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A STATISTICAL COMPARISON OF CEMENTING TECHNIQUES BY USE OF CEMENT BOND LOGS

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ABSTRACT

The determination of optimum cementing technique is possibly the most valuable use for Cement Bond Logging. This can be accomplished through the use of a large number of bond logs made on wells where various cementing procedures were employed.

Cement Bond Logs representing almost one-half million feet of cemented casing are herein used to compare the efficiencies of various cementing techniques. The study includes 352 bond logs from seven states. Results show that, in the average well, 71 percent of the cemented interval shows good bonding. Little variation is found to occur between average percentage of bonding and geographic area, setting time, well temperature below 300°F and depth. Rather wide variations are shown between percentage of bonding and the various oil companies, cement types, cement additives, mud types and casing size.

The data presented appear to justify increased use of bond logs for selection of optimum cement type, cement additives, casing size, slurry weight and in consideration of other cementing variables.

References and Illustrations at end of paper.

Only primary, single stage, cement jobs are studied so as to avoid using data influenced by squeeze cementing and fill-up problems. All logs studied employ the same type of equipment and calibration techniques.

"Good bonding" and "cemented interval" are defined. Each log studied is assigned a numerical value of percentage of good bonding within the cemented interval.

CBL (Cement Bond Logging) calibration methods and tool response are discussed to show that the quality of cement bonding in one well may be logically compared to that of other wells.

An average percentage of bonding from all wells studied is calculated and tabulations are made for each of the following variables:

- Geographic Location
- Cement Type
- Cement Volume
- Cement Additives
- Depth Range
- Slurry Weight
- Setting Time
- Casing Size
- Oil Company
- Maximum Temperature Measured

The justification for comparing percentage of bonding with cementing efficiency is discussed.

Complete data on the percentage of bonding measured for each reported variation in cementing technique is presented for study by the reader.

INTRODUCTION

A Cement Bond Log commonly describes the quality of a single cement job.[1] At present most cement bond logs are used to evaluate vertical isolation between zones in a given well. CBL provides a valuable method for estimating the origin of produced fluids. It identifies intervals behind pipe where probable hydrocarbon loss to other levels occurs, and permits recognition of reservoir contamination by waters from "higher pressured" water zones. CBL logs are commonly used to determine the need for squeeze cementing.

In addition, optimum cementing procedures can be determined through the use of available cement bond logs. By measuring the percentage of cemented interval showing good bonding, a merit value may be assigned to each cement job. Large scale study of bond logs will then provide a basis for evaluating and comparing cementing techniques.

THEORY AND DEFINITIONS

Cement Bond Logging involves the continuous measuring with depth, of the ability of the casing to transmit sound.[1] Casing is an excellent transmitter of sound when its vibratory movement is not restricted by adhering matter such as cement, or by solid material gripping its circumference. Opposite unbonded casing high measured amplitudes are observed. Where cement is in intimate contact with the casing it attenuates the sound and results in low measured amplitudes. This is due to the differences in acoustical properties between the casing and cement and the areal extent and intimacy of their contact. By simple comparison of the observed signal at any depth with that opposite uncemented casing, an estimate of the quality, and/or surface area of bonding can be made.

"Good bonding" as used in this paper is defined as those sections where the recorded amplitude is 20 percent or less of that opposite unbonded ("free") casing.

"Cemented Interval" is defined as the interval from the lowest depth logged in casing up to the highest indication of cement.

Data on the accuracy of bond logging in detecting channeling is available in the literature and is not discussed.[1,2,3,4] However, it must be mentioned that the failure to pump away large amounts of cement through

considered an essential ingredient for isolation. A well may show good cement-to-casing bonding and have communication between zones while another well will show no bonding and have isolation between zones. However, generally speaking, an interval showing good bonding is well cemented.

The use of a "time curve", in addition to an amplitude curve, to measure the time of first energy arriving at the receiver is, in many instances, necessary for correct interpretation of bonding. It provides a means for determining whether the amplitude curve is affected by things other than cement-to-casing bonding, i.e.; adverse interference effects of high velocity formation arrivals, casing size shift errors, decentralization errors, equipment malfunctions, etc.[2]

The terms related to Quality of Bonding as used in this paper are limited to a description of the degree of intimacy between casing and cement.[3] The bond logs used are two curve logs and not universally comprehensive for the determination of the quality of cement-to-formation bonding. Only single stage primary cement jobs are included to avoid data influenced by an overabundance of problem wells. All logs studied employed the same type of equipment and calibration techniques. Where two different sizes of casing were present only the casing (size) interval in which the calibration was made was used. Figure 1 shows a bond log in multiple strings of casing where errors in interpretation might result. Logs of doubtful reliability, such as those run in wells making gas, were also excluded.

