Chapter IX. Cementing Wells

Cementing Problem on the Gulf Coast

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(New York Meeting, February, 1930)

At the Sugarland and Raccoon Bend fields in the Gulf Coast area, all wells are drilled with rotary tools and the casing is always set in cement that is placed by the circulation method. After the cement is set, the rotary mud that fills the hole is not withdrawn or bailed out; consequently, it is not customary to give the cementing job a direct test either by putting pressure on the hole to see whether the cement will hold or by observing whether an effective water shut-off is secured.

About three years ago, this company started the practice of coring the cement left in the bottom of the casing and examining the core thus secured. If the core was hard and strong, the cementing job was judged a success but if the core was incoherent, soft, and crumbly, the job was considered a failure. Of course, there were intermediate types of cores and it was not always a simple matter from this examination to decide whether the job was a success or failure. After about two years, a summary of the core examinations that had been made indicated that of cementing jobs made at depths of 1000 ft. or less, 60 per cent. were failures; of those between 1000 and 2000 ft., 80 per cent. were failures, and of those between 3000 to 6200 ft., 100 per cent. were failures. This startling table emphasized the need of the study of the conditions under which the wells were cemented and of adopting means to reduce the percentage of failures.

In addition to these core tests, two wells gave direct evidence that the cementing jobs were not always successful. In one, a four-year-old well at Goose Creek, the casing was perforated, and when fluid was circulated some of the old cement was brought to the surface. Most of it was powdery and the few chunks that were brought up were soft and crumbly. The other was a well at Raccoon Bend which during a blow-out brought a number of chalky, soft and crumbly pieces of cement to the surface.

Suggested Explanations of Cementing Failures

Efforts were made at once to explain the causes of these cementing failures. As all of the cements used were of a high grade and gave

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satisfactory results when specimens were set above ground, it appeared that the trouble in the well might be due to the heat and pressure at the bottom of the hole, which might prevent the cement from setting properly. However, work at the laboratory of one of the cement manufacturers showed that as the temperature increased the cement set more rapidly, and that with temperatures up to 165° F., the strength of the cement after two days increased markedly as the temperature increased. Pressures of 2100 lb. had little effect upon the setting time or final strength of the cement. A few supplementary tests were made in the company laboratories in which cement was placed in a bomb or strong container and then mud pumped in to give a pressure of 2200 lb. per sq. in. and the temperature held at 125° F. The specimens set under heat and pressure were much stronger than similar specimens set under atmospheric pressure at 72°. As in the majority of wells, the temperatures do not greatly exceed 130° or 135°, it appeared that the trouble was not due to the pressure and temperature existing at the bottom of the well.

The soft, chalky and crumbly specimens of cement that had been in place for some time in the wells at Goose Creek and Raccoon Bend were analyzed and found to contain a large percentage of carbon dioxide, indicating that the cement compounds had been converted to carbonates, which were much softer and had much less strength than the original cement material. This fact led to the theory of carbonation. It was believed that carbon dioxide contained in the gas from the formation reacted with the cement as it was setting and that the resulting carbonates were responsible for the failure of the cement. To test this theory, several samples of the cement were placed in a bomb, the bomb was filled with carbon dioxide gas from a cylinder, and then drilling mud which had previously been saturated with carbon dioxide was pumped in to give a pressure of about 2200 lb. The resulting specimens were firm and strong and seemed not to have suffered at all from the carbon dioxide. On analysis, these specimens showed the presence of only small amounts of carbonates. As the concentration of the carbon dioxide in these experiments was many times as great as could exist at the bottom of the well and yet did not injure the cement in any way, it became apparent that the case of the poor cores that were removed a few days after the cement had set were not due to conversion to carbonates. This did not prove, however, that the soft cores that had been in place in the wells at Goose Creek and Raccoon Bend had not been altered in their composition by the reaction of carbon dioxide, for these had been in contact with carbon dioxide for a long period.

As most of the laboratory specimens had been prepared with city tap water instead of the field waters actually used in the field operations, it was thought that the failures might have been due to the presence of salts in the field waters, which interfered with the setting of the cement.

