CEMENT LABORATORY AUTOMATION USING A NEW ACQUISITION AND CONTROL SYSTEM

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ABSTRACT

A new, multi-purpose acquisition and control system makes monitoring and controlling various laboratory devices easy. The system, built specifically for use in an oil field laboratory, can monitor and control eight laboratory instruments simultaneously.

This paper discusses the capability of the system to control pressure, temperature, and motor speed of properly equipped laboratory instruments. The system controls these variables to follow schedules set by the user for the test. Merits of controlling the above variables are also discussed.

The system also has various time saving features, such as the use of the full spectrum of API Spec-10 schedules. The need for laboratory automation also requires that the system has two-way communication abilities with a host computer.

INTRODUCTION

A good cement test requires accurate control of the environment. In particular, temperature control is a major factor which can influence the outcome of a test. Inaccurate temperature control has shown effects from none to drastic depending upon the slurry type tested.

Test pressures and the amount of shear during the test are two other factors which are discussed in this paper. Usually, these factors are not major contributors to the outcome of a test. Yet, many researchers have experienced inconsistent results in the past; therefore, we should provide better control of these elements to produce good results.

In this paper, various means of controlling temperature, pressure, and shear rates are presented. We will also present a new acquisition and control system capable of monitoring and controlling eight laboratory instruments. Discussions will also cover advancements in this area, such as automation and networking.

The PID Controller

PID type controllers are the most popular type controllers used in the industry today. These controllers are abundantly available from many manufacturers and are usually quite economical. Essentially, the P(proportional) I(integral) D(differential) type control system uses the following principle:

$$Output = K1 * E + K2 * \int Edt + K3 * dE/dt$$

where, in a feedback system, E represents the error of the output relative to the setpoint (Figure 1). These type controllers can satisfy most applications in the industry because they are quite responsive, yet they can stabilize rapidly.

With the advancement of microprocessors, the development of intelligent PID controllers was the expected progression of this technology. The use of microprocessors allows more accurate control and better user interface for less cost.

High pressure, high temperature simulations are commonplace in the oil industry. In this environment, PID controllers are not as accurate and responsive as expected. The use of thick steel walls to contain the pressures of the fluids causes most cement laboratory instrumentation to have very large heat capacity. Conventional PID controllers can not control temperature of the tested fluids accurately within an acceptably short time. In fact, such controllers will have difficulty in controlling the temperature of the system if the desired temperature varies with time.

Multi-Channel Acquisition and Control System

The Multi-Channel Acquisition and Control System (Figure 2) was built to resolve those problems. Laboratory automation was also one of the primary criteria used in designing this system. In short, the design follows the following prescribed capabilities and constraints:

1. Menu driven.
2. Complete API Spec-10 schedules provide ease of use.
3. Capability to control pressure to follow schedules.
4. Improved accuracy in controlling temperature.
5. Motor control including motor speed and direction control, when equipped.
6. Attractive hardcopy output.

The capability to control and monitor a handful of instruments provides centralized access for the operator. In addition, it allows consolidation of data in one location ready to be plotted or sent to a host computer. With present hardware costs, it is also cost effective.

To improve efficiency of the laboratory, we included many time saving features in the system. Features like automatic shutoff and cooldown, or automatic capture of important test variables help the operator in reporting the test results. Report-ready data plots enhance report quality. Good power-fail handling features eliminate unnecessary repetitions of tests affected by power interruptions.

Menu Driven System

Menus create a user friendly environment and guide the operator through the steps required to operate the system. With menus, one can set the control parameters with very little instruction. For example, if the operator wants to program the system to control a channel, he would simply follow this procedure (Figure 3):

1. From the Main Menu, select "1. Program Setpoints". Channel number must also be entered at this time.
2. A new menu pops up; here, select "2. Manual Program"
3. In the next few menus, fill in desired values.

These menu selections communicate in plain English, instead of difficult engineering terms. Also note that the user is allowed to select stirring state (on or off) and stirring speed at this time (Figure 3).