In hard rock areas where the first arrival commonly precedes the arrival through the casing, all intervals where this occurred were excluded. In such intervals scope pictures or other forms of full wave recording are necessary for an evaluation comparable in quality to that obtained in the rest of the survey.[4] Figure 2 shows an example of the difficulty in using conventional bond logs recorded opposite very high velocity formations.

By observing these "ground rules" it is believed that the average bonding efficiency using one cementing technique, as shown by a group of surveys, may logically be compared to the overall averages of bonding efficiency from all wells studied, provided that a large number of wells are used.

To justify use of Cement Bond Logging data as a yardstick in determining ultimate cementing procedures it must be agreed that a well exhibiting good bonding is better cemented than one exhibiting no bonding and vice versa.

RESULTS

The average percentage of bonding for each var-

Geographic location (Table 1)
Cement type (Table 2)
Cement volume (Table 3)
Cement additives (Table 4)
Depth range (Table 5)
Slurry weight (Table 6)
Setting time (Table 7)
Casing size (Table 8)
Oil Company (Table 9)
Temperature (Table 10)
Mud Type (Table 11)

No information is presented as to percent bonding versus cement displacement rate, the use of centralizers, condition of casing surface, pipe reciprocation and other important considerations. The reason for this is that present cement bond log headings do not include space for such information. Future CBL headings are being designed to include such information. Also, a study of bonding versus hole enlargement, lithology, and bonding within the bottom 100 feet of casing would be quite interesting. However, since complete information is available in oil company files, individual studies may be made concerning any desired variable.

INTERPRETATIONS

The following observations by the author are made as layman in the field of cementing.

As an industry average, 71 percent of cemented intervals show good bonding.

Noticeable variations in percent bonding were found to occur within the various classifications of each broad category. As an example, in 34 wells where one brand of Class "E" cement was used, an average of 78 percent bonding was observed, whereas 10 other wells using another brand of Class "E" cement averaged only 48 percent.

Geographic location appears to have little effect on percentage of bonding (Table 1). However, several oil companies were found to obtain a higher percentage of bonding in one area than another.

General use of salt saturated cements may be more efficient than general use of other cements (Table 2). Salt saturated cements may be better suited than others under the common conditions of usage. However, since salt acts as an accelerator, it is possible that at least part of the apparent increase in bonding shown for the salt saturated cements may be caused by more complete setting up of this type of cement at the time of survey.

Cement volume appears to have only a minor effect on the percentage of bonding (Table 3). As expected, the percentage of good bonding decreases somewhat with increasing cement volume. This appears reasonable since the first cement pumped would have to travel a greater distance when large volumes of cement are displaced.

Wells in which no additives were used exhibited additives were used. In wells where additives of the decontamanant type were used, the percentage of bonding is shown to be 37 percent higher than average (Table 4).

Depth to the top of cement appears to have no effect on average percentage of bonding obtained (Table 5). Consideration must here be made to the efforts of the various companies to adjust the cementing techniques to well depth.

Slurry weight versus percent bonding yielded no uniform trend (Table 6). However, lower values of percent bonding are observed on wells where slurry weights exceed 17 pounds per gallon.

There appears to be little relationship between percentage of bonding and common variations in setting time (Table 7). A number of wells employing slow-set cement are included in this study where logging occurred after only 12 hours showing almost complete bonding. However, Figure 3 shows a well that was logged after 17 hours showing general poor bonding and includes a rerun after 27 hours showing excellent bonding. Data from only the second run was included in this study. Setting time should be sufficient for complete setting up of the cement in order for the efficient appraisal of procedures. The data shows that the average bond log in California is run after 32 hours while the average bond log in Oklahoma is run after 65 hours. The arithmetic average for setting time for the top four companies is 61 hours, whereas, it is 73 hours for the bottom four companies. The average setting time for company "B" is 58 hours. Company "D" runs most of its logs before 30 hours after cementing.

Casing size versus percent bonding relationships appear to become less favorable where casing sizes greater than 8" is used (Table 8).

Many oil companies enjoy a considerably higher percentage of bonding than others (Table 9). It would appear that these companies would also enjoy lower completion costs.