Laboratory analysis of the waters in question did not reveal the presence of any injurious salts, and laboratory specimens prepared with these waters gave sound results. The failures, therefore, could not be attributed to the composition of the water used in making the cement slurries.

Thus, one by one, the explanations that occurred to those working with the problem were shown to have little effect upon the success or failure of the cementing. The problem was then attacked with renewed vigor and studied from three angles: (1) a laboratory study of the effect of the use of excess water and mud contamination on the setting of cement, (2) a petrographic study of the cement cores taken from the wells and of specimens prepared in the laboratory under controlled conditions, and (3) the observation of cementing operations in the field with the view of detecting the causes of trouble in the light of the findings of the two studies and of correcting them. These three phases were closely interrelated and all contributed to the same final conclusion.

Laboratory Study

The laboratory study was started by making chemical analyses of cement pats prepared in the laboratory, muds and cement cores from the field. Muds from Raccoon Bend and from West Texas both showed about 20 per cent. loss on ignition, 55 per cent. silica and 15 per cent. lime. They differed only in their content of aluminum oxide and ferric oxide, the Raccoon Bend mud containing about 4 per cent. and the West Texas about 12 per cent. A laboratory pat containing only cement and water showed 25 per cent. loss on ignition, 16 per cent. silica, and 54 per cent. lime. A sample of cement mix that was actually used in the field for cementing a well was set above ground in contact with mud and on analysis was found to be almost identical in composition with the pat prepared in the laboratory. The principal difference between the composition of the muds and the cements was in the silica and lime contents, the cement containing much less silica and much more lime. Three cement cores taken from wells were analyzed; their silica and lime contents were found to be intermediate between those of the pure cements and the mud. A good core had a low silica and high lime content, approaching that of pure cement, whereas a poor core had a high silica and low lime content similar to mud. A moderately poor core had silica and lime contents intermediate between these two. These findings pointed to the fact that the well cores were contaminated with mud and that in general the poorer the core, the more mud it contained.

As it was known that there was a tendency in the field to make the cement mix as thin as possible to insure its easy pumping into the well, some laboratory work was undertaken to study the effect of excess water as well as mud contamination on the strength of the cement. A series of samples was prepared with varying amounts of water. A definite amount of the mix was placed in a 4-oz. oil-sample bottle; the bottle was tightly stoppered and set aside undisturbed for 72 hr. In the thinner mixes, the cement settled to the bottom of the bottle, leaving a layer of clear water on top. The amount of clear water was measured, then the bottle was broken and the strength of the cement pat was tested.

Mixes containing less than 65 parts by weight of water per 100 parts of dry cement did not form a clear water layer. It is not believed that all of the water reacted chemically to hydrate the cement, as only about 30 to 35 parts of water are usually required, but that the excess of water remained in the pore spaces formed by the cement crystals. As the amount of water in the mix increased beyond 65 parts, the amount of water in the water layer also increased, but not proportionally, which indicated that the amount enclosed in the cement pores per part of dry cement increased as the excess of water increased. The solid cement that settled to the bottom formed a strong substantial specimen. The actual tensile strength was not determined, but inspection showed that the specimens were strong. There was a tendency for the mixtures that had contained the greater amount of water to form weaker specimens. When a large excess of water had been used, a graduation in the cement that settled to the bottom was noticeable and the lower portions appeared stronger and the upper portions weaker.

A number of mixes were prepared with excess water and instead of being allowed to remain undisturbed were agitated while the cement was setting. Some were agitated by turning the bottle end for end every 10 minutes during the setting period and the remainder were agitated by bubbling a small stream of air through the mixture. This agitation prevented the cement from settling and the entire amount of excess water was enclosed in the cement specimen. The specimens were allowed to stand undisturbed for three or four days. When examined, they were all very damp, soft and porous, with a number of tiny water pockets. After these specimens had dried for several days, they were still soft and crumbly. These experiments showed that excess water is not seriously objectionable provided nothing is done to the mixture to prevent the settling of the cement particles and the formation of a clear water layer on top. If this settling is interfered with, by agitation with formation gas or by other means, a poor cement core will result.

