PRACTICAL FIELD PROCEDURES AND TECHNIQUES FOR FOAM CEMENTING

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ABSTRACT

A successful foamed cement job results from careful planning and precise control of densities, rates, and pressures. This paper discusses practical methods of obtaining unfoamed slurry densities, chemical injection rates, and nitrogen injection rates. It also discusses the continuous monitoring and logging of these parameters with a high-tech van. The importance of backside control, hole size, and volume calculations are presented.

INTRODUCTION

The introduction of a stable foamed cement system in the 1970's offered new solutions to critical well cementing problems. Initially, the most attractive feature of a foamed slurry was the reduction of hydrostatic pressures across weak zones. It was recognized that the introduction of air, or more often, nitrogen to a cement slurry could decrease the slurry weight far below that of a conventional high-water slurry without an accompanying loss of compressive strength and permeability. Later, foamed cement found applications in lost circulation control, insulating casing in geo-thermal wells, and squeeze cementing. Once looked on with some misgivings, foamed cement has gained wide acceptance with improved techniques and a history of successful jobs. Its use is now commonplace as an alternative in many situations to conventional cementing methods.

Some of the earliest foamed cement jobs were performed with methods adopted from foam drilling operations.[1] The jobs were performed using standard cementing equipment except for an air compressor and a T-connection at the air/neat slurry injection point. Despite rather crude methods, for instance gas injection rates were measured with an orifice flow meter and pressure gauges, many of these early jobs were successful, both from standards observable on the surface and standards downhole measured by bond logs and temperature surveys.

JOB DESIGN

Proper job design is essential to a successful foamed cement job.

The first step in designing a foamed job is determining nitrogen rates and volumes needed for the desired foamed slurry density. A computer program simplifies this process, calculating the complex relationships that temperature and pressure have on nitrogen. The computer calculates the amount of nitrogen, cement, and the final density of the cement at various temperatures and depths. (Table 1.)

Information required from the operator include:

a. Depth
b. Temperature gradient (BHST/BHCT)
c. Average hole size (by caliper log if possible)
d. Pipe size (O.D. and I.D.)
e. Depth of weakest formation(s) of loss zones
f. Density and properties of drilling fluids
g. Density of displacement fluid
h. Frac gradient
i. Top of completion cement
j. Top of filler slurry
k. Depth last casing set
l. I.D. last casing

One of the most important criteria is the average hole size or percent excess required to achieve calculated fill up. Ideally, all volumes of the openhole should be determined by a wireline caliper, however, past field experience may be substituted if no caliper is available.

CONSTANT DENSITY FOAM

One of the first foam systems used in the Permian Basin was the constant density system. With this system the base slurry rate is kept constant and the nitrogen rate is increased during the job to keep the foamed slurry density constant based on final placement in the annulus.

In designing a constant density job, it is important to calculate the maximum hydrostatic pressure that the weakest formation can stand and then adjust the job parameters accordingly. When figuring the hydrostatics of the cement column you need to add any backpressure held on the annulus and the additional hydrostatics if a cap of cement or a spacer is pumped ahead of the foam column.

One of the main advantages of using this system is that the compressive strengths, permeability, and porosity of the foam cement is consistent throughout the column. This helps to ensure that cement placed across corrosive water zones is adequate to protect the casing string.

The major disadvantage of a constant rate job is that the nitrogen rate must be frequently adjusted in small increments.

CONSTANT RATE

The simpliest foamed slurry design, at least operationally, is the constant rate method. With this method the nitrogen rate is held constant throughout the job. The foamed slurry density will vary from the top to the bottom of the cement column. The denser slurry will, of course, be at the bottom of the column due to the compressibility of the nitrogen. One drawback to this method is the decreased slurry density at the top of the column. The density can reach a point where compressive strength and permeability are not sufficient to provide a protective cement sheath. This doesn't pose a problem if poor cement can be tolerated, for instance, behind cased annulus.

SLURRY PROPERTIES

Slurry pump times and fluid loss properties are basically the same as those of an unfoamed cement.[2] Lab tests have concluded that the addition of nitrogen to a slurry has little effect on thickening time or fluid loss. Pump times can be determined by testing the unfoamed slurry according to the appropriate API schedule. Pump times can be adjusted with normal cement additives. Likewise, fluid loss can be controlled with common fluid loss additives. Compressive strengths can be determined by aerating a slurry to the desired density and then placing it into a sealed mold. Normal curing procedures are then followed.

