SETTING CEMENT PLUGS FOR WHIPSTOCKING AND DIRECTIONAL DRILLING

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Cement plugs are one of the most important types of cement jobs ever performed. Therefore, they deserve the very best effort we can give to a problem. A successful plug job requires more attention to detail than most other cement jobs; the reason most of them fail is because they do not get this attention. The following guidelines will not guarantee success but they will provide a higher ratio of successes if used every time! Plugs need properties different from most other cement systems because they are intended for a different application entirely.

Failure of cement plugs is most often due to a lack of hardness in the set cement. This lack of hardness usually can be traced to one or more of these common mistakes:

1. Mud contamination of the cement during placement
2. Drilling out too soon
3. Cement not initially designed for enough strength
4. Strong tendency of all people involved to want extra pumping time, so slurry is over-retarded
5. Inaccurate BHT information - well is colder than expected because circulation effect isn't considered and temperature is guessed rather than measured
6. Not enough cement volume used.

Proper planning can eliminate these errors. Do all possible to eliminate these problems.

SELECTING THE PLACE TO SET A PLUG

The best places to set a plug are the formations that drill easiest and most uniformly. Any formation that drills hard or washes out badly should *not* be chosen as a place to set a plug. Enlarged hole must be avoided because it can cause several problems:

1. Length of plug could be too short (not enough cement used to fill the desired footage).
2. Plug is not properly spotted and ends up being underdisplaced (because height of cement column in annulus was not as high as thought).
3. Cement channels through mud and does not completely fill annulus around pipe.

Because hole size is so important, an electric caliper should be run through the zone before cementing. This, along with drilling time records, will help select the proper spot to set the plug. Be sure to calculate volume requirements and displacement correctly — according to actual measured hole size.

DRILLING MUD

Mud is frequently in poor condition on bottom when it's time to set a plug. "Bottoms Up" is the minimum conditioning necessary prior to cementing.

Mud contamination is the main cause of plug failure for two reasons:

1. Muds usually contain organic chemicals that act as cement retarders. Conventional cement systems can lose more than half their compressive strength when mixed with only 20% mud (volume percent). Densified cement systems are not affected as much by mud as conventional cement systems with weighting materials. When both are mixed at the same density and contaminated with the same amount of a given mud, the densified cement will have a higher compressive strength than the slurry which contains weighting materials.
2. Many muds are clabbered into a "putty-

like" material when contacted by cement. Therefore, the mud and cement must be kept physically separated from each other. If it is a simple water-base mud, some chemically treated water ahead of and behind the slurry will work alright. If it is an oil-base or invert emulsion mud, an Oil-Base Mud Spacer must be used instead of the chemical wash water.

Enough spacer fluid should be used to provide at least a 200-ft column of spacer fluid on top of the cement slurry, both inside and outside the drill pipe. The spacer fluids must be run both ahead of and behind the cement slurry. The volume of spacer fluid behind the slurry must be calculated to give the same height fluid column inside the drill pipe as does the spacer fluid in the annulus, which was run ahead of the slurry. Ideally, the spacer fluid should be 1/2 to 1.0 ppg heavier than the mud, and the cement slurry should be 1/2 to 1.0 ppg heavier than the spacer fluid.

Another method of combating the mud contamination is to run a length of small OD tailpipe (such as 2-1/2 in. tubing) below the drill pipe. Since drill collars and tool joints are almost as large as the gauge hole, they tend to swab the hole, no matter how slowly the pipe is pulled out of the cement plug. The smaller tailpipe minimizes this effect and also allows the cement slurry to more easily replace the pipe wall void as it is pulled. For example, the space occupied by the wall of 2-1/2 in. tubing is only one-third that of 4-1/2 in., 20 lb/ft drill pipe.

CEMENT SLURRY DESIGN

Class H or special grind Class A cement is best to use. *Density* is very important! As mentioned above, slurry density (weight) must be heavier than the mud in order to be able to displace all the mud out of the hole and occupy the annular space. Also, experience has shown that the heavier the slurry mix the more successful plugs (with fewer failures). Laboratory work shows that the less mix water used with neat cement; (1) the higher its compressive strength, (2) the lower the porosity of the set cement, (3) the quicker it reaches set strength, (4) the less it is hurt by mud contamination, and (5) the better its drilling resistance.

These benefits come from using densified cement systems. They are actually low-water-ratio cement systems because the addition of dispersant to the cement allows mixing it up to about 17.5 or 18.0 ppg without adding any weighting material, just by using less mix water than normal.

