A LABORATORY INSTRUMENT TO CONTINUOUSLY MONITOR THE COMPRESSIVE STRENGTH OF CEMENT SLURRIES

Dr. John F. Burkhalter
David L. Sutton
Dr. Prabhakar P. Rao
Fred L. Sabins
Halliburton Services

INTRODUCTION

The "Ultrasonic Cement Analyzer" (UCA) is the name given a new generation device (Fig. 1) that continuously monitors strength development of oil well cement compositions.[1] A single sample of cement slurry is placed in the instrument under pressure and heated to simulate downhole conditions. Measurements of the cement's ultrasonic velocity are started during the fluid state and continue through initial set to any desired point of partial or final strength development. Strength values are continuously computed and displayed until the test is terminated. The result is a complete and precise history of initial set and strength development which can be plotted versus time at any point of interest.

The UCA functions with little operator attention aside from start up and shut down. The same information from standard API compressive strength crush tests would require curing a multitude of specimens to preselected test times, with no guarantee that the first test would be short enough or the final test long enough to accurately provide the critical information for the job.

Since its introduction some two years ago, the principal advantage of the UCA has been simply to speed collection of reliable compressive strength data. For example, one technician with an eight-chamber UCA can produce more data than eight technicians and 64 separate curing autoclaves. In addition, human error and the opportunity for bias is greatly reduced with the UCA.

DESCRIPTION AND OPERATION

The UCA system consists of four basic units as shown in Fig. 2:

1. An autoclave assembly which contains the sample chamber, heat control equipment, and ultrasonic pulser/receiver (A typical UCA system contains from four to eight separate autoclave assemblies.)
2. The pressure control unit.
3. The multiplexed control unit which includes display, control board, microprocessor, and data storage.
4. The plotter unit.

The sample chamber is designed for 20,000 psi maximum operating pressure at controlled temperatures up to 400° F. The sample volume is 250 cc in the form of a slightly tapered cylinder with a length/diameter quotient of 1.0. The transmitter and receiver transducers for the ultrasonic velocity measurement are placed outside the sample chamber and do not experience the high pressures of the test. The transducer compartments are recessed into the top and bottom ends of the sample chamber to provide the shortest travel time for the path through the slurry sample rather than through the steel chamber wall. The pulser sends a short, high voltage electrical pulse to the transmitting transducer. The transducer converts each electrical pulse into an ultrasonic acoustic wave (ca. 400kHz) which travels through the cement sample to the receiving transducer and is converted back into an electrical signal. This electrical signal is picked up by the receiver, amplified, conditioned, and sent to the microprocessor along with a timing signal from the initial pulse.

The multiplexed control unit sequentially selects chambers for data processing; each chamber is selected once every 10 seconds. The microprocessor uses the time delay between the initial transmitted pulse and the received pulse to calculate the ultrasonic velocity. The measured velocity is then used to calculate the apparent compressive strength from an empirically developed equation programmed into the microprocessor. The result of this calculation is displayed and stored in the memory section along with the elapsed time from the start of the test. At any time during the test, the elapsed time and the compressive strength information can be retrieved from the memory and output to the plotter in the form of a time versus compressive strength graph. In addition, the time to initial set (50 psi) as well as the time to reach a preselected second strength are placed in storage and can be displayed on command without plotting.

In addition to providing a calculated compressive strength value, the set cement specimen can be withdrawn from the chamber and used to determine a mechanical crush strength. This strength value may be used to confirm the final strength indicated by the UCA and can provide data for improving the equation used for the UCA calculations. The maximum deviation between the UCA calculated strength values and high quality triplicate crush strength tests is well within the error limits of API common sample cooperative tests for crush type compressive strengths.[5]

A complete eight-channel system was tested to determine the reproducibility of the UCA data. In this series of tests, 24-hour compressive strengths were measured on 23 samples of neat Class H cement and 38 per cent water at 120° F and 3000 psi pressure. The average coefficient of variation of the compressive test data was 6.7 per cent. This may be compared to two low temperature API cooperative compressive strength tests conducted in 1980 and 1981, where the percent variation was 15 per cent and 12 per cent respectively.[5] It has been observed that tests can be reproduced with better accuracy if the rate of sample heating is controlled very accurately.

