Part 7
(Conclusion)

Temperature

Wells Not in Thermal Equilibrium

C. Cementing Problems

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CEMENT generates considerable heat while setting. Its position behind casing can therefore be determined by making temperature measurements in the mud column at the proper time. Figure 7-1 is an example from a well of Tepetate, La. The top of the cement is shown by a temperature increase from 10 to 20 degrees below 7200 feet.

The magnitude of the temperature anomaly measured at a given point of the mud column is a function of the following factors:

- time
- quantity of cement
- nature of cement
- bottom-hole pressure and temperature
- size of casing
- conditioning of well.

Influence of Time

The relatively high bottom-hole pressures exising in rotary holes accelerate the setting of the cement. Setting usually starts within a very short time (one to three hours, according to conditions) after the cement job is finished, and it is virtually completed a few hours later (perhaps five to 12 hours).

Referring to Figure 7-2, Z represents tentatively the time-temperature chart at one point of the cement after pumping stopped. Let T, T_0 and T_F represent the cement temperature at any time t, the initial cement temperature (time $t = 0$) and the formation temperature, respectively. Until setting starts, T is approximately given by the following relation (see Part 5 of this series):

$$T = T_F - (T_F - T_0)e^{-\frac{2t}{d}}$$

d being the hole diameter. This gives arc AB of the graph.

When setting starts, the cement temperature increases steadily and may become higher than the formation temperature (arc BC). The maximum temperature T_M occurs perhaps at time t_M, shortly before setting is virtually completed. After that time less heat is generated within the cement than is transferred to the mud and formation, and the cement temperature gradually decreases until it reaches the formation temperature after several days (arc CD).

During the setting process the mud temperature T' lags behind the cement temperature, and it is represented by arc ABC'D' of curve Z' whose maximum T'_M is less than T_M and occurs at at time t'_M greater than t_M. After that time, the mud temperature gradually reaches the cement temperature, i.e., the formation temperature.

WHILE setting, cement releases a considerable amount of heat. The resulting temperature increase can be used for determining the exact position of the cement behind a freshly cemented pipe.

The foregoing discussion is evidently oversimplified in that it neglects the influence of depth and the horizontal temperature gradient within the cement. Nevertheless, graph ABC'D' is probably qualitatively correct, at least for the sections of the holes where there is an appreciable amount of cement, namely where large caves existed.

In sections which did not cave, the temperatures are less than shown by graphs Z and Z' (less cement, therefore the heat generated by setting is dissipated faster), and the resulting graphs are perhaps as shown by Y and Y'. Y refers to the cement temperature and Y' to the mud temperature.

In practice, graphs Y' and Z' give the limiting temperatures, and the actual temperatures would be given by points comprised between these two curves. The position of these points is controlled primarily by the degree of formation caving.

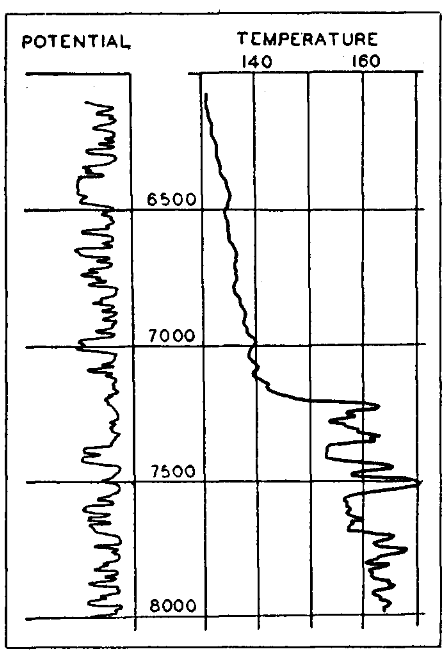

Figure 7-1. Potential graph and temperature graph in a freshly cemented well of Tepetate, South Louisiana.
After Deussen & Guyod, Courtesy AAPG.

All the foregoing data should be used only qualitatively since they are somewhat hypothetical.

Magnitude of Anomaly

Referring to Figure 7-3, E and F are the time-temperature graphs which would be obtained in the mud column if the hole were not cemented. E refers to sections which caved appreciably, while F refers to sections which did not (see Part 5 of this series). Graphs Z' and Y' discussed in the preceding section have been reproduced also on Figure 7-3 for convenience.

