FLUID CALIPER — A USEFUL TOOL TO IMPROVE PRIMARY CEMENTING

A. R. Stringer and N. D. Barrett
Dowell Schlumberger

ABSTRACT

Primary cementing is simple, i.e., displace drilling mud with cement to form a hydraulic seal between the pipe and the borehole. All too often, efficient drilling mud removal is not achieved, the cement cannot form a hydraulic seal and the result is communication between zones.

This paper provides a discussion on the use of a fluid caliper to improve the success rate of primary cementing. The fluid caliper is an extension of mud conditioning and, used in conjunction with centralizers and other proper cementing procedures, provides for a surer primary cement job.

Procedures and case histories are included.

DISCUSSION

As stated above, primary cementing is conceptually simple, i.e., displace drilling mud with cement to form a hydraulic seal between the pipe and the borehole. Unfortunately, and all too often, efficient drilling mud removal is not achieved, the cement cannot form a hydraulic seal and the result is communication between zones, sometimes with extreme consequences.

Even the most technically correct and carefully designed cement slurry will not form a hydraulic seal if less than appropriate mud removal measures are employed.

Many different mud removal techniques are available to the operator and the use of and success of these techniques are primarily dependent on the operator. Popular mud removal techniques that enhance mud removal include (1) centralizing the pipe; (2) moving the pipe (either to reciprocate and/or rotate); (3) placing spacer and/or wash ahead of the cement; (4) considering appropriate flow regimes of drilling mud, chemical wash, spacer and cement slurry; (5) fitting a shoe joint with the float collar one or two joints off bottom; (6) using one or two bottom plugs and a top plug; and (7) mud conditioning and circulating at least "bottoms up." Unfortunately, these processes may be costly and the tendency is to hurry through and minimize these processes.

Smith[1] stated that pipe movement is one of the best ways to assure mud removal. Bradford[2] stated that centralization is critical to mud removal. Both pipe movement and centralization are essential; however, in deviated holes, pipe movement may not be possible. Hence, centralization and other mud removal procedures must be used. Numerous papers, textbooks and patents have been published concerning mud removal. Several of the more significant publications are referenced in this paper.[3-7]

A discussion is given on the use of a fluid caliper to improve primary cement job success. As described here, the fluid caliper is an extension of mud conditioning and mud circulation. When used in combination with the appropriate mud removal procedures already listed, successful primary cementing comes closer to being a given and less of a gamble.

A fluid caliper measures the percent of drilling mud being circulated by comparing it with the total hole volume. If volumes are quite large, the fluid caliper can be based on time rather than volume. Both procedures are discussed here. Figure 1 is a pressure, rate, volume and time plot illustrating a fluid caliper procedure.

In all situations, the circulating pressure must be monitored for any abnormalities, and decisions made accordingly.

PROCEDURE I — USING THE "TOTAL HOLE VOLUME" FLUID CALIPER

These are the necessary steps to follow in a fluid caliper process.

1. The operator should caliper the hole prior to running the casing. A four-arm caliper is recommended. It is a better tool for measuring the hole volume than a two- or three-arm caliper.

2. Using the mechanical caliper information, calculate the total mud in the hole after the casing has been run. Break out the annular openhole volume and the constant hole volume (see Figure 2).

   - The annular openhole volume is that volume between the casing to be cemented and the openhole (noncased hole) volume.

   - The constant hole volume is the volume in the casing/casing annulus plus the internal volume of the casing string to be cemented.

   For purposes of the fluid caliper technique, the cased hole volume plus the internal volume of the casing string to be cemented is considered 100% circulatable.

3. Select an appropriate tag or marker. A popular tag in water-base mud is carbide, which decomposes into acetylene (C_2H_2) and is detected by a gas sniffer when it is circulated to the surface. Carbide is easily added downstream from the mud pump through a lateral valve arrangement.

   Other tags that may be used include cottonseed hulls, oats, whole corn, dye, oil or paint. Dye, oil or paint may affect the toxicity of the mud; hence, only environmentally safe materials should be used or the operator should be prepared to properly dispose of the tagged mud. The tagging material must not adversely affect downhole or surface equipment.

4. Calibrate the mud pumps before beginning the tagging operation. The efficiency of the pumps must be accurately known to determine the exact amount of fluid pumped. To calibrate, pump a known quantity of mud or pump into a calibrated tank and count the number of pump strokes necessary to move a given volume. An accurate flowmeter in the mudline works quite well, and also should be calibrated.

