeeze cementing results have been greatly improved through use of fast setting, expansive foam cements to obtain an effective squeeze without breaking down weak formations. With this unique fluid, squeeze cementing jobs have had a significantly higher success ratio for controlling water zones and sealing corroded casing. In cases where standard lightweight cement slurry compositions have proven ineffective because pumping pressures exceed formation breakdown pressure, foam cement has been used to help prevent fracturing weak formations.

Field results and job procedures will be emphasized to illustrate how foam cement is being used in the Permian Basin to improve squeeze cementing job results when low formation breakdown pressures are present.

INTRODUCTION

Foam cement was developed more than eight years ago to provide a lightweight, high strength material for cementing applications. Its use has included primary cementing across weak and cavernous formations, stopping lost circulation during drilling and workover, sealing off water flows, and for insulation purposes.[1] Foam cement's exceptionally high strength to density ratio[2] and high compressibility have turned many a problem well into a success story. Alternatives to foam cement in such applications have often turned out to be ineffective and more costly in the long run.

Squeeze cementing with foam cement is one area that has diversified and grown substantially over the last few years. In fact, the very nature of foam cement has broadened the scope of work that would fall under the category of squeeze cementing. The development of computer programs[3] has aided in the design of some of these applications and there are yet further areas that could be explored and developed in this type of work.

The purpose of this paper is to present the various types of applications for squeeze cementing with foam cement. The unique properties of foam cement will be discussed as well as how they are useful in squeeze cementing operations. Also, the role of computer simulation as a design tool for some of these applications will be presented. Finally, case histories of the different types of squeeze jobs will be given to illustrate how foam cement has been used to solve a variety of cementing problems.

UNIQUE PROPERTIES OF FOAM CEMENT

Foam cement has a number of unique properties that make it particularly advantageous in certain squeeze cementing applications:

1. High strength at low density. Some weak formations will fracture far below the hydrostatic pressure of conventional cement slurries. Fracturing has been observed at gradients less than 0.5 psi/ft (equivalent to 9.6 lb/gal). Cavernous formations which offer no restriction can have connate fluid pressure of <0.4 psi/ft (7.7 lb/gal equivalent). Water extended slurries with useful compressive strength are limited to about 10.5 lb/gal, and microsphere slurries have a minimum density limit of 8 to 10 lb/gal. Even at these low densities the bottomhole pressure caused by these slurries can be enough to fracture the formation, resulting in the loss of slurry in the formation and inadequate sealing of areas of interest with cement. Foam cement allows slurry density to be reduced to as low as 4.0 lb/gal.

2. Compressibility. The high compressibility of the foam cement allows it to expand or be compressed based on changes in pressure. Unless positive squeeze pressure is obtained, hydrostatic pressure of the foam will adjust to an equilibrium pressure, limited by the formation breakdown pressure. With conventional slurries the level in the pipe simply drops and all surface pressure indications and surface control are lost. Foam can expand and allow surface pressure indication to be retained. The compressibility also allows placement of lightweight cement under "dynamic" conditions, then squeezing to a higher density under "static" conditions. This makes possible the placement of slurry densities that could not be obtained dynamically due to prohibitively high circulating pressures. Finally, cement compressibility has been shown to help stop invasion of formation fluids into a fluid cement annulus.[4] This helps provide protection against annular invasion where overbalance pressure is minimized because of low fracture gradients.

3. Viscosity/thixotropy.[5] Although foam cement's viscosity/ thixotropy characteristics often cause higher frictional pressures under dynamic conditions, these same properties help provide resistance to water fluxes under both dynamic and static conditions.

4. Stable intermixing. Laboratory tests indicate that foam cement may intermix with water fluxes downhole and still remain competent. The only effect this intermixing appears to have is an increase in the water ratio of the cement phase of the foam, thus reducing the compressive strength of the foam some degree.

5. Low fluid loss. This may curb dehydration of the slurry during placement and allows for better bonding to salt formations.