At any time after cementing, the temperature anomaly in a section which caved appreciably is measured by the vertical distance T_A between graphs Z' and E, while the anomaly in a section which did not cave equals T'_A, distance between Y' and F. Average anomalies, such as T''_A are comprised between these two values.

It is evident that if too much time elapses before the temperature measurements are taken (time t", for example), the anomaly is of the same order of magnitude as those found where there is no cement. A temperature log made under such conditions will usually fail to indicate by inspection the sections which are cemented.

Quantity of Cement

If D_c and D_h represent the outside diameter of the casing and the diameter of the hole, respectively, the quantity of cement at any point is proportional to $(D_h - D_c)^2$. If D_c equals seven inches and if D_h varies from ten inches (bit size) to 15 inches (maximum caving), the volume of cement in certain sections is seven times greater than in others. However, the temperature anomalies are not in the same ratio. Generally, T_A is roughly twice as great as T'_A. The log of Figure 7-1 is typical in that respect. If there is extreme caving in certain sections of the hole (abnormal shales) the ratio may reach the value of 4. On the other hand, if the hole is reasonably uniform (little caving), the anomalies are small (T'_A) and the top of the cement is usually difficult to pick on the log, even if the measurements are taken early. In such cases it is almost imperative to have a caliper log or an electric log to interpret the temperature data, as will be explained later.

Miscellaneous Factors

Quick-setting cements give large temperature anomalies faster than other cements but these anomalies are of shorter duration. With slow-setting cements, very large anomalies are still observed as long as three days after the cement job is done, while temperatures of the same order are observed only

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WELL LOGGING

within much shorter times with quick-setting cements, all other factors being approximately the same. Tentative time-temperature graphs for slow-setting cements are given on Figure 7-4 which shows that the temperature at points C and C′ is greater than for quick setting cement. This is due to the fact that the temperature of the cement before setting (points B and B′) was relatively high. Whether the cement itself is actually slow (or quick) setting, or the conditions (depth) are such that they slow down (or accelerate) the process, is immaterial. In either case the temperature anomalies are about the same.

If the size of the casing is large, the heat available from the cement has to warm a relatively great volume of mud. The resulting temperature increase is less than in casing of smaller diameter.

When mud or water is circulated in the hole—even for a very short time—after cementation part of, or all, the heat evolved by the cement is dissipated, and temperature measurements made subsequently may fail to exhibit significant anomalies.

Picking Cement Top

In most instances the cement top can be readily determined from a temperature log when the measurements are taken at the proper time. For example, in the case illustrated on Figure 7-3, it is obvious that from six to 24 hours after the cement job the temperature anomalies will be large enough to permit picking the top of the cement from the log. After that time the anomalies may be too small to allow making this determination by inspection.

There are cases when the graph does not exhibit any sharp break, even when the measurements are taken at the proper time. This happens, for example, in certain wells having penetrated shales which do not cave appreciably, and more particularly when the diameter of the casing is large with respect to the size of the bit: the quantity of cement behind the pipe is relatively small and resulting temperature anomalies may be of the same order of magnitude as those which are found in wells not cemented (see Part 5 of this series). Then, the cement top cannot be picked with certainty from the temperature graph. Fortunately, if other records are available, the problem can usually be solved. The most desirable record for doing so is a caliper log, and the information which it supplies is used as follows:

It has been seen that in a relatively deep hole (more than 2000 to 3000 feet) which is not cemented, the mud temperature is less in formations which cave than in those which do not. The opposite condition is found in holes which have been recently cemented. Therefore, by comparing the temperature and caliper logs, it is usually possi-