5. Tag the mud at even intervals for easier tracking. A good volume to use can be the annular openhole volume, or 100 to 150 bbl. If using hulls, oats or similar kinds of tags, the tag (or pill) can be 10 bbl mud with 50 lb tagging material.

6. Circulate the drilling mud, plus tag, at the maximum rate at which the cement is to be pumped or displaced. Changes in rates can affect the fluid caliper volume, thus the reason for the maximum rate. It is obvious that this rate should be such as to avoid lost circulation.

   The selected maximum rate should be held constant once fluid caliper procedures are started.

   As more and more gelled mud is loosened and circulated to the surface, the mud may become progressively more viscous. As the mud becomes more viscous, the amount of mud being circulated from the hole increases. If specific flow regimes for mud, spacer and cement have been preplanned, contingency plans should be made either to allow for the increased mud viscosity or mud thinner added to reduce the mud viscosity to what it was when the cement job was designed. In any case, the properties of the mud out should be the same properties as the mud in before cementing.

7. Require proper centralization, particularly in deviated holes.

8. Recommend pipe movement during fluid caliper procedures.

9. Do not cement if cuttings are still being circulated from the hole. Continue to circulate until the mud is clean.

10. Do not cement until the percent circulatable mud in the annular open hole approaches 90% or does not increase for several tags.

Figures 2 through 8 pictorially represent a fluid caliper procedure.

Procedure I — Example 1: Using the Mechanical Caliper

This example is a detailed description of a fluid caliper where the total hole volume is known via a mechanical caliper.

Previous Casing	:	20-in., 94-lb/ft set at 1653 ft
Bit Size	:	17.5-in.
Calipered Openhole Size	:	18.0-in.
Casing to be Cemented	:	13-3/8-in., 68-lb/ft at 5010 ft
Constant Hole Volume	:	(5010 ft)(0.1497 bbl/ft) + (1653 ft)(0.1815 bbl/ft) = 1050 bbl
Annular Openhole Volume	:	(5010 ft - 1653 ft)(0.1410 bbl/ft) = 473 bbl
Total Mud in the Hole	:	1050 bbl + 473 bbl = 1523 bbl

Equation 1 — used to calculate the percent mud being circulated.

$$\%\ \text{Mud being Circulated} = \left(\frac{S - T}{THV}\right)(100)\ ,$$

where

S = barrel count when tag returns to the surface,
T = barrel count when tag was injected, and
THV = total hole volume.

Also,

CHV = constant hole volume (casing volume + volume of casing/casing annulus), and
ADH = annular openhole volume.

(a) Begin circulating at a constant rate.
(b) Pump Tag 1 at 200-bbl count.
(c) Pump Tag 2 at 500-bbl count.
(d) Pump Tag 3 at 800-bbl count.
(e) Tag 1 to surface at 1000-bbl count. (e - b/1523)100 = 53% of mud is circulating.
(f) Pump Tag 4 at 1100-bbl count.
(g) Pump Tag 5 at 1400-bbl count.
(h) Tag 2 to surface at 1450-bbl count. (h - c/1523)100 = 62%.
(i) Pump Tag 6 at 1600-bbl count.
(j) Pump Tag 7 at 1800-bbl count.
(k) Tag 3 to surface at 1960-bbl count. (k - d/1523)100 = 76%.
(l) Pump Tag 8 at 2000-bbl count.
(m) Tag 4 to surface at 2250-bbl count. (m - f/1523)100 = 76%.
(n) Tag 5 to surface at 2650-bbl count. (n - g/1523)100 = 82%.
(o) Tag 6 to surface at 2900-bbl count. (o - i/1523)100 = 85%.
(p) Tag 7 to surface at 3150-bbl count. (p - j/1523)100 = 89%.
(q) Tag 8 to surface at 3470-bbl count. (q - l/1523)100 = 96%.

Cementing operations can commence at about 90% mud circulation, if the mud is free of cuttings and mud in has the same properties as mud out.

The best mud removal may commonly be expected after approximately two total hole volumes have been circulated. This was the experience of the authors, as shown in Table 1, and also the recommendation of Rike.[3]

Procedure I — Example 2: Using the Percent Excess Factor

In a given field or off a given platform when mechanical calipers have been run on offset wells and a percent excess factor has been established, the following procedure can be used to run a fluid caliper.