Maximum temperature versus percentage bonding relationships appear to be less favorable where temperatures of over 300°F are reported (Table 10).

A notable relationship is shown between the recording of good bonding and wells where salt muds were used in drilling (Table 11).

CONCLUSIONS

Cement bond logs may be used as a guide in evaluating the quality of a single cement job. Possibly even more important, cement bond logs made on a large were employed may be used to relate cementing efficiency with cementing technique. Such action will improve overall cementing techniques and greatly reduce well completion costs.

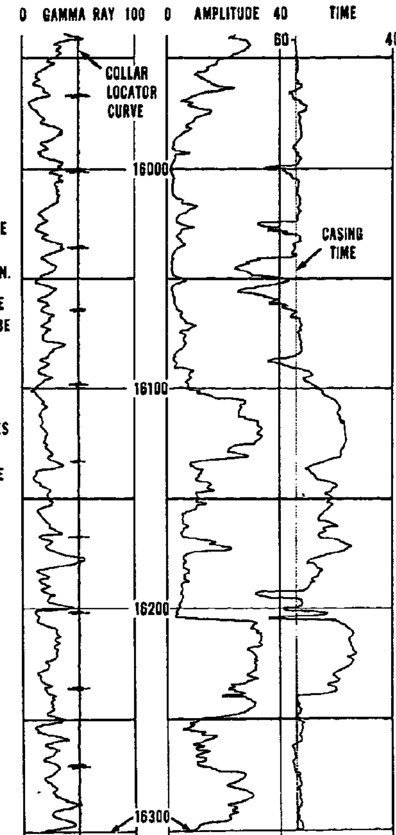
REFERENCES

1. Anderson, W. L., and Walker, T., "Research Predicts Improved Cement Bond Evaluations with Acoustic Logs", Journal of Petroleum Technology, November, 1961.

2. Pickett, G.R., "Acoustic Character Logs and Their Applications in Formation Evaluation", 37th Annual Fall Meeting of SPE, Los Angeles, California, Oct. 7-10, 1963.

3. Pardue, G. H., Morris, R. L., Gollwitzer, L. H., and Moran, J. H., "Cement Bond Log – A Study of Cement and Casing Variables", Journal of Petroleum Technology, May, 1963.

4. Muir, D. M., "Evaluation of Cementing Conditions by Use of the Photographic Recording of the Complete Acoustic Wave Train", The Log Analyst, Aug-Sept, 1964.



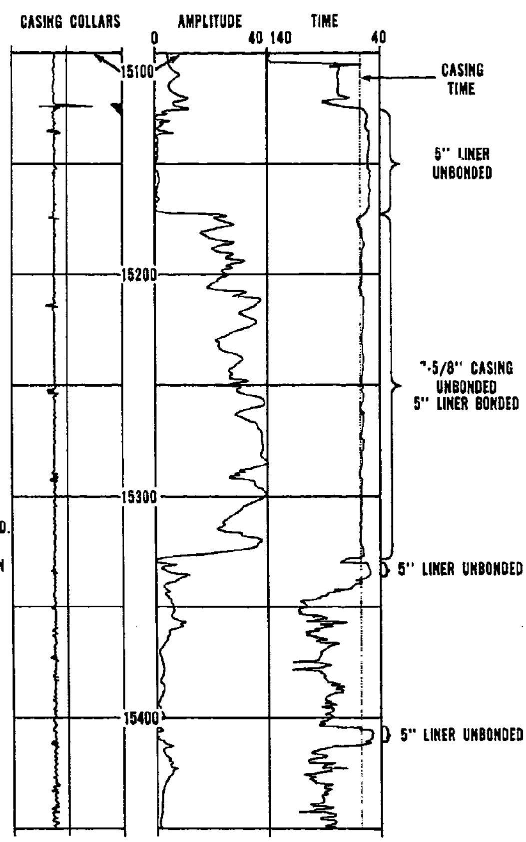
CBL LOG MADE OPPOSITE HIGH VELOCITY FORMATIONS.

OBSERVANCE OF FIRST ARRIVAL TIME PRECEDING CASING TIME INDICATES THAT AMPLITUDE CURVE IS INFLUENCED BY ENERGY ARRIVING THROUGH THE FORMATION.

MEASURED AMPLITUDE DURING THE CASING TIME GATE WOULD THEN BE A COMPOSITE OF "FORMATION" AND "CASING" ENERGIES.