Complete API Spec-10 Schedules

As a time saving feature, the instrument offers the full spectrum of API schedules. In the case where the user wants to program a channel to follow API Spec-10, Hesitation Squeeze, Schedule 19, he follows the simple procedure below (Figure 4):

1. From the Main Menu, select "1. Program Setpoints." Channel number must also be entered at this time.
2. A new menu pops up; here, select "1. API Schedule Program"
3. In the next menu, select "4. Hesitation Squeeze"
4. Finally, select "3 19 - 14,000 ft.(4270m)."

In five simple keystrokes, the full API Spec-10, Schedule 19, has been programmed for the channel. Note that the program includes temperature, pressure, and motor control parameters.

Advanced Pressure Control

Accurate control of pressure is probably not considered as important as temperature control. Laboratory data shows that small variations of pressure do not affect test results. However, some researchers have shown some effect of pressure variation on hydration time.[1]

To provide the scientist with a tool for obtaining accurate thickening time or other parameters, we included pressure control capabilities in the system. The instrument has to be equipped with pressurizing equipment, such as shown in Figure 5. In this configuration, an air operated intensifier pump is used. The system uses an electro-pneumatic air valve (a) to increase pressure, while a high pressure valve (b) is used to reduce output pressure. Figure 6 shows the capability of the system to control pressure. Note that line (P1) overlaps the dotted line representing desired pressure schedule.

Improved Temperature Control

As mentioned earlier, the use of PID control systems is widely accepted in the industry. When the desired temperatures are constant, or when the controlled instrument has low heat capacity, use of these control systems is more than adequate. In cement laboratories, however, the above conditions are unusual. In fact, most cement lab equipment has large heat capacities, and the desired temperatures are not constant. For this application, a more sophisticated temperature controller is necessary. We found out that the use of a proprietary modified PID:

$$\text{Output} = K1 * E + K2 * \int E\,dt + K3 * dE/dt + K4 * F(E,t)$$

provides very accurate results. Figure 6 shows that T1, the slurry temperature in a consistometer, closely duplicates the programmed schedule (dotted line). The system achieves control accuracies of 0.1 deg F during steady state conditions.

A less well-behaved cement (Figure 7) even further demonstrates the effectiveness of this system in controlling temperature. Note that T1 again follows the programmed schedule closely even though the heating bath temperature, t1, substantially varies with time. Even following a large amount of heat due to hydration (at the end of test), the system manages to control T1 effectively.

The Need for Motor Control

Motor control can be observed as either a luxury or a necessity. When designed properly, it helps users in their day-to-day work and therefore saves time. Motor control can be limited to ON/OFF or can be elaborate such as speed and directional control.

For systems with no remote control abilities, remote ON/OFF is the easiest feature to add to the system. Remote ON/OFF allows a processor to turn the system off when the test is completed. Therefore, the user does not need to be present throughout the test.

Speed control provides the user the capability to simulate actual jobs. The shear induced by pumping cement downhole can be simulated by turning the paddle at a specific rate. A simple relationship between flow rate inside the pipe and paddle speed is as follows:

N = K * Q / D**2 ,

where N is the paddle speed in rpm, D is the pipe inside diameter and Q is the flow rate. For cements flowing in the annulus,

N = K * Q / (Dh**2 - Dp**2)

where Dh and Dp are hole diameter and pipe outside diameter, respectively.

When both static gel strength and consistency tests are to be performed on the instrument, conventional methods to control speed can not be applied. Standard consistency tests require speed of 150 RPM. On the other hand, static gel testing operates at very low speeds, typically 0.1 degree/minute. This large spread of ranges requires more sophisticated controls and equipment. One approach implemented in the Multi-Channel Acquisition and Control System is the use of a stepper motor to output the full range of speeds. The advantage of using a stepper motor with these tests this is that the system can switch between the two test types easily. For example, Figure 8 shows results of a consistency test using a hesitation squeeze schedule. During the "Stirring Off" period, however, the control system automatically performs static gel strength tests. Using this approach, the researcher can observe cement characteristics during hesitation squeeze.

Output Plots

Output plots provide the user a quick view of test results. Strip chart type plots provide this function, but are often long and hard to handle. In the design of this system, we feel that offering attractive, condensed plots (Figures 6,7,8) is beneficial. These plots show everything the user needs to know -- P & T schedules, test measurements, and important parameters of the test.