APPLICATIONS

Squeezing Weak Formations

The need to squeeze low fracture gradient formations is caused by a variety of conditions. Each condition, though, is similar in that the problem in each case is a formation which is easily broken down by standard cement slurries and job procedures. Basically all foam cement applications involve cementing low-fracture gradient formations. Many of these applications involve squeezing to fill uncemented annuli to help protect casing and help prevent annular fluid migration.

Squeeze jobs to control or seal cavernous zones are similar to primary cement jobs for the same type of zone. Complete filling of the interconnected voids is often neither economically feasible nor required for casing protection. Foam cement, however, provides the viscosity/thixotropy needed to limit slurry penetration into such zones.

Squeezing Water Flows

The problems presented by weak formation squeeze work can be compounded by water flow. However, foam cement's viscosity increases its resistance to washout by formation water, and if water does commingle with the foam cement, it can be incorporated within the foam structure without seriously affecting the cement's integrity.

Case History:

A production casing was perforated in two different zones, followed by acid breakdowns. Following each treatment, water production occurred. The well was tested and results showed the two zones to be in communication.

Conventional slurries were used when a block squeeze was attempted, followed by an attempt to squeeze off the top perforations. Each attempt resulted in formation breakdown and the well went on vacuum. After drilling out retainers the zones were still in communication with each other.

A squeeze technique was then attempted with foam cement. A retainer was set above both zones at 4821 ft. The suggested job procedure was as follows:

	Rate (bbl/min)	Pressure (psi)	Nitrogen Rate (scf/bbl)
1. Establish Injection	3	750	0
2. Pump 10 bbl slurry	2	1200	500
3. Pump 8 bbl slurry	2	1250	450
4. Pump 4 bbl slurry	2	1300	400
5. Pump 3 bbl slurry	2	1000	0
6. Displace with 26 bbl	2-3	1000	0
7. Shut down	0	1250	0
8. 1 minute shut down	0	750	0
9. Pull out retainer and pump + 2 bbl slurry to pit			

Computer analysis yielded the following job data:

1. An 11.0 lb/gal foam cement slurry would be obtained with a surface pressure of 750 psi.

2. Final hydrostatic pressure at 5000 ft under these conditions would be 3016 psi.

3. Formation breakdown would occur at 3150 psi with a 2200 psi fracture extension pressure.

4. A conventional cement of 14.8 lb/gal would exert a hydrostatic pressure of 3850 psi plus the injection pressure with the tubing full.

During the foam squeeze the 3150 psi was exceeded, but the compressibility of the foam inhibited fracture propagation and allowed it to go into equilibrium once pumping was stopped. After drilling through the first zone, the zone was pressure tested to 1000 psi and held. The well was drilled to the float collar and tested to 1000 psi. This time there was a slight leakoff. However, investigation showed the plug was not bumped and that the cement had been overdisplaced 15 bbl on the primary job, suggesting that there may have been a wet shoe. A retrievable bridge packer was set at 5100 ft and the lower interval was reacidized. Foam cement controlled the breakdown and a tracer survey indicated the breakdown occurred between 5045 and 5070 ft. The latest report was that the well had been producing 20 BOPD with no water for the last 10 months.

Squeezing with Quick Setting Slurries

In squeezing off water flows an additional advantage can be obtained by using a quick setting foamed cement. This technique rapidly creates a solid cementitious material that will help resist washout while still providing a lightweight, high strength material.

Details of the use of this quick setting foamed slurry to seal off open annuli with water flow problems is documented by Garvin and Creel.[6] Details of a typical job of this type are given below.

Case History: Foam squeeze with quick setting slurry

A corrosive water flow caused substantial erosion of casing in a well. When water started flowing out around the collar and all over location the need to solve the problem became mandatory.

Three attempts were made with conventional slurries to set a cement plug to stop water flow, but all were unsuccessful. On the third job the tubing became stuck outside the casing and was pulled in two.

A quick setting foamed cement job was designed with 2-3/8 in. tubing to be left in the well, set open ended at ± 2150 ft (Fig. 1).

The job was designed such that the foamed slurry would circulate around the tubing back to surface and then set. The remainder of the slurry would continue to be pumped, squeezing it into any washed out or void areas.

When the job was conducted returns stopped, giving an indication that the slurry set and that it had successfully sealed off the water flow. Injection of foam cement continued followed by the displacement with fresh water. The well was pressure tested up to 1500 psi after shutdown and then closed in.