Weighted cement systems contain weighting agents such as metal ores, and are mixed with extra water in addition to that normally required for the cement. In addition to the faults already listed, at temperatures above 230°F BHST this set cement quickly suffers strength retrogression in a matter of two or three days unless silica is added to the slurry. The densified cement systems do not normally suffer this strength retrogression for several days longer, even without any added silica.

Also, in order to use weighted slurries it is necessary to add the extra materials in large quantities, and these make the slurry harder to mix in the field. Because of the extra mix water, weighted slurries usually allow settling of the solids and free water separation on top of the slurry. This sometimes causes low strengths, too. Obviously, this is not a problem with densified slurries.

Weighted slurries are much more easily contaminated with mud and suffer more strength loss due to the contamination than do densified slurries.

In designing the slurry, its density will be determined by compressive strength needed and drilling mud weight. The cement slurry should be about 1 ppg heavier than the mud. The cement should reach the highest strength it can possibly be designed for, and it should reach it in the shortest time possible; and these two strength requirements can only be met by using the densified cement systems. We normally use 17 to 17.5 ppg densified slurries, except for special cases.

Strength is the most important design factor for plug systems. A requirement of a cement plug is that it be harder to drill than the formation. Drilling resistance is directly proportional to the strength, density, and hardness of the set cement, and is inversely proportional to the porosity and permeability of the set cement. Strength is the only one of these properties that we routinely measure in the lab on all our slurries, and is the property we know best, and can correlate easiest.

Both experience and lab data indicate we can design plug slurries for 7000 psi compressive strength in many cases at the higher temperatures and about 5000 psi at low temperatures. But in order to get these strengths in 24 hours or less, we must use densified cements with densities above 17.0 ppg. At BHST of 200-250°F, 17.0 ppg can be used, but 17.5 is better and should be used. At BHST of 150-200°F, 17.5 ppg can be used, but 18.0 ppg is better. Below 150°F, 2% accelerator is added to either 17.5 or 18.0 ppg slurries.

Sand is a very controversial item, and there is a basic problem as to the meaning of the word. Because of this, we must say *exactly* what we mean. Frac sand should not be used at all, because the grains do not adequately bond to the cement. The result is that the set cement crumbles and does not drill hard. If any sand is used at all, it should be *angular,* not *rounded.*

Fine mesh silica is used to prevent strength retrogression and should not be called sand. These finer grain materials should be called silica. Sand is larger mesh and is used as a filler only.

Considering that a cement plug is temporary and not intended to last more than a matter of days, densified cement has adequate strength to function as a successful plug without silica until temperature exceeds 300°F BHST.

If the cement system is densified properly, sand will not increase its strength any higher than it already is.

The principal effect of the sand is to dilute the cement, usually making it weaker. So it is actually best not to use any sand at all. When it is used, 15-30% sand with a size between 40 and 200 mesh is best for West Texas cements. Large amounts of sand can actually lower the compressive strength of the set cement, but it does not hurt densified cements as much as conventional density cements.

WOC times will vary from 12 to 24 hours depending on well temperature. If the plug is not hard enough by 24 hours, either (1) the well is cooler than was thought, (2) the slurry is contaminated with mud, or (3) the thickening time is too long (over-retarded cement). Inadequate WOC is a common cause of plug failure.

Pumping times should be designed for the actual job time plus about one-half hour, and no more! Excessive and unneeded time will result in a slower-setting cement and less chance to get a good plug. Every hour of lab thickening time will cost about four hours of WOC time (maybe more). Don't over-retard the cement! When retarder *is* required, use one of the standard low temperature ones.

Accurate well temperatures are needed to properly design these slurries. Consult logs to determine the effect of mud circulation and shutdown periods. Try to determine the actual temperature of the well at the time of cementing.

SLURRY VOLUME

A common mistake is using too small a volume of cement. Always assume some of the cement will be mud-contaminated. Also, the hole is probably enlarged a little bit (or a whole lot) whether you think it is or not; consider the effects of mud circulation, fishing attempts, trips, previous attempts to whipstock, etc. Calculate a plug length of at least 300 ft using a realistic hole size. Extra cement isn't nearly as expensive as redoing the job.

MIXING AND PLACEMENT

Batch mixing will provide more uniform slurries and should be used for all plug jobs in deep wells. If forced to use continuous mix, do it at a pump rate which allows the best control of slurry weight. Remember, slurry density is very important and should be closely controlled. Density determines strength!