JOB MONITORING

Careful job monitoring and on-site communications is critical to job execution. A high-tech van provides a central station to monitor and control the job. Using microchip computing capabilities, the monitor can calculate and display job parameters such as nitrogen rate, unfoamed slurry rate, pump pressure, backside pressure, and total barrels pumped (Table 2.) The service supervisor, in radio communication with the cement crew, can control the job from the van. This control makes coordinated efforts possible.

NITROGEN MEASUREMENT

One of the limitations on early foamed cement jobs was the lack of precision in monitoring of the nitrogen injection rate. Nitrogen pumping equipment measured rate by the pump displacement method, i.e., counting pump strokes. This method, while sufficient for the high nitrogen rates encountered on foam frac jobs, was inadequate on low rate/low pressure foamed cement jobs.

The introduction of in-line nitrogen flowmeters improved the control over the nitrogen injection rate and consequently the foamed slurry density, especially, important where small changes in rate cause a large change in final density. (Table 3 & 4.)

One such flowmeter is an intrusive device housed in a 2" T-assembly. (Figure 1.) A small "target" is centered and perpendicular to the nitrogen flow. The force exerted on the disc by the moving gas is transmitted via a lever arm to a strain gauge bonded to a flexure tube. A microprocessor converts the output signal, along with treating pressure and measured gas temperature to produce a standard cu.ft. per min. (SCFM) flowrate. Different diameter targets are available to ensure accurate measurements over a wide range of flowrates.

An accurate turbine-type flowmeter is also available.

FOAM GENERATOR

The design of the foam generator, critical for the proper dispersion of nitrogen into the neat slurry, has undergone several important changes. The first generator consisted simply of a T-assembly. Later, the nitrogen inlet was designed to intersect the main flow line tangentially since research indicated this method provided superior mixing action. (Figure 2.) Several injector sizes were experimented with to increase the nitrogen velocity at low rates to provide excellent atomization. A sparge-type generator has also been designed. This device consists of a finely meshed stainless steel screen centered in the flow line. It provided the highest nitrogen/slurry contact area.

CHEMICAL INJECTION

A foamed slurry requires the injection of a surfactant/foaming agent and a stabilizer. Normally these additives are injected into the high pressure discharge line between the cement pump unit and the nitrogen injection point. A standard tri-plex pump is capable of delivering the required additives with an accuracy of +/-10%, even at the low rates encountered, i.e., 2-5 gal./min.

Several steps have been taken in the field to simplify the chemical injection procedure. These include pre-mixing the stabilizer in the neat slurry mix water. This method eliminated the need for one chemical pump and ensured the accuracy and even mixing of the chemical before the start of the job.

At least some research has reached the conclusion that a stabilizing additive is unnecessary. Foam stability was found to be almost entirely dependent on the proper dispersion of the nitrogen in the cement slurry and the activity level of the foaming agent. The more discrete and well dispersed the nitrogen, the more stable the foam slurry. The foam stability was found to deteriorate when initial thickening occurred and the nitrogen bubbles were allowed to burst and coalesce. For this reason a foamed slurry needs to be in place before initial set occurs.

NEAT SLURRY CONTROL

In the field, mixing the neat slurry to the correct density is critical to the success of the job. All unfoamed slurry should be mixed using recirculating equipment or batch mixers. The batch mixer has the advantage of providing an inventory of properly mixed slurry. This inventory eliminates the problems resulting from unexpected interruptions in bulk delivery rates or tub levels. A turbine-type flow meter or other type flow measuring device is needed to measure the unfoamed slurry rate.

BACKSIDE PRESSURE

One of the ways to control the weight of the cement slurry on a foam job is to increase or decrease the annulus pressure. By increasing the backside pressure just 100 psi, the operator can increase the weight of the cement 1-2 lbs/gal. (Table 2,5 & 6.) With the increase in weight there is a corresponding increase in the compressive strength and decrease in the permeability of the cement.

The easiest way to control the pressure on the annulus is to close the blow-out preventers and regulate the pressure through the manual choke on the rig. The main disadvantage of this method is that a piece of loss circulation material or cutting can block the choke causing a rapid increase in pressure. This could result in fracturing the formation.

Another way to control the annulus pressure is to bypass the rig's choke system and use a 2" full opening valve to regulate the pressure. (Figure 3.) An operator can monitor the pressure and clear a valve of any obstructions before there is a large pressure increase.