Afterwards the cement was tagged at 2150 ft inside the tubing and at 1776 ft in the 2-3/8 in. × 7 in. annulus. Multiple cement plugs were eventually placed on top of the foamed quick setting slurry plug to finally bring cement back to surface.

Bradenhead Squeeze

Often in older fields, only the lower portion of the casing was cemented either because of cement lost to a weak formation or less than adequate cementing practices. Casing corrosion problems in these older wells can necessitate cementing the unfilled annulus to protect casing and stop water flow. Again, weak formations can make circulation of standard lightweight slurries impossible in one stage.

Foam cement can be designed to be placed under dynamic conditions all the way back to surface, but the density of the foam cement may be excessively low near the surface due to low hydrostatic pressures. Once the slurry is in place, however, it can be compressed to an acceptable level by performing a Bradenhead squeeze on top of the cemented annulus with a normal density cement slurry. Since the whole column of cement is in a static condition, a higher overall fluid density column can be created because there is essentially no frictional pressure due to circulation.[3] This technique helps achieve annular fill to the surface with good compressive strength.

The Bradenhead Squeeze technique on the cemented annulus is also useful in primary cementing applications.

Case History: Bradenhead Foam Squeeze on Primary Job

A 5-1/2 in. production casing was to be set at 7025 ft. Cement was to cover a weak zone with a fracture gradient of 0.65 psi/ft. This same zone had a water flow requiring a 10.0 lb/gal equivalent circulating density (0.52 psi/ft) to prevent annular invasion of water.

Foam cement design and job simulation programs were used to arrive at a final slurry design and job procedure to cement this well. Various fluids were pumped in the well with the nitrogen ratios given below. Figure 2 is a plot of the estimated pressure at 4600 ft (the weak zone), showing that the pressure should remain below the 3000 psi fracture pressure while staying above 2400 psi (formation pressure) during the second half of the job. Figure 3 shows the improvement of the slurry density after the squeeze as compared to before the squeeze.

The job was conducted as follows:

1. Pumped 50 bbl brine (10 lb/gal) at 5 bbl/min with 100 scf nitrogen/bbl.

2. Pumped 140 bbl Class C cement at 5 bbl/min with 150 scf nitrogen/bbl in first 81 bbl and 225 scf/bbl in last 59 bbl.

3. Pumped 195 bbl Class C cement at 6 bbl/min with 225 scf nitrogen/bbl.

4. Pumped 100 bbl 50:50 pozzolan:Class C cement (tail) at 6 bbl/min.

5. Pumped 137 bbl 50:50 pozzolan:Class C cement (tail) at 10 bbl/min.

6. Dropped plug on fly and displaced with 10 lb/gal brine - 160 bbl at 7 bbl/min followed by 7 bbl at 4 bbl/min.

7. Bumped plug at this point.

8. Rigged up to Bradenhead and applied a squeeze with 100 sks of Class C cement.

9. Closed in 2 hours, tested, and began rigging down.

Analysis of bond logs indicate a complete cement sheath throughout the interval with good bonding.

Open Hole Squeezes

Squeezing an open hole with foam cement can be useful in a couple of different situations. One is when lost circulation zones are encountered while drilling. The loss of drilling fluid can be an expensive problem if the zone will not seal off with the addition of lost circulation material to the mud, or by other common techniques. Squeezing with foam cement has proven to be an effective method for sealing off lost circulation zones.

To squeeze off a lost circulation (LC) zone a lightweight foam cement plug is spotted across the LC zone with some volume of water or light fluid on top of it, or with a packer. The slurry can be compressed by applying pressure to increase its density and strength while forcing some of the slurry into voids in the LC zone.

Similar situations have been encountered with the added problem of a water flow. The high viscosity of the foam, along with its stability when intermixed with water help foam cement to resist being washed out.

A second type of open hole squeeze job is consolidating old open hole completions. Often a well with open hole completion will have been shot numerous times with nitroglycerine, leaving the hole in a rough and unconsolidated state. The presence of a weak formation will prevent the use of normal density cements, leaving hollow sphere or foam cements as the only option to solve the problem because of their lightweight, high strength characteristics.