Future Directions

The system allows host computers to retrieve data from the tests. This promotes networking and full laboratory automation. Data obtained by the system can be stored in a host computer data base for further cement research and for cement job design.

With prices of microprocessors continuing to drop, we foresee that all individual test instruments will be equipped with control systems as discussed in this paper. The importance of network planning becomes relevant as we continue to strive to consolidate data at the host computer.

Reference

1. Rahman, A.A., and D.D. Double, "Dilation of Portland Cement Grains During Early Hydration and The Effect of Applied Hydrostatic Pressure on Hydration," Cement and Concrete Research, Vol 12, pp 33-38, 1982.

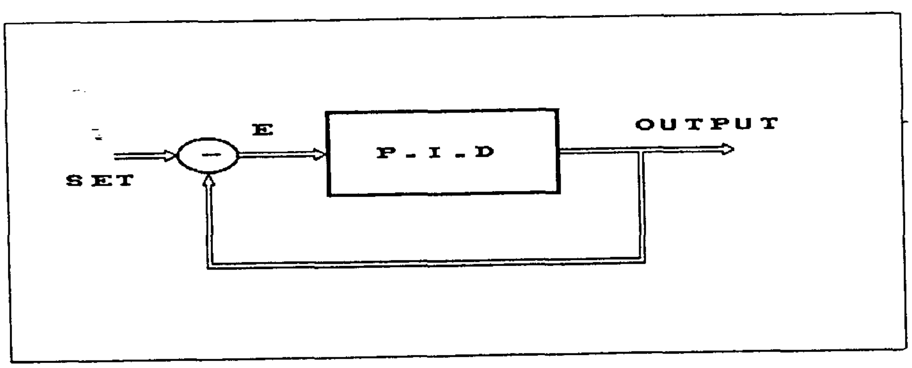

Figure 1 - PID control with feedback

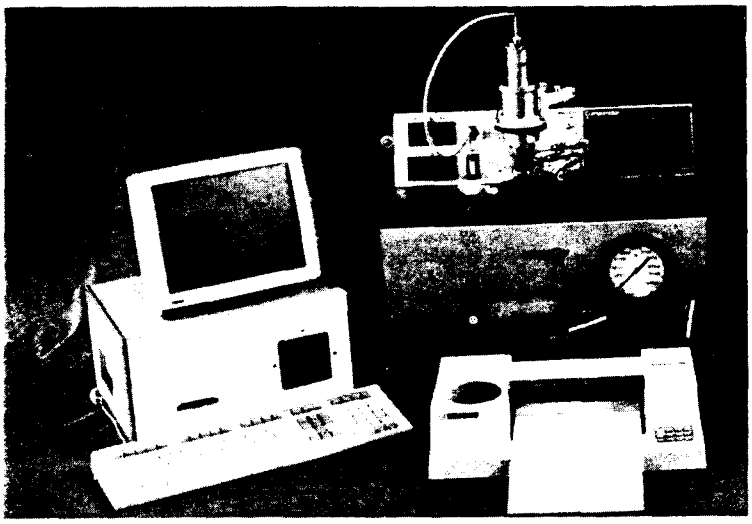

Figure 2 - Control system (left) shown with portable consistometer

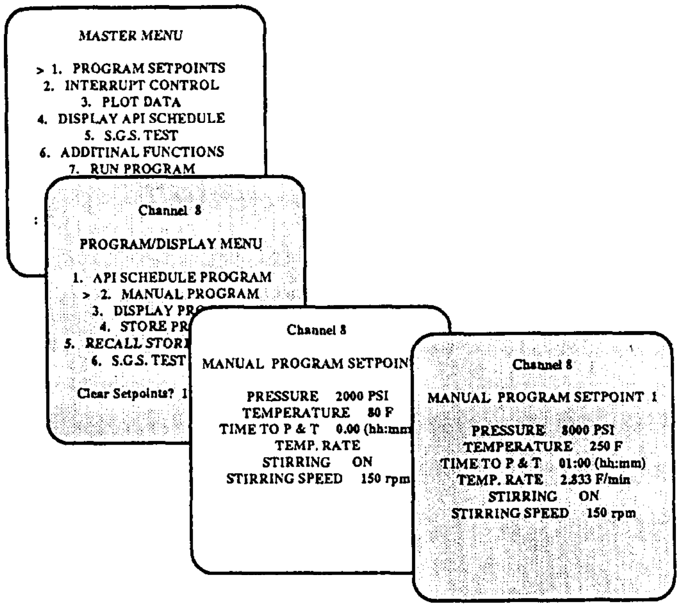

Figure 3 - Menu sequence to program a channel