A feature of the UCA which enhances its utility is the nature of the collected information; that is, a complete strength development curve is obtained. The very shape of the compressive strength curve even without absolute values can be used to estimate such parameters as initial set time, when to run a temperature survey, when to drill out, and when to perforate. With reference to Fig. 3B, a calculation error of 200 psi in compressive strength would cause an initial set time error of less than 30 minutes and such an error would have even less effect on the time needed to reach 1000 psi.

RESEARCH APPLICATIONS OF THE UCA

The first eight-chamber UCA was installed in August 1981 at the Halliburton Services Chemical Research Department, Duncan, Oklahoma. Since that time the UCA has provided information useful to many research efforts.[2,3,4] In the final analysis, the principal advantage of the UCA is high efficiency generation of a very large volume of compressive strength data. The most outstanding specific advantage is that UCA records all of the critical points in the strength development history. This feature has been exceptionally useful in projects to relate thickening time test data to initial set time data and for retrogression studies.

An examination of Fig. 3 illustrates the usefulness of the UCA for retrogression studies. The results of only three UCA tests clearly show the function of added silica and the effect of silica particle size in preventing strength retrogression. Fig. 3A clearly illustrates retrogression in a single UCA run. To approximate this curve by conventional techniques would require a minimum of 12 crush strength tests. Fig. 3B illustrates the use of finer silica flour in the prevention of retrogression effects. Fig. 3C clearly shows that the coarse silica allows a significant loss of strength, but overcomes this loss after a relatively short time period. Without the UCA the effect of the coarser particle size might go undetected.

The UCA has been used in several extensive research projects requiring large amounts of compressive strength data. In one study,[3] over 30 slurries were tested utilizing the UCA for determining set times. The data was collected at temperatures in the range of 144° to 288° F. The set times of the cement slurries utilizing the UCA were compared to conventional heat of hydration set times.

In another study,[4] over 150 tests were conducted utilizing the UCA on cement slurries at temperatures of 80° to 350° F. The study required mainly 12 and 24 hour compressive strengths. A variety of different slurries were tested including: light weight filler cements; neat cements with fresh and sea water; pozzolan cements and cements with silica, fluid loss additives, and dispersants. The UCA strength values at 12 and 24 hours were compared with crush strengths of the same sample in 80 per cent of the tests. Results were very comparable and proved as accurate as crushed samples would indicate.

FIELD APPLICATIONS OF THE UCA

To date, the UCA system has been installed in 10 Halliburton Services' field laboratories and in every instance has proven to be a valuable addition due to their ability to produce a large amount of compressive strength data efficiently and to provide a complete history of strength development. One of the most important field uses is to confirm initial set times of cement slurries with thickening times which are very sensitive to retarder concentration. For example, in some high temperature slurry designs a 10 per cent increase in retarder concentration may overly extend the thickening time beyond that desired by the operator on a particular job.

If thickening time alone is being used as an indicator of initial set, an excessive thickening time can cause great concern and result in much subsequent reblending and retesting. However, if the UCA shows over retardation did not appreciably extend the initial set, the extended thickening time becomes much easier to accept.

An initial set time less than the thickening time is a pseudo-abnormality in oil well cement testing, which is often misunderstood and not widely appreciated. This phenomena is due to a high temperature (BHST) schedule for the strength tests, a lower temperature (BHCT) schedule for the thickening time tests, and the differences in cement behavior under dynamic as opposed to static test conditions. Without the UCA, good initial set time data is experimentally difficult to obtain and is usually left unconfirmed. With the UCA, this information is easily illustrated and the conventional conclusion that initial set is approximated by the thickening time for all cement slurries is being challenged.

In another important field application, the UCA can determine waiting on cement (WOC) time. WOC time is the time required for the cement to reach a predetermined strength level which is adequate to continue well operations. Normally, strength values of at least 500 psi are required to drill out and values as high as 2000 psi are required for perforating, depending on the operator and/or well conditions. Traditional compressive strength values are generally determined only at 8, 12, and 24 hours. These strength values are then used to interpolate or extrapolate a WOC time. With the continuous plot of compressive strengths given by the UCA, the exact WOC time can be determined or a future WOC time can be accurately projected from the slope of the compressive strength curve. Ultimately the UCA saves rig time.