Case History: Open hole squeeze

A water flow problem of 160 bbl/min was encountered while drilling open hole. Log correlations from offset wells indicated that the water flow interval was located from about 5010 to 5250 ft. Three previous attempts to squeeze the flow with thixotropic slurries failed to slow the water influx, even though increasingly higher squeeze pressures were obtained. While drilling out the third squeeze job, the drill bit failed before the flowing interval was completely drilled out.

A squeeze job was conducted with 200 sks Class C cement with 2% calcium chloride. The slurry was mixed at 14.8 lb/gal and foamed with 800 scf nitrogen/bbl. Fifty sacks of the same slurry, unfoamed, was used for a tail cement.

When the foamed interval was drilled out the water flow rate was found to have been reduced to 20 gal/min.

Liner Squeezes

Primary

As with long one-stage cement jobs, there are occasions when liners need to be cemented across low fracture gradient formations. To minimize pressure across weak zones and maximize compressive strength, the compressibility of foam cement can be used to advantage.

A liner squeeze job is conducted in a similar manner as a long string job. Cement is mixed and pumped followed by the displacement fluid. However, before the last volume of displacement is pumped to bump the plug, a packer, placed on top of the liner, is activated to seal off flow of cement up into the casing/drill pipe annulus. Displacement is continued until the plug is bumped, compressing the foam cement in the liner/hole annulus. What this technique accomplishes is the placement of a higher density, higher compressive strength foam cement than could be placed under dynamic conditions without breaking down a weak formation. As with the Bradenhead squeeze technique there is little or no frictional pressure in the annulus due to circulation once the packer is closed.

Remedial

Another liner squeeze technique can be utilized when, because of weak zones, complete coverage of the liner was not accomplished during the primary job. A simple Bradenhead squeeze is performed on the liner top to provide a better cement sheath around the liner. Again, the unique properties of the foam cement slurry, i.e., compressibility and high strength-low density, allow for successful placement in cases where conventional slurries would break down a formation, lose surface pressure control, and fail.

Case History: Remedial liner top squeeze with foam cement

A primary cement job was attempted on a 7 in. liner set from 10,400 ft up to 4,420 ft inside an 8-5/8 in. intermediate casing (Fig. 4). When the job was conducted with unfoamed cement, circulation was lost prior to bumping the plug, indicating a formation had been fractured. A temperature survey showed top of cement at ±7500 ft.

To cover the upper portion of the annulus with cement a conventional liner top squeeze was attempted. A retainer was set at 4,223 ft (Fig. 5), and the following slurries were pumped:

Lead: 200 sks 50:50 pozzolan:Class C cement + 4% bentonite + 6 lb/sk salt + 0.4% fluid loss additive + 0.1% dispersant; 6.44 gal/sk water, 14.0 lb/gal, 1.37 cu ft/sk

Tail: 100 sks Class C cement + 2% $CaCl_2$ + 6.3 gal/sk water; 14.8 lb/gal, 1.32 cu ft/sk

During the job the formation was fractured and slurry was lost to the formation, still leaving an open annulus. At this point a foam squeeze was attempted to allow placement of cement in the open annulus (Fig. 5). The job was conducted by pumping the following slurries.

Lead: 250 sks Class C cement mixed at 14.8 lb/gal with 1500 SCF nitrogen/bbl, yielding 3 cu ft/sk downhole

Tail: 50 sks Class C cement mixed at 14.8 lb/gal

Table 1 is a computer printout of calculated downhole foam cement densities, hydrostatic pressures, and expansion factors at various intervals.

The slurry was displaced to the retainer and and shut in with 600 psi at the surface. The drill pipe was pulled out of the retainer and reverse circulated to the pit.

After the cement was allowed to set up, the top of the liner was pressure tested to 1000 psi.