Previous Casing	:	20-in., 94-lb/ft set at 1653 ft
Bit Size	:	17.5-in.
Assumed Openhole Size	:	19-in. average (25% excess)
Casing to be Cemented	:	13-3/8-in., 68-lb/ft at 5010 ft
Constant Hole Volume	:	(5010 ft)(0.1497 bbl/ft) + (1653 ft)(0.1815 bbl/ft) = 1050 bbl
Assumed Annular Openhole Volume	:	(5010 ft - 1653 ft)(0.1769 bbl/ft) = 594 bbl
Assumed Total Mud in the Hole	:	1050 bbl + 594 bbl = 1644 bbl

(a) Pump and tag as before, circulating at a constant rate.
(b) Pump Tag 1 at 200-bbl count.
(c) Pump Tag 2 at 500-bbl count.
(d) Pump Tag 3 at 800-bbl count.
(e) Pump Tag 4 at 1100-bbl count.
(f) Tag 1 circulates to surface at 1200-bbl count. (f - b/1644)100 = 61%.
(g) Pump Tag 5 at 1400-bbl count.
(h) Tag 2 circulates to surface at 1600-bbl count. (h - c/1644)100 = 67%.
(i) Pump Tag 6 at 1700-bbl count.
(j) Tag 3 circulates to surface at 1950-bbl count. (j - d/1644)100 = 70%.
(k) Tag 4 circulates to surface at 2300-bbl count. (k - e/1644)100 = 73%.
(l) Tag 5 circulates to surface at 2600-bbl count. (l - g/1644)100 = 73%.
(m) Tag 6 circulates to surface at 2900-bbl count. (m - i/1644)100 = 73%.

In the absence of a mechanical caliper, a 19-in. hole (25% excess) was assumed. After obtaining the fluid caliper values, two more assumptions can be made — (1) the open hole may be smaller than assumed, and (2) at this pump rate, all circulatable mud is being circulated (or both). Cementing operations can commence after assuring that the mud is carrying no cuttings, and mud in equals mud out. Cement volumes need to be adjusted if they were based on the excess factor.

PROCEDURE II — USING THE "CIRCULATABLE MUD" AS A METHOD TO MEASURE HOLE VOLUMES

If large volumes are involved, a fluid caliper based on mud volume pumped may be more desirable.[8] A mechanical caliper may or may not be run. If it is run, use it to calculate the total mud volume in the hole.

Procedure II — Example 1

If the mechanical caliper is not run, then a fluid caliper can be used to determine the effective hole volume, i.e., the amount of circulatable mud being circulated at a given maximum pump rate. Holding the mud circulation rate constant, tag the mud at consistent time intervals.

Constant Maximum Mud Circulation Rate	:	10 bpm
Constant Tag Time	:	every 10 min

		Time Difference on Mud Returns
(a)	Tag 1 circulates after 80 min	—
(b)	Tag 2 circulates after 120 min	40 min
(c)	Tag 3 circulates after 155 min	35 min
(d)	Tag 4 circulates after 185 min	30 min
(e)	Tag 5 circulates after 210 min	25 min
(f)	Tag 6 circulates after 230 min	20 min
(g)	Tag 7 circulates after 235 min	15 min
(h)	Tag 8 circulates after 245 min	10 min
(i)	Tag 9 circulates after 257 min	12 min
(j)	Tag 10 circulates after 277 min	10 min
(k)	Tag 11 circulates after 288 min	11 min
(l)	Tag 12 circulates after 298 min	10 min

As shown, the initial differences in tag circulation time are indicative of more and more mud circulation, thus more and more mud removal. The time lapses between Tags 8 through 12 are relatively constant, indicating that additional circulation may not result in additional mud removal, all other things being equal. If the mud and the hole are in good condition, cementing operations can commence.

CASE HISTORIES (Table 1)

In all cases, cement was planned to be returned to the surface. Note the importance of fluid calipers <u>and</u> centralizers in Wells 21 through 24. Centralizers alone (Cases 19 and 20) were <u>not</u> sufficient to achieve good mud removal.

Well Parameters	:	20-in. conductor was set near 2000 ft 13-3/8-in. surface was set near 3300 ft

SUMMARY

Attention to the basic concepts of mud removal prior to and during primary cementing operations may add additional cost to the cement job. However, these concepts can prevent costly repair jobs, not to mention the cost of lost production and potential environmental damage.

The fluid caliper technique is one of several mud removal procedures that falls into the category of good primary cementing practices.