A third method, if casing movement during cementing is not used, is to land the casing, pack it off, and bring returns through the bradenhead.

CONCLUSIONS

In the past ten years foamed cement has gone from the experimental to the commonplace. However, success still depends on careful planning and execution of the job. The best foam system, constant rate or constant density, should be selected depending on the application. All rates must be carefully monitored and communicated throughout the job. Lessons learned in the field and more precise measuring equipment has improved job quality.

ACKNOWLEDGMENTS

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SELECTED REFERENCES

1. Davies, D. R., Hartog, J. J. and Cobbett, J. S.: "Foamed Cement -- A Cement with Many Applications," paper SPE 9598 presented at the 1981 SPE Middle East Oil Technical Conference and Exhibition, Manama, Bahrain, March 9-12.

2. McElfresh, P. M. and Go Boncan, V. C.: "Applications of Foam Cement," paper SPE 11203 presented at the 1982 SPE Annual Technical Conference and Exhibition, New Orleans, Sept. 26-29.

Table 1

TOTAL CIRC. DEPTH	7000 FT	DEPTH LAST CSG SET	1000 FT
ID LAST CSG SET	8.050 IN	HOLE DIA	7.875 IN
OD SCG	5.500 IN	ID CSG	4.950 IN
BHST	140 F	BHCT	95 F
FRAC GRAD	.58 PSI/FT	EXCESS IN O.H.	100 %
BACK PRESSURE HELD ON ANNULUS (IF REQUIRED)			100 PSI

FLUID DATA

DEN OF MUD	8.8 LB/GAL	DEN OF DISP FLUID	8.5 LB/GAL
DEN OF TAIL	14.4 LB/GAL	DEN OF FILLER	9.5 LB/GAL
VOL OF TAIL	123.4 BBL	VOL OF FILLER	280.4 BBL
DISPLACEMENT	166.6 BBL		

NITRIFIED CEMENT DATA

RUNNING TOTAL BBL AT DEPTH	BASE CEMENT BBL AT 4.0 BPM	NITROGEN DATA SCF/MIN	NITROGEN DATA SCF/INCR	INCREMENT DEPTH
33.6	21.5	287	1548	1000
95.3	39.6	694	6873	2000
157.0	39.6	1089	10780	3000
218.7	39.6	1466	14518	4000
280.4	39.6	1822	18040	5000
TOTALS	180.0 BBL		51760 SCF	

Table 2
Hi-Tech Van Output

ELAPSED TIME	PUMP PRESS	BKSIDE PRESS	TOTAL RATE	RATE CH 1	DENS CH 1	RATE CH 2	DENS CH 2	N2 SCFM	N2 SCF x 1000	TOTAL BBLS
00:26:54	840	50	8.4	.0	.0	5.0	15.0	1100	37	143
00:26:24	870	40	8.3	.0	.0	5.0	14.8	1100	36	140
00:25:54	890	40	8.9	.0	.0	5.0	15.0	1300	36	138
00:25:24	890	40	8.4	.0	.0	5.0	15.0	1100	35	135
00:24:54	870	60	8.2	.0	.0	5.0	14.9	1000	35	133
00:24:24	870	40	8.2	.0	.0	5.0	14.9	1000	34	130
00:23:54	870	50	8.2	.0	.0	5.0	14.8	1000	34	128
00:23:24	880	40	8.1	.0	.0	.0	14.8	1000	33	125
00:22:54	900	40	8.4	.0	.0	.0	14.8	1100	33	123
00:22:24	870	40	8.5	.0	.0	.0	14.9	1100	32	120

Table 3

TOTAL CIRC. DEPTH	7000 FT	DEPTH LAST CSG SET	1000 FT
ID LAST CSG SET	8.050 IN	HOLE DIA	7.875 IN
OD CSG	5.500 IN	ID CSG	4.950 IN
BHST	140 F	BHCT	95 F
FRAC GRAD	.58 PSI/FT	EXCESS IN O.H.	100 %
BACK PRESSURE HELD ON ANNULUS (IF REQUIRED)			100 PSI

FLUID DATA

DEN OF MUD	8.8 LB/GAL	DEN OF DISP FLUID	8.4 LB/GAL
DEN OF TAIL	14.4 LB/GAL	NITROGEN RATE	800 SCFM
VOL OF TAIL	123.4 BBL	VOL OF FILLER	280.4 BBL
DISPLACEMENT	166.6 BBL		