Computer Aided Job Design

Job design is performed using computer programs to (1) calculate nitrogen injection rates to obtain a given density for critical intervals, and (2) dynamically simulate pumping the job under specified hole and casing conditions. This second program can give equivalent circulating densities at zones of interest taking friction pressures into consideration. Its use is detailed by Kulakofsky, Creel, and Kellum.[3]

CONCLUSIONS

1. The high strength/low density characteristics of foam cement provide low hydrostatic pressures in squeeze applications where conventional slurries will break down a formation without squeezing off desired zones.

2. The compressibility of foam cement allows the slurry to expand to equilibrium, helping prevent propagation of fractures rather than allowing the loss of large volumes of slurry which can occur with standard density slurries.

3. Slurry compressibility allows for "static squeeze" applications to maximize slurry density and strength.

4. The high viscosity and texture of foam cement help resist washout when cementing across water flow intervals. Foam cement has proven to be effective in eliminating or greatly reducing water flow where conventional slurries often fail.

5. Foam cement squeeze jobs can be designed and modelled with the aid of computer design and job simulation programs.

6. Foam cement squeeze jobs cover a broad range of conventional applications because of foam's unique physical properties.

REFERENCES

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4. Sutton, D.L., Sabins, F.L., Faul, R.R., "Preventing Annular Gas Flow", (Two Parts), Oil and Gas Journal, Dec. 10-17, 1984.

5. Harms, W.M., and Febus, J.S.: "Cementing of Fragile-Formation Wells with Foamed Cement Slurries," SPE 12755, 1984 California Regional Meeting, Long Beach, CA, April 11-13, 1984.

6. Garvin, T.R., and Creel, P.G., "Foamed Cement Restores Wellbore Integrity in Old Wells," Oil & Gas Journal, August 20, 1984.

Table 1
Foam Cement Squeeze on Liner Top
Job Data

INTERVAL NO.	LENGTH FT	FLUID DENSITY - LB/GAL SURFACE UNFOAMED	DOWN-HOLE AVG	DOWN-HOLE TOP	DOWN-HOLE BOTTOM	PRESSURE PSI TOP	PRESSURE PSI BOTTOM	AVG. TEMP °F	GAS SCF PER BBL	AVG. EXP. FACTOR BBLS FOAM PER BBL SLURRY
1	4223	8.5	8.5	8.5	8.5	600	2465	100	0	1.000
2	577	14.8	14.8	14.8	14.8	2465	2908	100	0	1.000
3	1000	14.8	7.3	7.1	7.5	2908	3287	100	1500	2.394
4	1000	14.8	7.7	7.5	7.9	3287	3688	100	1500	2.262
5	700	14.8	8.0	7.9	8.2	3688	3980	100	1500	2.168

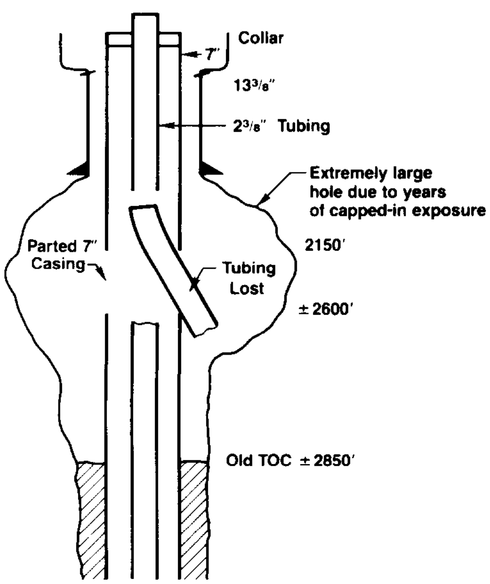

Figure 1

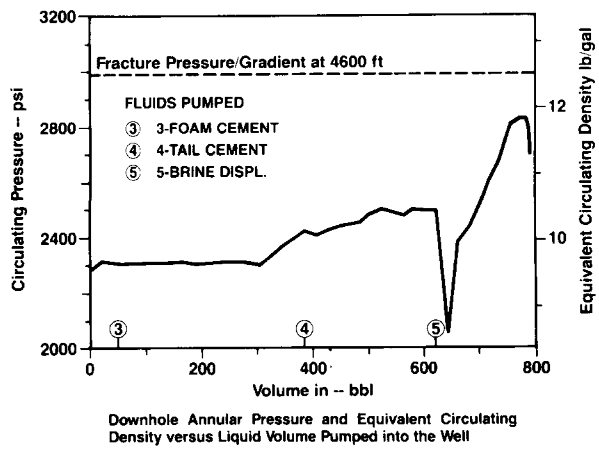

Figure 2—Circulating pressure and density at 4600 ft. (primary foam cement job)