The placement technique must include all known methods to reduce mud contamination and allow the cement slurry to displace all mud out of the hole. These items are most important:

1. Slightly underbalance the plug during placement, but don't overdo it; 1/2 to 1 bbl is best. Calculate displacement accurately before the job, and measure it accurately during the job.
2. Slow the displacement rate to an annular velocity of 90 ft/min (or less) just before the mud spacer leaves the bottom of the drill pipe, and continue this rate until the plug is in place. Cement (and viscous mud spacers) should always move up the annulus at this plug flow rate. But chemical washes should be pumped at a fast rate. (However, don't forget to reduce rate when cement gets to bottom of drill pipe). It may be necessary to use a back-pressure valve on the annulus to regulate this flow rate if the slurry is a lot heavier than the mud. It will be necessary to accurately know the hole size, too, in order to calculate the pump rate necessary to give the desired velocity. (This is another reason for running a caliper).
3. Rotate the drill pipe while the mud spacer (or chemical wash) and the cement slurry are traveling up the annulus. This helps

remove more mud from the annulus. Do not reciprocate! It only leads to more mud and cement mixing in the annulus. Stop this pipe movement when plug is spotted.

4. Do not rotate pipe while pulling out of plug; use chain method to break connections on the floor until pipe is out of the cement. Do not disturb the cement in any way after it is in place.

SUMMARY OF RECOMMENDED PRACTICES

1. Prior to cementing:
   a. Determine well temperature accurately.
   b. Caliper the interval.
   c. Set the plug in a sand or lime that had good drilling time. Avoid hard formations and enlarged holes.
   d. Use densified cement (preferably without sand).
   e. Obtain samples of mud and mix water from location for compatibility lab tests.
   f. At the very least, bottoms-up circulation is necessary to get good mud on bottom and condition the hole.
2. Cement design:
   a. Use a spacer fluid ahead of and behind cement. Volume should be enough for a 200-ft. column. Use a chemical wash for low-density water-base muds. Use oil-base mud spacer for emulsion and oil-base muds. This type of spacer fluid should be 1/2-1 ppg heavier than the mud and pumped at plug flow conditions (less than 90 ft/min in the annulus.
   b. Class H (or coarse-grind A) cement is used.
   c. Use enough slurry volume to fill at least 300 feet of both drill pipe and annulus.
   d. Mix it at correct density.
   e. All plugs should be batch-mixed.
3. Placement technique:
   a. Pump it up the annulus at 90 ft/min or less.
   b. Do not overdisplace.
   c. Rotate drill pipe during placement.
   d. Stop rotating pipe when plug is in place, and don't allow pipe to turn while pulling pipe up out of plug.
   e. Use tailpipe below the drill pipe.

BIBLIOGRAPHY

1. Morris; Wahl; and Horton: Improved Cement Slurries by Reduction of Water Content, API Paper, Mar. 1964.
2. Mid-Continent District Study Committee: The Effects of Drilling Mud Additives on Oil Well Cements, API bull. D-4, Mar. 1963.
3. Waggoner: Additives Yield Heavy High-Strength Cements With Low Water Ratios, *Oil & Gas Jour.*, Apr. 13, 1964, pp. 109-111.
4. Various Dowell laboratory reports including data from the New Orleans, Tulsa, and Midland laboratories, plus intracompany correspondence.

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TABLE 1—LABORATORY DRILLING RATE USING DIAMOND CORE DRILL

Cement System	Slurry Density, Lbs/Gallon	Set Cement Density (Bulk)	% Porosity	Compressive Strength, PSI	Drilling RATE Mins/Ft
Class H Neat	16.25	1.77	28	7170	7.5
Class H Neat	17.55	2.01	19	7600	11.5
H + 17% Sand	17.55	1.91	25	7500	5 5
H + 17% Silica Flour	17.55	1.96	24	7740	5.7
H + 8% Sand + 8% Flour	17.55	1.80	29	8400	7.2
H + 0.5% TIC	18.35	2.27	10	11350	14.0
H + 2% TIC	18.95	2.30	8	12800	15.7

TABLE 2—WEIGHTING AGENT REQUIREMENTS TO OBTAIN VARIOUS SLURRY WEIGHTS WITH CLASS H CONVENTIONAL AND REDUCED-WATER CEMENTS

Slurry Weight Lbs/Gal.	Lbs Ilmenite/Sack with Dispersant	Lbs Ilmenite/Sack Without Dispersant
16.2	None	None
17.0	None	12.0
17.5	None	18.0
18.0	6.6	28.0
18.5	13.4	34.0
19.0	20.6	46.0
19.5	28.2	53.0
20.0	36.2	62.8
20.5	44.6	73.0
21.0	53.5	83.8

TABLE 3—LOW TEMPERATURE COMPRESSIVE STRENGTHS OF CLASS A CONVENTIONAL AND REDUCED-WATER CEMENTS*

Slurry Weight (Lbs/Gal)	% $CaCl_2$	40°F (Hrs) psi 4	8	16	24	60°F (Hrs) psi 4	8	16	24	80°F (Hrs) psi 4	8	16	24
15.6	2.0	9	40	289	746	154	1181	2388	2720	625	1706	2981	4013
17.0	2.0	45	81	558	1538	360	1662	4098	5162	1200	2825	4730	7475

* Contains 2% dispersant by weight of dry cement.