NITRIFIED CEMENT DATA

RUNNING TOTAL BBL AT DEPTH	BASE CEMENT BBL AT 4.0 BPM	NITROGEN AT SCF/INCR	800 SCFM SLURRY DEN	INCREMENT DEPTH
33.6	9.8	1955	4.31	1000
95.3	32.8	6558	7.86	2000
157.0	42.2	8434	10.11	3000
218.7	47.1	9427	11.30	4000
280.4	50.0	10002	11.99	5000
TOTALS	181.9 BBL		36376 SCF	
STATIC GRADIENT	0.57 PSI/FT	FRACTURE GRADIENT		0.58PSI/FT

Table 4

TOTAL CIRC. DEPTH	7000 FT	DEPTH LAST CSG SET	1000 FT
ID LAST CSG SET	8.050 IN	HOLE DIA	7.875 IN
OD CSG	5.500 IN	ID CSG	4.950 IN
BHST	140 F	BHCT	95 F
FRAC GRAD	.58 PSI/FT	EXCESS IN O.H.	100 %
BACK PRESSURES HELD ON ANNULUS (IF REQUIRED			100 PSI

FLUID DATA

DEN OF MUD	8.8 LB/GAL	DEN OF DISP FLUID	8.4 LB/GAL
DEN OF TAIL	14.4 LB/GAL	NITROGEN RATE	1000 SCFM
VOL OF TAIL	123.4 BBL	VOL OF FILLER	280.4 BBL
DISPLACEMENT	166.6 BBL		

NITRIFIED CEMENT DATA

RUNNING TOTAL BBL AT DEPTH	BASE CEMENT BBL AT 4.0 BPM	NITROGEN AT SCF/INCR	1000 SCFM SLURRY DEN	INCREMENT DEPTH
33.6	7.7	1923	3.39	1000
95.3	26.2	6561	6.29	2000
157.0	36.2	9060	8.69	3000
218.7	42.5	10620	10.19	4000
280.4	46.3	11579	11.11	5000
TOTALS	159.0 BBL		39744 SCF	
STATIC GRADIENT	0.52 PSI/FT	FRACTURE GRADIENT		0.58PSI/FT

Table 5

TOTAL CIRC. DEPTH	7000 FT	DEPTH LAST CSG SET	1000 FT
ID LAST CSG SET	8.050 IN	HOLE DIA	7.875 IN
OD CSG	5.500 IN	ID CSG	4.950 IN
BHST	140 F	BHCT	95 F
FRAC GRAD	.58 PSI/FT	EXCESS IN O.H.	100 %
BACK PRESSURE HELD ON ANNULUS (IF REQUIRED)			200 PSI

FLUID DATA

DEN OF MUD	8.8 LB/GAL	DEN OF DISP FLUID	8.4 LB/GAL
DEN OF TAIL	14.4 LB/GAL	NITROGEN RATE	800 SCFM
VOL OF TAIL	123.4 BBL	VOL OF FILLER	280.4 BBL
DISPLACEMENT	166.6 BBL		

NITRIFIED CEMENT DATA

RUNNING TOTAL BBL AT DEPTH	BASE CEMENT BBL AT 4.0 BPM	NITROGEN AT SCF/INCR	800 SCFM SLURRY DEN	INCREMENT DEPTH
33.6	14.5	2900	6.39	1000
95.3	38.8	7763	9.31	2000
157.0	45.3	9069	10.87	3000
218.7	49.0	9791	11.74	4000
280.4	51.1	10230	12.27	5000
TOTALS	198.8 BBL		39753 SCF	
STATIC GRADIENT	0.62 PSI/FT	FRACTURE GRADIENT	0.58PSI/FT	

Table 6

TOTAL CIRC. DEPTH	7000 FT	DEPTH LAST CSG SET	1000 FT
ID LAST CSG SET	8.050 IN	HOLE DIA	7.875 IN
OD CSG	5.500 IN	ID CSG	4.950 IN
BHST	140 F	BHCT	95 F
FRAC GRAD	.58 PSI/FT	EXCESS IN O.H.	100 %
BACK PRESSURE HELD ON ANNULUS (IF REQUIRED)			400 PSI

FLUID DATA

DEN OF MUD	8.8 LB/GAL	DEN OF DISP FLUID	8.4 LB/GAL
DEN OF TAIL	14.4 LB/GAL	NITROGEN RATE	800 SCFM
VOL OF TAIL	123.4 BBL	VOL OF FILLER	280.4 BBL
DISPLACEMENT	166.6 BBL		