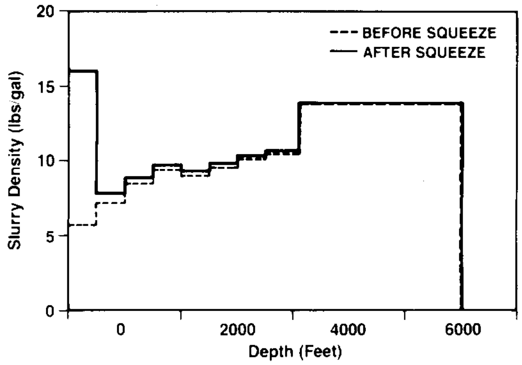

Figure 3—Slurry density vs. depth (before and after Bradenhead squeeze)

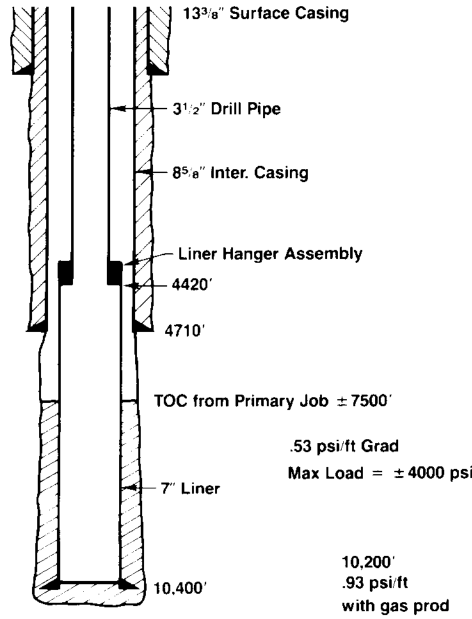

Figure 4—Liner job

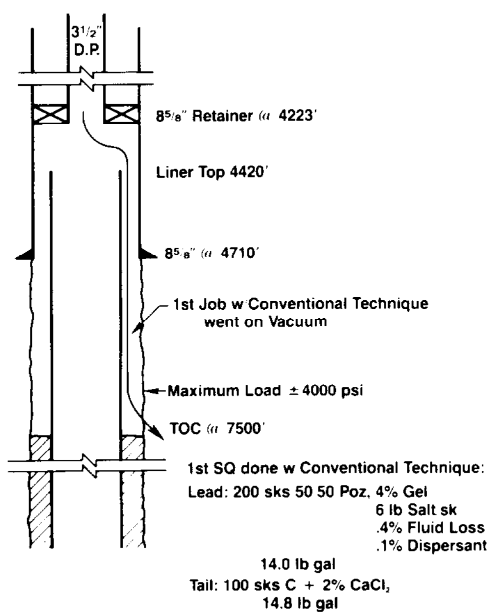

Figure 5—Conventional liner top squeeze

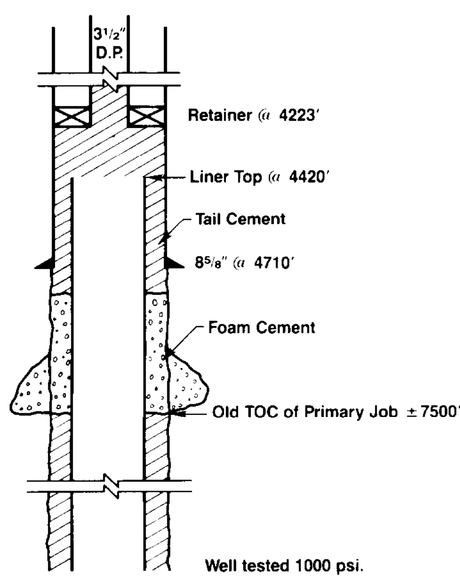

Figure 6—Foam cement liner top squeeze