CONCLUSION

The UCA will only be used at its fullest potential when the industry becomes aware that the instrument provides a complete strength development history. Old operational procedures based on very limited compressive strength data will then be replaced by new procedures utilizing the UCA to provide real savings in rig time and improved operations. The UCA can be used to:

1. Simplify and improve slurry design for long interval jobs and also reduce WOC for such jobs.
2. Aid quality control and make reliable onsite confirmation of results a reality.
3. Provide more precise WOC times to run logs, drill out, or perforate.
4. Aid research efforts in the areas of cement chemistry, additives and processes.

BIBLIOGRAPHY

1 Rao, P. P., Sutton, D. L., Childs, J. D., and Cunningham, W. C., "An Ultrasonic Device for Nondestructive Testing of Oilwell Cements at Elevated Temperatures and Pressures", J. of Petroleum Technology, Vol. 34, pgs. 2611-2616, November 1982.

2 Sabins, F. L. and Sutton, D. L., "Here's How to Apply Laboratory Cement Test Specifications to Actual Operations", Oil and Gas Journal, May 23, 1983.

3 Sabins, F. L. Sutton, D. L., and Cook, C., Jr., "The Effect of Excessive Retardation on the Physical Properties of Cement Slurries", SPE 10221, 56th Annual Fall Technical Conference and Exhibition of the SPE, San Antonio, Texas, October 5-7, 1981.

4 Sabins, F. L. and Sutton, D. L., "The Relationship of Thickening Time, Gel Strength, and Compressive Strengths of Oilwell Cements, SPE 11205, 57th Annual Fall Technical Conference and Exhibition of the SPE, New Orleans, Louisiana, September 26-29, 1982.