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Table 1
Case Histories

WELL NO.	BIT SIZE (in.)	PIPE SIZE (in.)	ANNULAR GAS PRESSURE	MUD CONDITION	NO. OF CENTRALIZERS	VOLUME OF CEMENT CIRCULATED TO SURFACE	TOTAL VOLUME OF CEMENT PUMPED (bbl)
1	17-1/2	13-3/8	No	Bottoms Up	6	Top Out	531
2	17-1/2	13-3/8	No	Bottoms Up	6	Top Out	540
3	17-1/2	13-3/8	Yes	Bottoms Up	6	50 bbl	666
4	17-1/2	13-3/8	No	Bottoms Up	6	50 bbl	665
5	17-1/2	13-3/8	Yes	Bottoms Up	0	---	---
6	17-1/2	13-3/8	Yes	Bottoms Up	6	Yes	665
7	17-1/2	13-3/8	Yes	Bottoms Up	0	Top Out	655
8	22	16	Yes	Bottoms Up	6	10 bbl	789
9	22	16	Yes	Bottoms Up	0	10 bbl	644
10	22	16	Yes	Bottoms Up	6	300 bbl	781
11	17-1/2	13-3/8	Yes	Bottoms Up	0	Top Out	629
12	17-1/2	13-3/8	Yes	Bottoms Up	3	Yes	789
13	17-1/2	13-3/8	Yes	Bottoms Up	0	180 bbl	621
14	17-1/2	13-3/8	Yes	Bottoms Up	6	320 bbl	618
15	17-1/2	13-3/8	Yes	Bottoms Up	0	182 bbl	677
16	17-1/2	13-3/8	Yes	Bottoms Up	10	371 bbl	819
17	17-1/2	13-3/8	Yes	Bottoms Up	0	165 bbl	629
18	17-1/2	13-3/8	Yes	Bottoms Up	9	380 bbl	707
19	17-1/2	13-3/8	Yes	Hole Volume	23	182 bbl	677
20	17-1/2	13-3/8	Yes	Bottoms Up	23	10 bbl	557
21	14-1/2	10-3/4	No	2 Hole Volume+	18	15 bbl	---
22	17-1/2	13-3/8	No	2.5 Hole Volume+	43	5 bbl	604
23	17-1/2	13-3/8	No	2 Hole Volume+	23	10 bbl	618
24	17-1/2	13-3/8	No	2 Hole Volume+	23	10 bbl	629

+Fluid caliper processes were used.