OBSERVANCE OF ARRIVALS PRECEDING CASING TIME INDICATES AT LEAST FAIR ACOUSTICAL COUPLING (BONDING) BETWEEN THE CASING AND FORMATION.

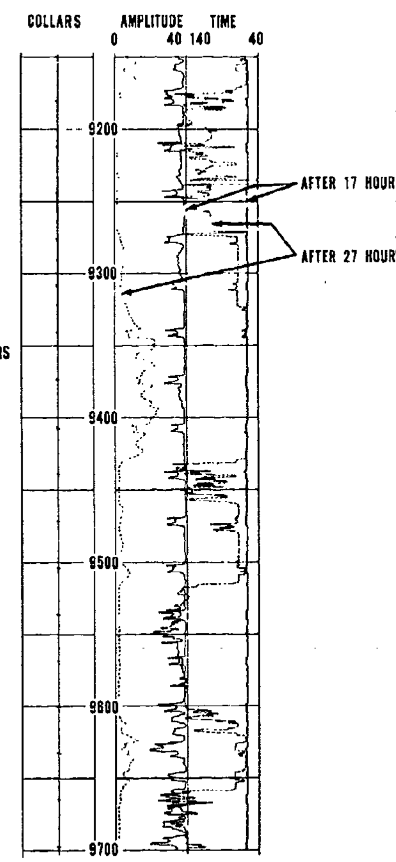
FIGURE 2



CBL LOG IN A WELL WITH TWO STRINGS OF CASING

7-5/8"CSG TO 15340
5" LINER 15125– TD

NOTE LOW AMPLITUDE BETWEEN 15125–15172 EVEN THOUGH THE LINER IS UNBONDED. THIS WAS CAUSED BY CALIBRATION OF LOG IN 7-5/8"CASING.



TWO RUNS MADE IN A WELL, 17 AND 27 HOURS AFTER CEMENTING.

LOGS SHOW ALMOST COMPLETE LACK OF BONDING AFTER 17 HOURS BUT CONSIDERABLE GOOD BONDING AFTER 27 HOURS.

PERCENT BONDING VERSUS STATE
(352 wells, 489,576 feet of hole)

State	Number of Wells	Average Cemented Interval	Average Bonded Interval	Average Percent Bonding
Arkansas	2	612	542	90
California	112	1468	965	70
Louisiana	94	1703	1172	72
Mississippi	5	862	784	67
New Mexico	6	604	390	62
Oklahoma	36	837	554	70
Texas	98	1272	867	70
Total	352	Ave 1388	Ave 1082	Ave 71

Table 1

CEMENT TYPE VERSUS PERCENT BONDING
(217 wells, 212,697 feet of hole)

Cement Type	Number of Wells	Average Cemented Interval	Average Bonded Interval	Average Percent Bonding
Fly Ash Common (Class "A")	1	896	849	95
Pozzolan, Salt Saturated	4	1049	991	93
Class "D"	7	2087	1899	92
50-50 Pozzolan, Salt Saturated	1	1135	1035	91
Lite Wate, Salt Saturated	3	2094	1735	83
50-50 Pozzolan	29	1165	950	83
Common (Class "A"), Salt Saturated	2	2260	1882	74
Pozzolan	23	1220	825	72
Lite Wate	7	1873	1379	72
Class "G", 1.1 Perlite	5	1412	990	71
Class "G"	67	1460	1020	71
Slow-Set (Class "E")	44	1644	1166	70
Common (Class "A")	17	1152	748	65
Class "C"	3	610	216	62
Class "G", 1 1 Pozzolan	3	1941	728	53
Total	217	Ave 1441	Ave 1040	Ave 73

Table 2

NUMBER OF SACKS VERSUS PERCENT BONDING

Number of Sacks	Number of Wells	Average Cemented Interval	Average Bonded Interval	Average Percent Bonding
0 – 399	133	1071	805	74
400 – 799	65	1690	1209	71
800 and over	33	2279	1504	67
Total	231	Ave 1432	Ave 1018	Ave 72

ADDITIVES VS PERCENT BONDING
(three or more wells)

Additives	Number of Wells	Average Cemented Interval	Average Bonded Interval
Decontamonant	3	999	931
None	19	1025	703
Silica Flour	43	1430	1006
0 – 4% Bentonite	52	1743	1262
Accelerators	60	1431	966
Retarders	12	1122	1072
Lost Circulation Materials	27	1501	1011
Over 4% Bentonite	10	1221	906
Turbulent Flow Additives	30	1629	1196
Diatomaceous Earth	5	1142	694
Total	266	Ave 1462	Ave 1087