NITRIFIED CEMENT DATA

RUNNING TOTAL BBL AT DEPTH	BASE CEMENT BBL AT 4.0 BPM	NITROGEN AT SCF/INCR	800 SCFM SLURRY DEN	INCREMENT DEPTH
33.6	19.3	3863	8.52	1000
95.3	43.7	8733	10.47	2000
157.0	48.0	9601	11.51	3000
218.7	50.6	10113	12.13	4000
280.4	52.2	10441	12.52	5000
TOTALS	213.8 BBL		42751 SCF	
STATIC GRADIENT	0.68 PSI/FT	FRACTURE GRADIENT	0.58PSI/FT	

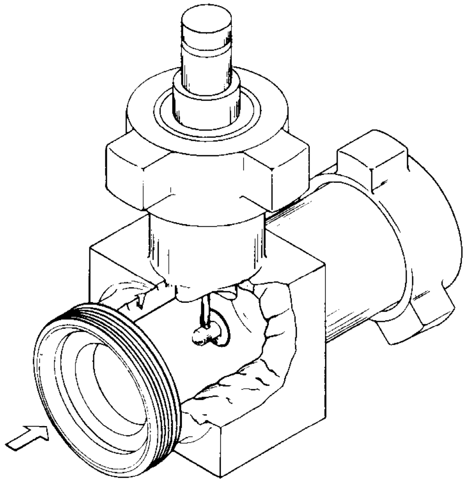

Figure 1—Nitrogen flow meter

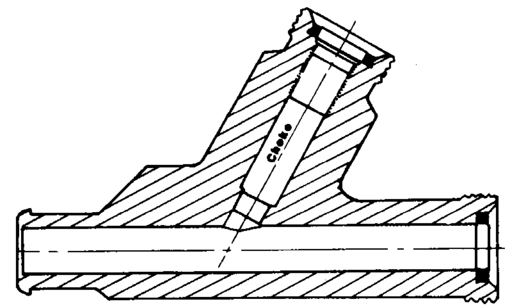

Figure 2—Foam generator

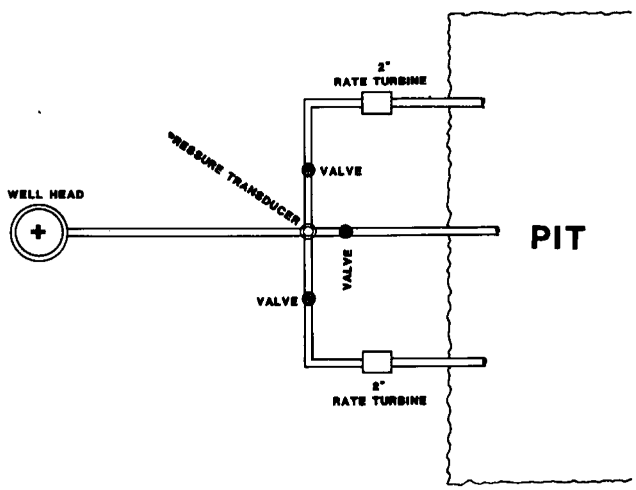

Figure 3—Backside

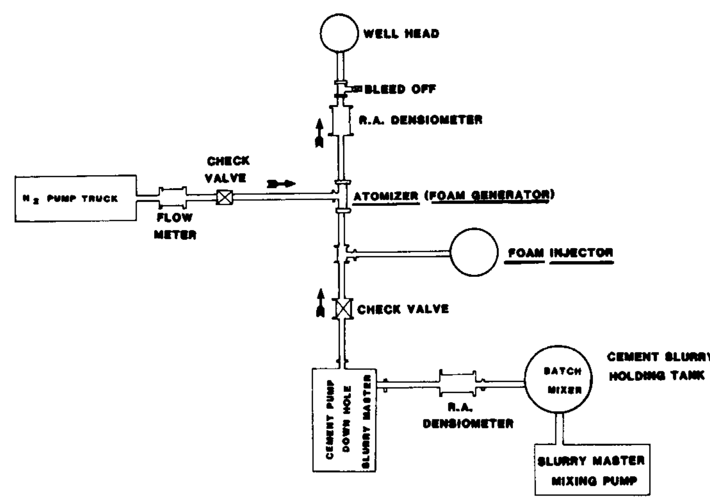

Figure 4—Equipment layout for
foamed cementing