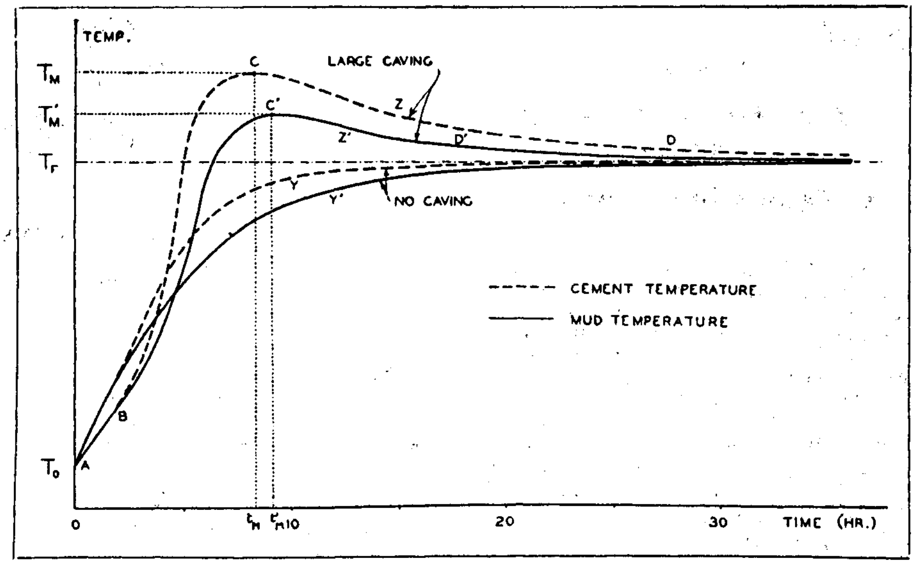

Figure 7-2. Hypothetical time-temperature graphs at a given level of a freshly cemented well (quick-setting cement).

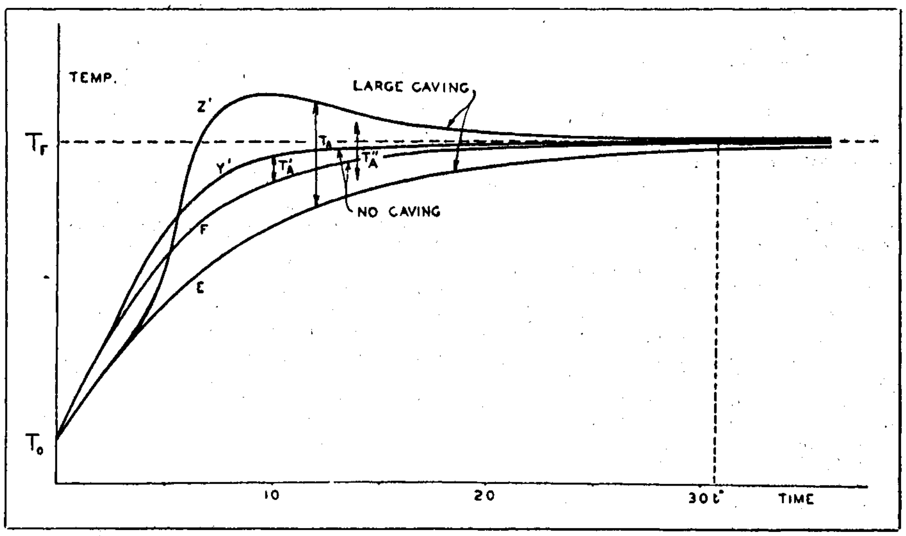

Figure 7-3. Graph for estimating temperature anomaly due to cement (partly hypothetical).