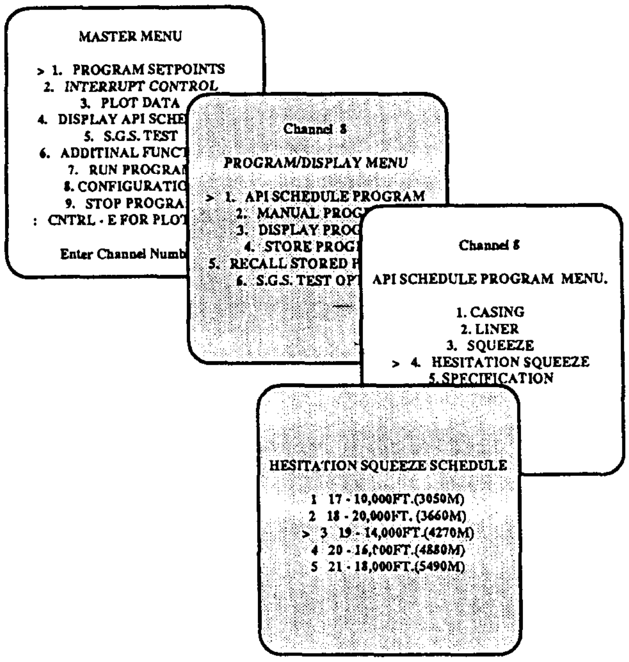

Figure 4 - Programming using API Spec-10 schedules

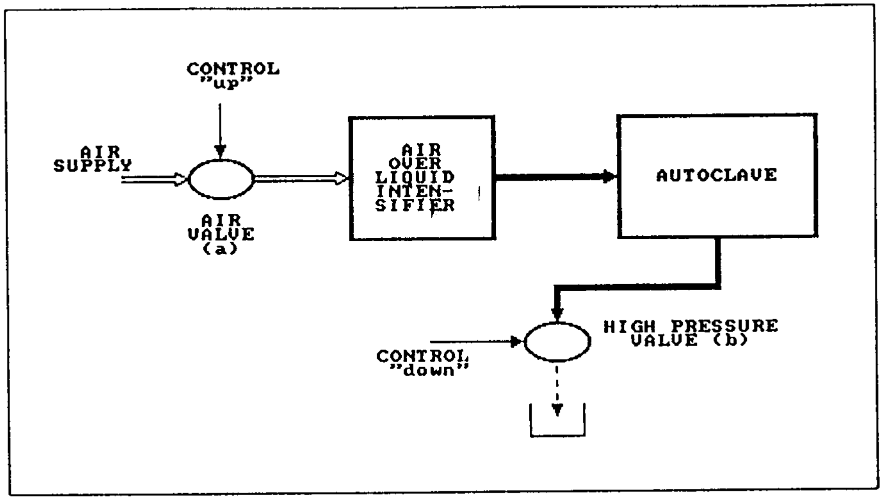

Figure 5 - Typical pressurizing equipment

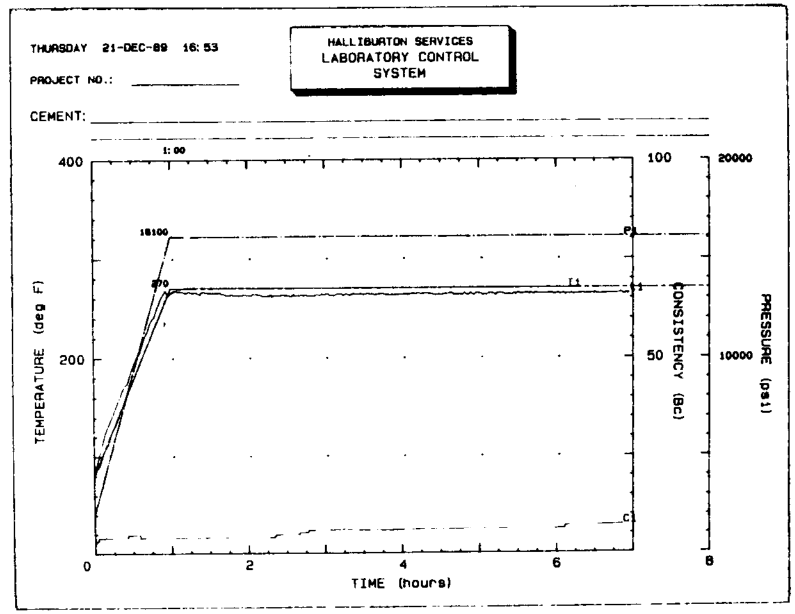

Figure 6 - Sample output plot of the system

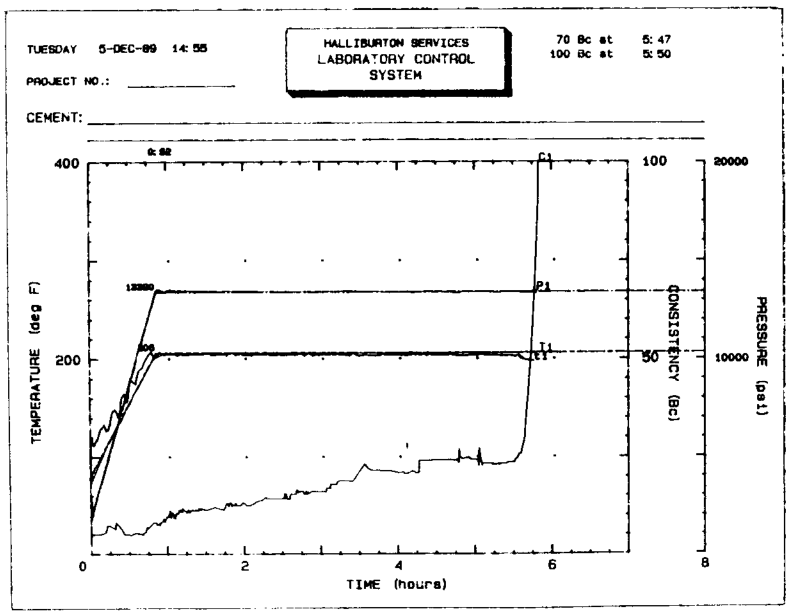

Figure 7 - Plot showing effective temperature control

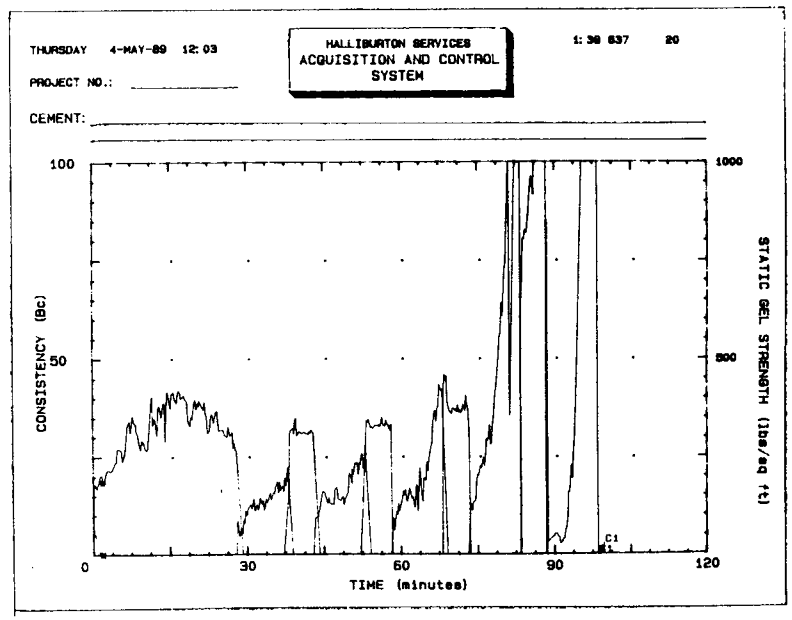

Figure 8 - Plot showing gel strength development
and consistency development simultaneously