The effect of lack of uniformity of the water content of the cement mix was illustrated by filling a glass tube of 1 in. dia. with alternate layers of thick and thin mixtures. Several days later, when the tube was examined, it contained alternate portions of strong and weak cement. Apparently, there was insufficient time for the entire cement portion to settle. The more concentrated portions set more rapidly than the less concentrated and after they had set the settling was confined to the zones between the solidified portions, which caused the alternately strong and weak layers.

Contamination with Drilling Mud

Some laboratory work was undertaken to study the effect of contamination with the drilling mud upon the strength of the cement. In most of these experiments, the mud was from Raccoon Bend and represented a Gulf Coast drilling mud, but in some cases mud from West Texas was used. The results were not materially affected by the type of mud used. Series of mixes were made using varying amounts of water and to these mixes various amounts of mud were added. The mixtures were allowed to set for 72 hr. in stoppered 4-oz. sample bottles.

When the mixture contained less than about 65 parts of water per 100 parts of dry cement, no clear water gathered on top. The addition of the mud weakened the specimens; the greater the amount of mud, the weaker the specimens. With mixes that had been prepared with more than 65 parts of water per 100 of cement, a clear water layer gathered on top but the amount of water was less than it would have been if no mud had been added, and an increase in the amount of mud decreased the amount of water that gathered. The effect of the mud on the specimen was very much the same as though the mixture had been agitated to prevent settling.

Small amounts of mud were effective in preventing the settling of the cement. With a mixture containing 120 parts of water per 100 of cement the presence of as little as 1 per cent. mud decreased the amount of water gathered on top from 18 to 8 c.c. With a mixture containing 100 parts of water per 100 parts of cement, the water layer was reduced from 16 to 10 c.c. As the amount of mud was increased, the size of the water layer decreased and by adding enough mud, the water layer could be reduced to almost nothing. The addition of 10 per cent. mud was usually enough to reduce the water layer to a small fraction of the original value.

Specimens containing excess water and little mud looked very much like specimens with the corresponding amount of water that had been agitated to prevent the cement from settling . As the mud content increased, the specimens became correspondingly weaker. Pats containing equal quantities of water and cement to which 10 per cent. of mud had been added were soft and crumbly when dry and were easily crushed between the fingers, and resembled some of the poorest cores from the wells. Many of the laboratory specimens that contained less excess water and to which less mud had been added resembled some of the cores of the wells that were rated as poor cores.

In mixes containing a large excess of water to which mud had been added, there was a gradation in quality from the bottom to the top of the specimen, the bottom being stronger and the top weaker. There were some cases where the bottom was quite sound, whereas the top was soft and worthless.

Petrographic Study

In the petrographic study of this problem, 55 specimens of cement were examined. Of these, 9 were prepared in the laboratory as experimental controls and 46 were cores taken from wells at depths ranging from 100 to 3500 ft. and varying in appearance from excellent looking cores to crumbly incoherent failures. There seemed to be no correlation between the failures and the depth from which they were taken, as some of the best cores came from the deepest wells, whereas some of the cement used for surface casing produced very poor cores. Each sample was examined by inspection as to apparent success or failure of the cementing job, hardness, brittleness, type of fracture and porosity. Thin sections were prepared and examined under the microscope. They were examined for degree of hydration, amount and kind of foreign matter, evidence of formation of carbonates, and type of fabric. It might be well to define what is meant by "fabric." This term is used to signify the relation between the crystalline and amorphous material, the size of the crystals and the amount of interlocking of the crystals.

There was a good correlation between the appearance of the cores on inspection and the appearance under the microscope. A laboratory specimen of 33 parts of water per 100 of cement which, of course, looked excellent on inspection, had an excellent fabric, moderate amount of hydration, no foreign material and although it showed a slight conversion to carbonate, this was limited to one border of the specimen. Sets containing increased amounts of water showed poorer fabrics and a greater degree of hydration. Sets to which mud had been added indicated poor fabrics and the presence of the mud could be detected easily. Where mud was added to thick mixtures, the mud was present in islands but where it was added to thin mixtures it was evenly distributed throughout the mixture. The mud could be identified by the presence of grains of pyrite, quartz and feldspar.