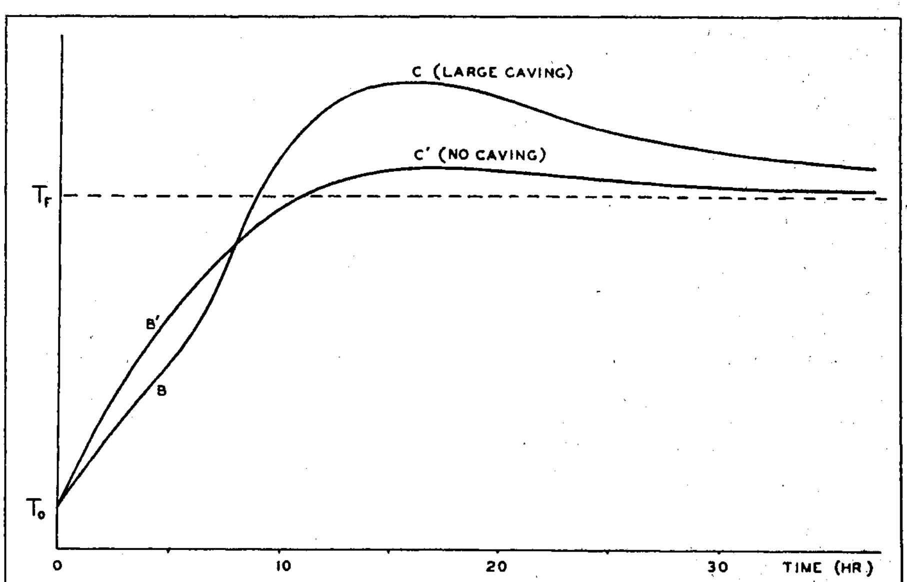

Figure 7-4. Hypothetical time-temperature graphs at a given level of a freshly cemented well (slow-setting cement).

ble to determine which sections contain cement. Referring, for example, to Figure 7-5, it can be seen that above 5800 feet the sections which caved are slightly colder than the others while the opposite holds true below 6000 feet. Therefore, the top of the cement is situated between 5800 and 6000 feet.

If no caliper log is available, good results are nevertheless obtained in most cases by using an electric log and assuming that shales cave more than sands. This assumption is usually correct except sometimes in very young formations (above the Eocene).

By tipping the temperature log of Figure 7-5 and sighting along the mean line it can be observed that there is a slight change of slope around 5980 feet. This may be associated to decreasing amounts of cement from 7000 to 5980 feet (some kind of tapered channelling). However, there is no evidence that this assumption is correct.

Tapered temperature logs are generally found in wells which have traversed formations caving only a little. Where shales cave appreciably the cement top is usually sharply defined, and the mean temperature line in cement is approximately parallel to the mean line in the non-cemented section of the hole (see Figure 7-1).