Table 4

DEPTH VERSUS PERCENT BONDING

Depth to Top of Cement Bonding	Number of Wells	Average Cemented Interval	Average Bonded Interval
0 – 4999	192	1354	908
5000 – 9999	128	1367	1008
10,000 – 14,999	34	1495	991
Total	354	Ave 1372	Ave 952

Table 5

SLURRY WEIGHT VERSUS PERCENT BONDING

Slurry Weight	Number of Wells	Average Cemented Interval	Average Bonded Interval
Less than 13.0	10	1662	1186
13.0 – 13.9	13	1609	1089
14.0 – 14.9	27	1942	1665
15.0 – 15.9	26	1146	692
16.0 – 16.9	20	1559	998
17 and over	6	1187	662
Total	102	Ave 1550	Ave 1107

SETTING TIME VERSUS MERIT VALUE

Setting Time	Number of Wells	Average Cemented Interval	Average Bonded Interval	Average Percent Bonding
0 – 23 hrs.	32	1364	1055	74
24 – 47 hrs.	68	1226	909	72
48 – 71 hrs.	31	1643	1357	69
72 – 99 hrs.	29	1177	682	63
100 – 160 hrs.	16	1672	1238	76
Over 160 hrs.	54	1671	1129	71
Total	230	Ave 1431	Ave 1,006	Ave 71

Table 7

CASING SIZE VERSUS PERCENT BONDING
(from a study of 466,094 feet of hole)

Casing Size	Number of Wells	Average Cemented Interval	Average Bonded Interval	Average Percent Bonding
4 1/2	62	942	611	70
5 – 5 1/2	116	1198	841	72
6 5/8 – 7	114	1599	1183	74
7 5/8 – 7 7/8	8	2051	1647	71
8 5/8	31	1631	1031	64
9 – 9 5/8	5	2333	1391	62
10 3/4	1	1058	587	55
11 3/4	2	764	153	19
13 3/8	1	5131	2610	51
Total	340	Ave 1371	Ave 959	Ave 70

Table 8

PERCENT BONDING VERSUS COMPANY
(seven or more wells)

Oil Company	Number of Wells	Average Cemented Interval	Average Bonded Interval	Average Percent Bonding
A	11	854	696	86
B	8	1554	1148	82
C	14	1354	1162	82
D	7	558	470	82
E	7	1734	1300	80
F	7	1419	1252	80
G	28	1728	1484	80
H	8	2312	1756	76
I	61	1294	952	74
J	22	1334	834	66
K	14	2500	1564	65
L	8	874	582	64
M	8	992	496	56
N	7	1214	624	54
O	9	1078	542	54
P	11	1806	614	35
Total	230	Ave 1440	Ave 1008	Ave 71

Table 9

PERCENT BONDING VERSUS TEMPERATURE

Temperature	Number of Wells	Average Cemented Interval	Average Bonded Interval	[illegible]
Under 100	10	783	604	[illegible]
100 – 149	110	1106	793	[illegible]
150 – 199	70	1654	1248	[illegible]
200 – 249	27	1516	1104	[illegible]
250 – 299	14	2119	1614	[illegible]
300 & over	2	3555	1535	[illegible]
Total	233	Ave 1386	Ave 1013	Ave [illegible]

Table 10

MUD TYPE VERSUS PERCENT BONDING

Mud Type	Number of Wells	Average Cemented Interval	Average Bonded Interval	[illegible]
Salt Mud	7	1307	1207	[illegible]
Natural	5	1453	1261	[illegible]
Lignosulphonate Mud	21	2061	1663	[illegible]
Caustic Mud	7	1907	1645	[illegible]
Water or Fresh Water	10	1072	792	[illegible]
Inverted Emulsion	4	1381	1134	[illegible]
Oil Emulsion	10	2392	1878	[illegible]
Crude Oil or Oil	21	875	675	[illegible]
Clay Base	40	1301	888	[illegible]
Salt Water	56	1384	873	[illegible]
Oil Mud	13	2107	1363	[illegible]
CaCl	3	2838	1474	[illegible]
Mud	10	1768	948	[illegible]
Complex Phosphate	2	2391	1176	[illegible]
Water Base	7	1675	695	[illegible]
Chemical	1	1027	233	[illegible]
Total	297	Ave 1409	Ave 988	Ave [illegible]

Table 11