TABLE 4—COMPRESSIVE STRENGTHS OF CLASS A CONVENTIONAL AND REDUCED-WATER CEMENTS* AT VARIOUS TEMPERATURES

	95°F psi		140°F psi		170°F psi	
Hours	15.6 lb/gal	17 lb/gal	15.6 lb/gal	17 lb/gal	15.6 lb/gal	17 lb/gal
2	not set	not set	not set	not set	not set	not set
3	not set	not set	517	190	1306	575
4	not set	not set	957	1525	1968	1031
5	158	not set	1563	2981	2331	2743
6	265	427	1900	3991	2700	2912
7	396	687	2154	4518	3412	4000
16	1600	3812	--	--	--	--
24	2662	5100	4225	8100	4500	6187

* Contains 2% dispersant by weight of dry cement.

TABLE 5—COMPRESSIVE STRENGTHS OF CLASS A CONVENTIONAL AND REDUCED-WATER CEMENTS WITH DRILLING MUD CONTAMINATION

Class A
Compressive Strength (psi)

%	18 Hour				24 Hour			
	15.6 lb/gal.		17 lb/gal.		15.6 lb/gal.		17 lb/gal.	
Mud	140°F	170°F	140°F	170°F	140°F	170°F	140°F	170°F
0	4000	4250	6980	5995	4225	4500	8100	6187
10	3675	3643	6475	5612	3556	4072	5450	5125
40	1250	1587	2362	4437	1677	1706	3843	4775
60	1090	1337	2343	3050	1247	1415	2856	3255

Composition of Drilling Mud

	Lb/Bbl
Ferro-Chrome Lignosulfonate	12.0
Caustic	3.5
SAPP	4.0
Clay and Bentonite	121.0
Weight	10 lb/gal
pH	9.5

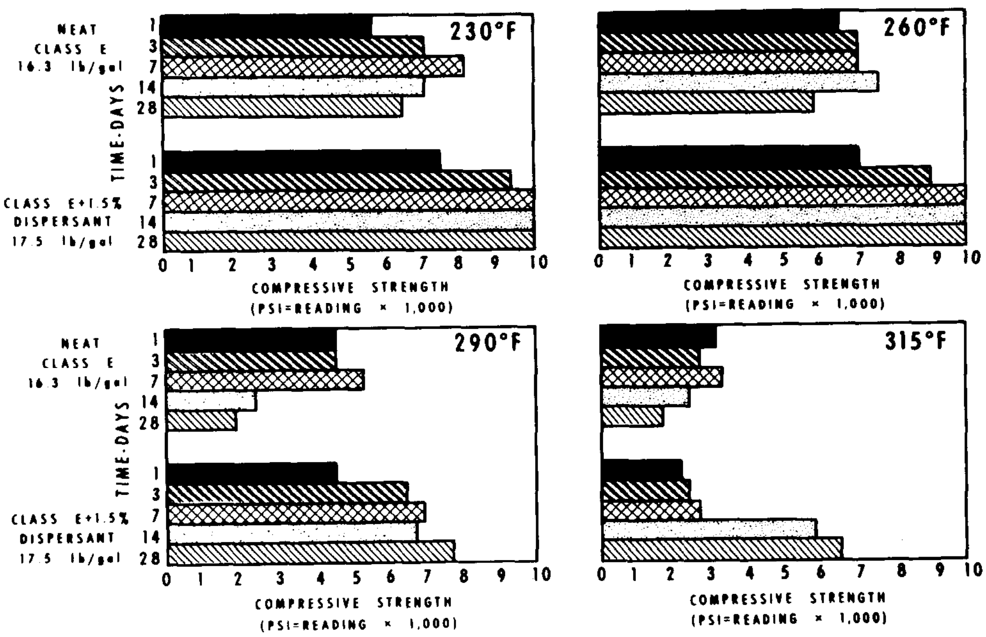

FIG. 1—STRENGTH RETROGRESSION OF CLASS E CONVENTIONAL AND REDUCED WATER CEMENTS AT EXTENDED CURING TIMES