In all soft, crumbly well cores, the fabric and degree of hydration resembled that which was characteristic of the laboratory samples to which mud had been added. These cores showed the presence of much foreign material such as quartz, feldspar and pyrite, and in some fossils could be identified. As it is impossible for a commercial cement to contain such materials and as the drilling mud does contain them, this proved that these cores had been badly contaminated with drilling mud. The type of fabric and the degree of hydration indicated that a large amount of water had been used in the cement mix, although in this case the evidence was not so decisive. The good cores showed the presence of foreign material but the amount was small and the mud instead of being evenly distributed seemed to be more in the form of islands. It appeared also that less excess water had been used.

The cases cited are the extremes of very good and very poor cores. The cores of intermediate quality indicated that the excess of water and the extent of contamination was between these two extremes. Very few of the cores, either good or bad, indicated that carbonation had taken place to any material extent.

Conclusions from Laboratory and Petrographic Study

The laboratory work and the petrographic study both led to the same conclusions; namely, that the poor cores had resulted from the use of too much water in making the cement mixture and the subsequent contamination of this mixture with mud and not from the conversion of the cement or parts of it to carbonates. The laboratory work led further to the conclusions that the use of excess water is not in itself seriously objectionable provided nothing prevents the settling of the cement particles to form a compact mass at the bottom. Agitation with formation gas or contamination with mud will interfere with the settling. Where the amount of excess water used is small, even relatively large amounts of mud do not seriously weaken the cement, but with a large excess of water, small amounts of contaminating mud will produce a poor core. As it is impossible to eliminate mud contamination altogether, the amount of water used should be reduced to a minimum. In any case where the cement has settled, the sounder portions will be toward the bottom so that it is possible to get a satisfactory core from the bottom and an unsatisfactory one from the top; therefore the cores for inspection should always be taken as near the bottom of the hole as possible.

Field Observations

Having arrived at these conclusions from work in the chemical and petrographic laboratories, observations were made in the field to see whether these conclusions were substantiated by field practice and if so, to suggest a remedy.

All cementing for this company in the Gulf Coast area is done under contract, the contractor using the circulation method. The contractor furnishes the equipment for mixing the water and the cement and pumping it into the well as well as the man and helper to supervise the job and operate the machinery. The company furnishes the cement, the water and the additional labor necessary. As the contractors were specialists in this field and had considerable experience, their work previously had not been observed by this company in a critical light.

One of the first points studied was the use of excess water. It was found that the amount of water used was not measured, the operator using as much water as he thought necessary to give the mixture the proper consistency for pumping into the well. As speed is essential and as a thin mixture is easier to handle and can be pumped more rapidly, the tendency was to use too much water. It was difficult to measure directly the amount of water used, for although the tanks from which the water was taken could be gaged, a large amount of water was used in flushing out the pumps, washing the machinery, and for purposes other than mixing with the cement.

The amount of water used was estimated by measuring the density of the cement slurry. By taking these density measurements at frequent intervals, it was found that the water content of the mixture was not uniform. If the cement hung up in the hopper or if the operator at any time did not have a bag of cement on hand ready to dump into the hopper, the water continued to enter the mixing vat although there was no cement to mix with it. As the capacity of the vat was small, any interruption in the cement supply meant that a very thin mixture was pumped into the well. The nonuniformity of the mixture was remedied considerably by providing two platforms on which the cement bags could be opened and two men to open the cement bags, thus insuring a steady supply of cement, and by impressing upon the operators the objections to nonuniformity. Positive displacement water meters were provided to measure the water actually mixed with the cement so that the water-cement ratio could be definitely determined.

It was found that in some cases the mud had not been circulated long enough to be sure that all accumulations of heavy mud had been removed from the bottom of the hole. Such accumulations of mud would have a tendency to contaminate the cement. Furthermore, the second plug between the cement and the mud was frequently omitted in order to save time. The trouble from mud contamination was minimized by having the mud circulated for a long period and insisting upon the use of the second plug. A special manifold for introducing the plugs into the casing without making or breaking any threaded joints was provided. This made the introduction of the plugs more rapid and convenient and reduced the time for cementing well considerably.