5 Report of API Task Group on Cooperative Testing, 1980 and 1981.

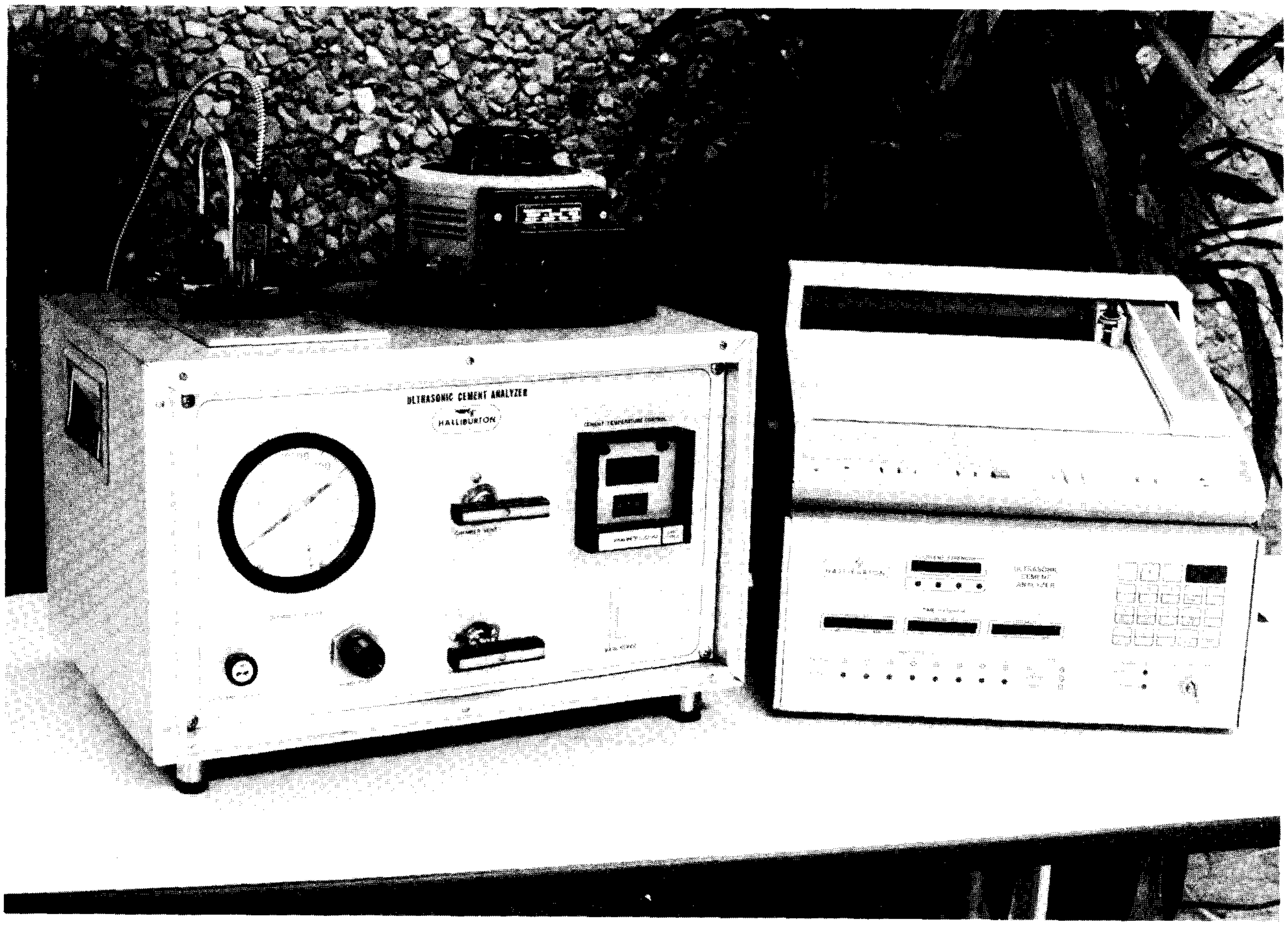

Figure 1 - Ultrasonic cement analyzer