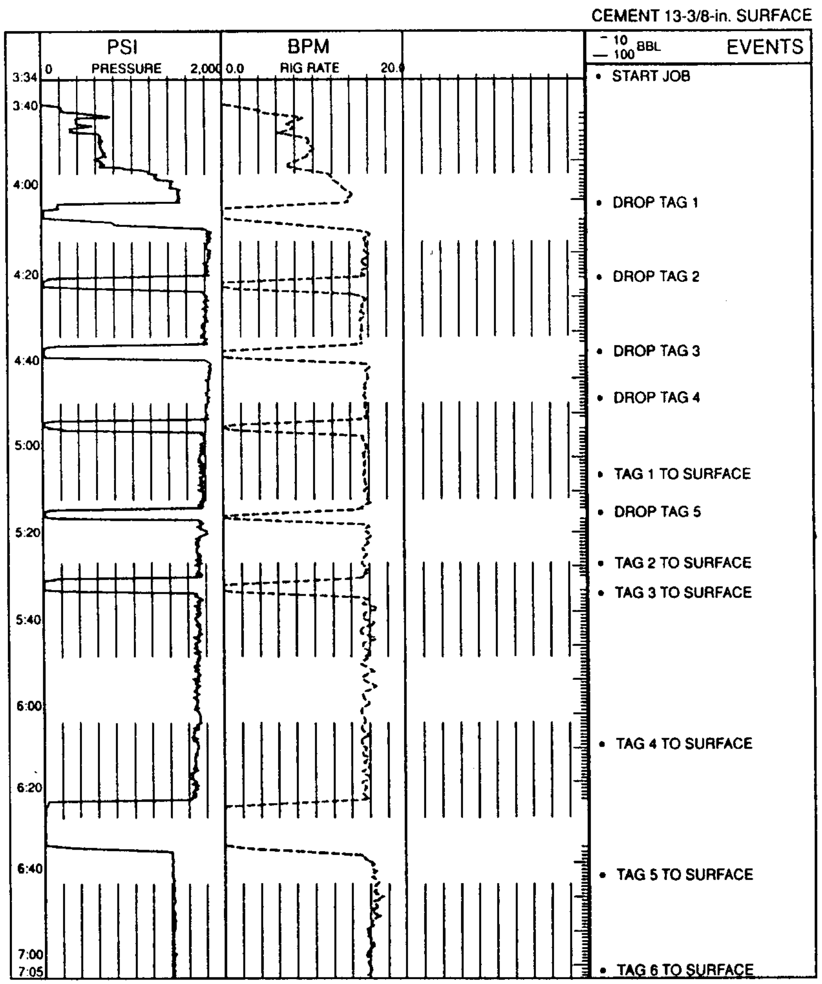

Figure 1 - Typical pressure rate plot of fluid caliper process

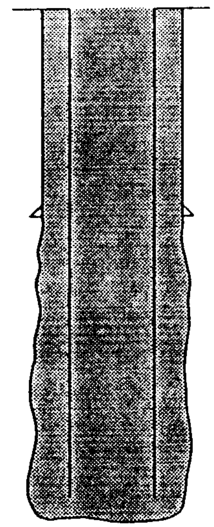

Figure 2

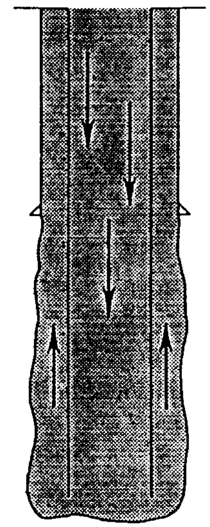

Figure 3

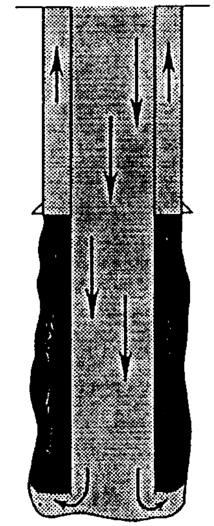

Figure 4

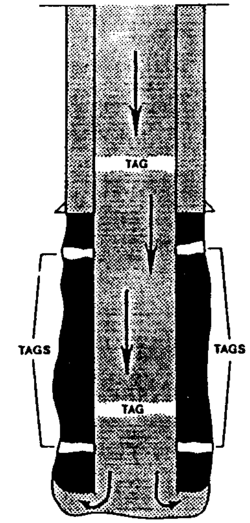

Figure 5

Figure 2 - Standing mud in pipe/annulus prior to circulation.

Figure 3 - Ideally, all mud should circulate freely when pumping starts.

Figure 4 - In reality, when circulation begins, only a portion of the mud moves and may be moving as fluid channels through gelled mud.

Figure 5 - One way to measure the amount of mud being circulated is by a fluid caliper using tags or markers in the mud, and calculating the volume between tag injection and return.

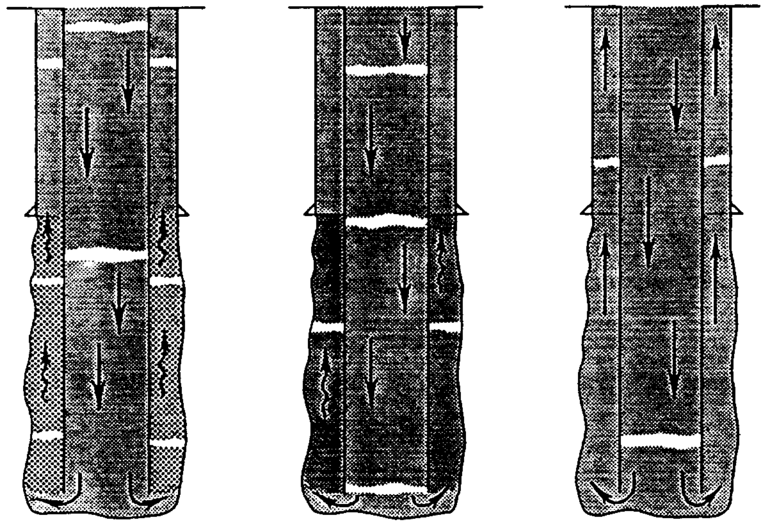

Figure 6 Figure 7 Figure 8

Figure 6 - As circulation continues, the drag of the circulating mud pulls more and more gelled mud with it.

Figure 7 - The increasing volume of circulating mud indicates that gelled mud is breaking up.

Figure 8 - When circulating volumes approach 90%, cementing can commence.