Observation revealed the fact that occasionally the cement operator allowed the pump to take suction faster than the cement slurry was prepared in the mixing vat and that the pump would draw in air and force it into the well. This was obviously objectionable because the air bubbles which were distributed through the cement would form voids to weaken the cement and make it less impervious. The operators were cautioned to keep the end of the suction pipe below the surface of the slurry at all times.

It was found that the cores were not always taken from the bottom of the cement that was left in the hole but after the importance of securing cores from the bottom was explained to the drillers, little difficulty was observed.

When the work was started, accelerators were frequently used with the cement. It was found that the operator had considerable trouble in adding the accelerator uniformly to the cement mixture. As most wells were not being drilled under competitive conditions and extreme speed was not urgent, the use of the accelerator was eliminated entirely and all later cementing was done without it. However, a reburned and reground cement having a relatively short setting time was used in all later work.

Recommendations

As a result of this study of cementing in the Gulf Coast, the following recommendations were made: (1) As thin a mud as possible should be circulated before cementing to soften and remove the accumulations of thick heavy mud; (2) plugs should always be used ahead of and behind the cement; (3) as little water as possible should be used with the cement and the water-cement mixture should be uniform; (4) sufficient cement should be left in the hole to prevent the mud that follows the cement from approaching too near the casing seat; (5) cores for examination should be taken near the bottom of the casing to avoid the soft, unsound cement layer that may be near the upper part.

Ever since these recommendations have been put into effect, a poor looking core has been infrequent. There still remains, however, the problem of cementing in the hot formations encountered in deep wells. These hot formations are very troublesome but as yet the proper way of handling them has not been found.

Acknowledgments

The writer gratefully acknowledges the contributions made to this paper by W. T. Doherty, who carried on the early experimental work and assisted in the field observations; by George E. Cannon, who carried on the later laboratory work and assisted in the field observations; and by L. S. Brown, who carried on the petrographic study.

DISCUSSION

B. B. Cox,* New York, N. Y.—How much cement was recommended to be left in the hole?

H. H. Hill,† New York, N. Y.—At least 30 to 40 ft., and with deeper jobs somewhat larger quantities.

I. I. Gardescu,‡ Pittsburgh, Pa.—The permeability of the rock surrounding the cement affects to an appreciable extent the quality of the setting. Very unsatis-

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factory results are obtained in attempting to cement a string of casing in a thick impervious clay horizon. This can be proved by performing a simple experiment. Two receivers are used, the first impervious, made of clay, the second porous, made of sandstone or plaster of Paris. Both receivers are submerged under water. A small amount of cement is poured in each one and allowed to set under water. The cement in the porous receiver will set in a shorter time and will be superior in quality to the cement placed in the impervious receiver.

MEMBER.—Does anybody know anything about shooting the cement in?

R. C. PATTERSON,* Taft, Calif.—We experimented in California on that considerably.

H. H. HILL.—Will you tell us something about cementing in the deep wells in California, where temperatures are as high as 200°?

R. C. PATTERSON.—The coldest water obtainable is used in preparing the cements, doing away with the quick-setting reagents they have been using and using a cement with slower initial set than is customary; practically going back, it is interesting to note, to a type of cement that was introduced in the industry in the earlier periods of cementing, with a low initial set.

H. H. HILL.—Is that an ordinary portland cement or is it a special mixture?

R. C. PATTERSON.—It is specially prepared. And talking about this type of cement to do away with the gas effect, they are using new equipment now; when they finish pumping in the cement, they have a back-pressure ranging from 1000 to 1500 lb. they will build up higher pressures as soon as they have equipment to handle it, and by so doing hope for more success.

C. P. PARSONS,† Duncan, Okla.—The problem in the Gulf Coast primarily was one of coring cement. In other words, when the double-tube core barrels were used, there was a tendency to grind up the cement. Consequently, every time a core was taken it could be crumbled in one's hands. They are now using the old basket type of core barrel for coring cement in that territory; that is very important. It appears best at present to core cement with a single-tube core barrel, or figure it as experimental with a double-tube core barrel.