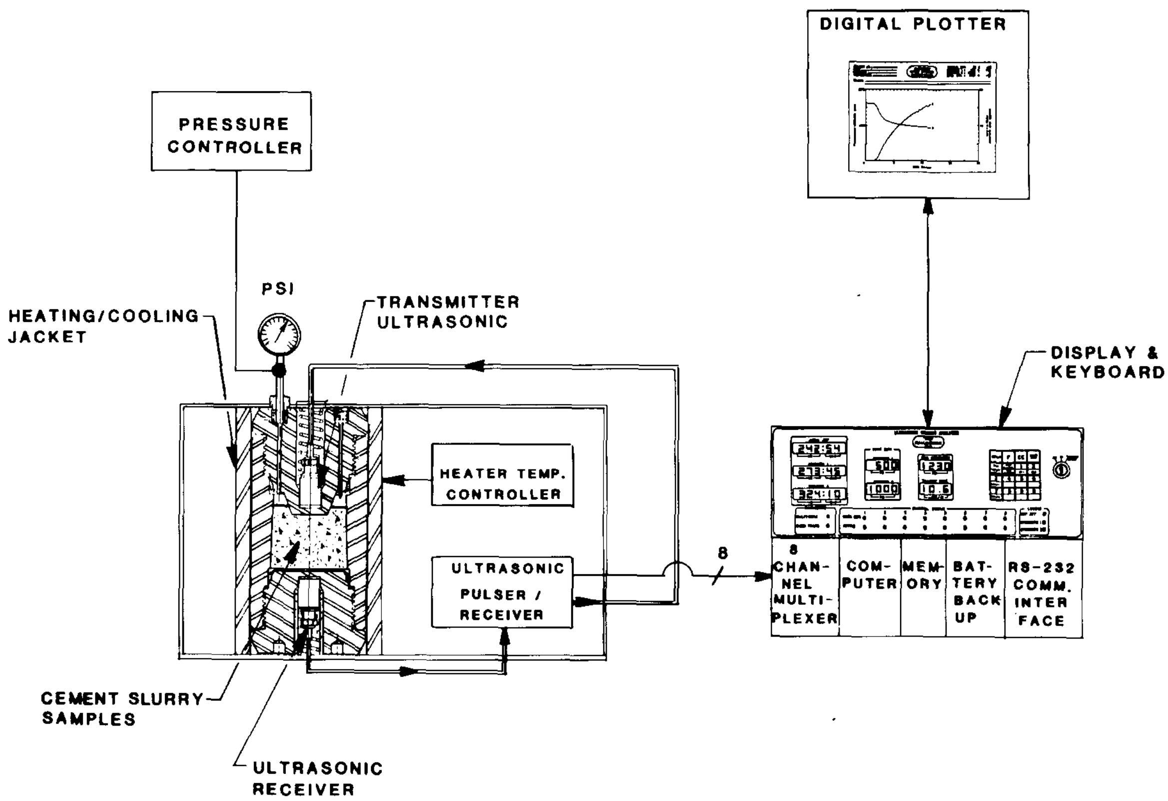

Figure 2 - UCA system configuration schematic

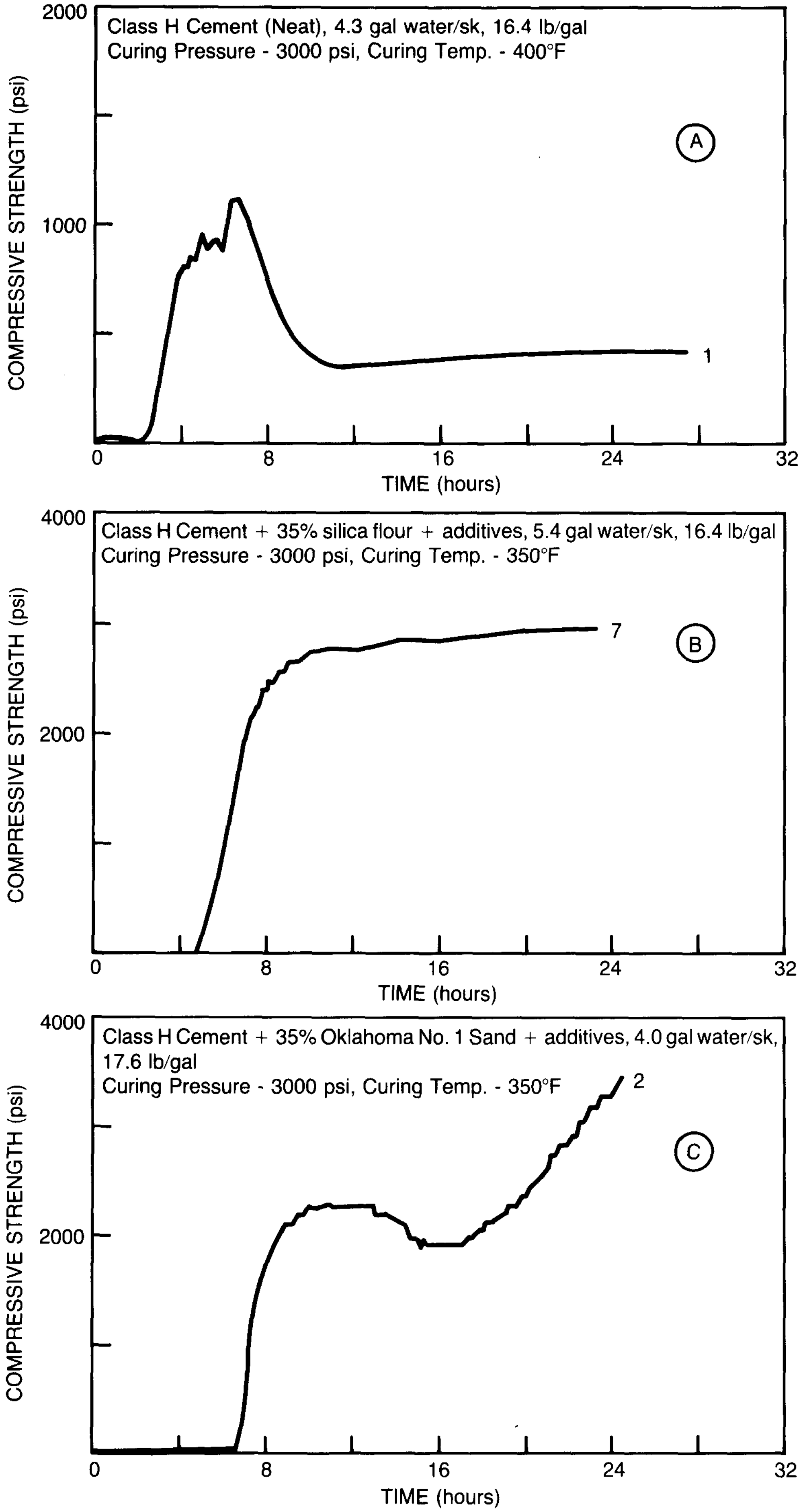

Figure 3 - UCA cement retrogression data