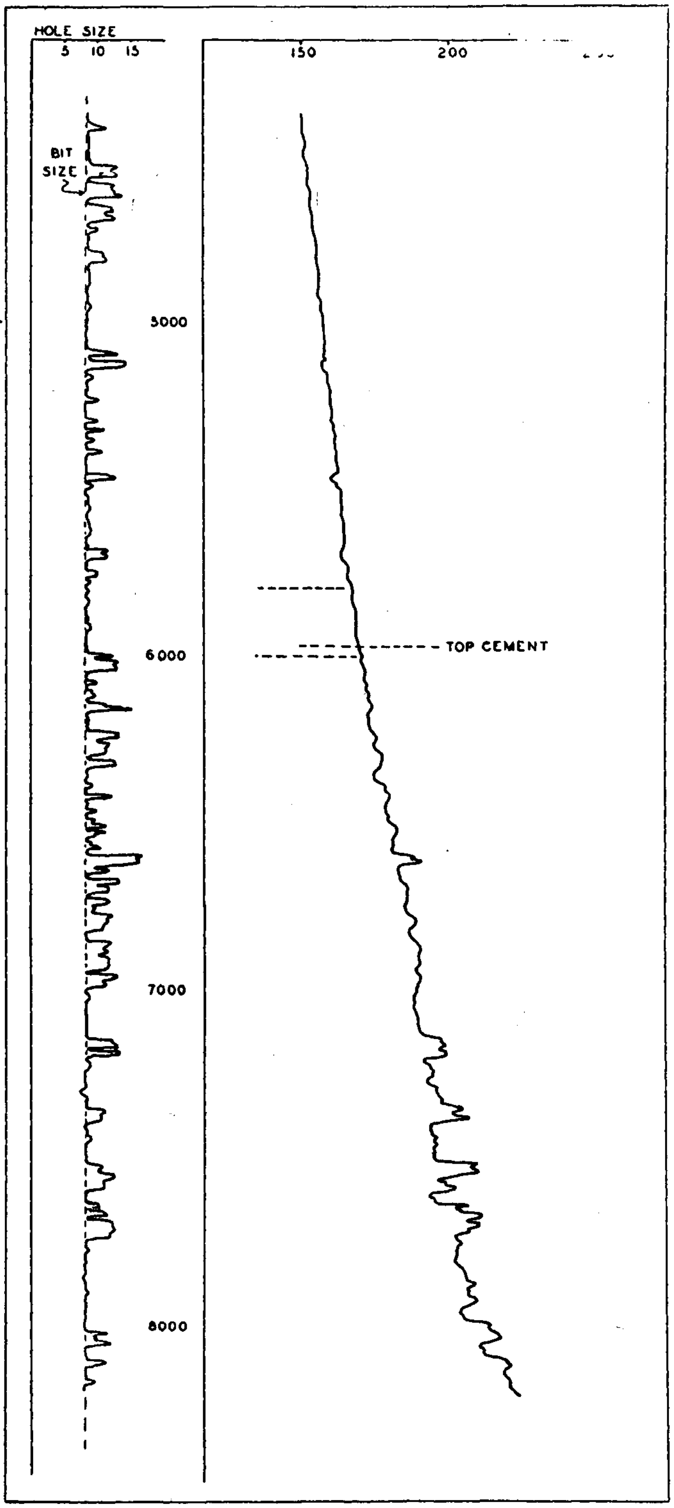

Figure 7-5. Use of temperature log and caliper log for accurately picking top of cement.

Squeeze Jobs

After cement is squeezed, it is usually necessary to wash the hole for a short time. If the washing is held to a minimum (20 minutes) little heat is dissipated by the mud stream and it is possible to locate the cement behind the pipe by temperature measurements. Figure 7-6 is an example of a successful job done under such conditions: the temperature data are substantiated by gamma-ray measurements shown in the center of the figure (carnotite was mixed with the cement). Run No. 1 was made before squeezing and Run No. 2 afterwards.

If circulation lasts a few hours, a large amount of the heat evolved is dissipated and it is usually impossible to locate the cement from the temperature graph, especially if setting was fast (deep holes).

Quality of Cement Job

A large increase of temperature in the mud column usually indicates a large volume of cement behind the pipe. The temperature graph, however, does not indicate how this cement is segregated. It may be all around the casing or it may be only on one side. In either case, the temperature recorded will be substantially the same. In short, the temperature log tells where there is cement behind the casing, but it does not tell whether the cement job is good or bad.

Cement Penetration

From the temperature logs available to the writer it seems that there is little cement penetration, if any, in permeable formations, except perhaps in fractured limestones for which no conclusive data could be obtained.

Conclusion

Temperature measurements for the location of cement should be made preferably from five hours to 24 hours after cementation if the cement sets fast, and somewhat later if setting is slow.

No circulation should be made in the hole between cementing and temperature logging. If it is imperative that the hole be washed, the circulation should be kept to a minimum; even so, the temperature log may fail to locate the cement.

Acknowledgments

An appreciable amount of the work described in this series of articles was suggested by numerous investigations conducted during the last two decades by C. E. Van Orstrand and associates, the API and many others. Some of the results obtained by these workers have been incorporated in these articles. Specific acknowledgment of the original work is difficult because the literature on temperature is extremely scattered. Nevertheless the writer wishes to emphasize that, without the basic information gathered from the work of the previous investigators, he would have been unable to understand fully the problem and to present adequately a summary of the subject.

The writer is also particularly grateful to Halliburton Oil Well Cementing Company for its financial help, without which most of this work would not have been possible.

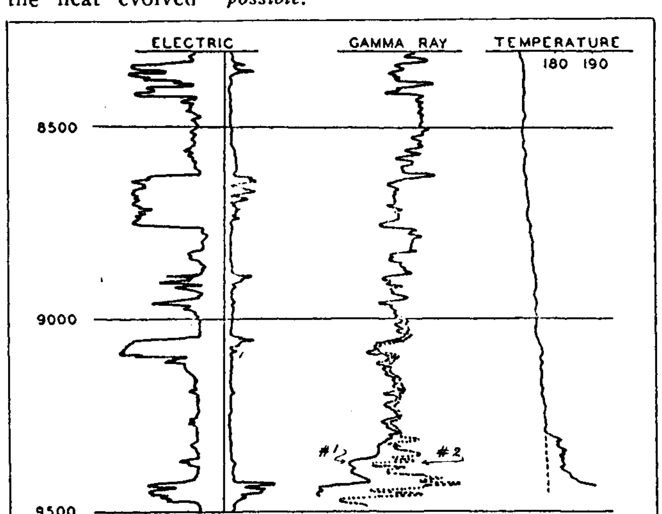

Figure 7-6. Location of cement behind pipe after squeeze job.
After Teplitz & Hassebrok.