Another important point about which a question was asked in this discussion, is the amount of cement to be left in the casing. There is no way in which that can be definitely determined, but we suggest that 10 ft. of cement be left in the casing for every 1000 ft. of casing, with a minimum of 25 ft. In that way the main body of cement is around the casing shoe. The laitance, or light fluffy cement usual on the top of a cement column, will be left in the casing.

Water meters are being tried to determine their suitability for measuring exactly the amount of water mixed with the cement. They meter the water that is injected into the mixer, and consequently the cementer can take a look at his meter and instantly see how much water he has mixed with a certain number of sacks. The status of the meter at present is experimental. There is a considerable load on a water meter doing this kind of work in the field, therefore such a meter should be rugged and constantly accurate.

Another important point is the uniformity of the mix. In the vacuum jet mixer the little jet nipple can be set to mix a certain minimum water-cement ratio, which can be as low as 3 gal. per sack, then the varying to higher ratios can be done by regulating the by-pass. There is a question as to just what is a practical water-

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cement ratio. Considerable experimentation with cement has shown that the lower the water-cement ratio the higher the strength, but we should look at the low water-cement ratio in relation to sub-surface conditions under which it is to be placed.

In the Gulf Coast very heavy muds are used. One well in the Hull field is circulating while drilling with 2300 lb. pressure per square inch. That is hardly conceivable, but it is true; the reason is that a heaving shale was encountered and a heavy drilling mud is used. Consequently, if it were decided to run casing in that well and cement it there would be 2300 lb. pressure to begin with in order to start the cement into the hole. Proper placing of cement behind the casing under such a condition calls for a higher water-cement ratio than ordinarily.

That brings up the question as to what is a practical range of water-cement ratios. It might be said that the maximum practical water-cement ratio would be the ratio at which water does not liberate freely from the neat cement, and that ratio is around 5½ to 6 gal. per sack. Consequently, if there is a tight hole neat cement with a ratio of 5½ gal. per sack of cement would be sufficiently dense and have sufficient strength to accomplish its purpose, and yet be fluid enough to be placed.

Water-cement ratios excessively above that would have a tendency to segregate into alternate layers of cement and free water. A minimum practical water-cement ratio is dependent on the workability of the mixture.

So far as pumping is concerned, a water-cement ratio slightly higher than 3 gal. per sack can be pumped. It is too difficult to start pumping at such a low ratio but it can be obtained after the pump has been started at a higher ratio. About 3.2 gallons per sack would be a practical minimum ratio. That is about 27 per cent. cement by weight; it makes a neat cement weighing nearly 18 lb. per gallon.

H. C. George,* Norman, Okla.—There is one thing I think should be added to our record. I heard it given at Ardmore, Okla. several years ago by Ed. Shell, who is a drilling contractor. Mr. Shell said, "In cementing the water string of casing in wells which were later standardized and completed by cable tools, I have found that the jarring action of the cable tools would loosen the last two or three joints of the water string of casing. This was due to the fact that the circulating mud left a ring of hard mud on the shale walls of the hole and upon the introduction of cement, the cement made contact with the hard mud rather than with the shale walls. Later this mud would loosen and cause the lower part of the water string of casing to swing loose in the hole and sometimes break loose, and in other cases cause the entrance of top water. In many wells drilled later, I corrected this difficulty by setting the water string of casing in the shell at the top of the oil sand."

R. C. Patterson.—In California, they use a dual system of meters so that if one meter fails after pumping is started, the second meter is left to check up with.

C. P. Parsons.—In California they are trying meters for measuring the displacement of fluid pumped in after the cement but we are using them for measuring the amount of water that goes into the mix.

R. C. Patterson.—With regard to the placing of plugs, it has been found that at the time of putting in the last plug, and before it reaches the top of the cement, the weight of the cement going down the hole draws in large quantities of air, thus creating an air pocket. That was quite a serious thing to contend with.

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