CONTROL OF POLYMER ADDITION FOR SLUDGE CONDITIONING: A DEMONSTRATION STUDY

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ABSTRACT

The need for automatic control of sludge conditioning systems resulted in the development of the sludge conditioning controller (SCC). The fundamental concept behind the SCC and the development of the commercial prototype are described in the paper. The final phase of the program involved demonstrating the operation of the SCC at a full-scale dewatering plant. The SCC was installed on a two metre belt press, dewatering anaerobically digested sludge. The evaluation was conducted by comparing the results of historical manual operation with those achieved on the same press under automatic SCC control. Analysis of the data indicated that an average 24% polymer saving could be achieved by the automated system. The paper also describes the practical problems that were encountered during the installation of the control system.

KEYWORDS

Sludge; rheology; conditioning; dewatering; automatic control; instrumentation; costs; demonstration.

INTRODUCTION

Sludge handling and disposal represents a major cost component of any sewage treatment system. Sludge volume reduction or dewatering can be instrumental in reducing this cost. With few exceptions, a dewatering system must be preceded by some form of conditioning in order to flocculate the sludge and enhance the ease with which water may be removed. Chemical conditioning of sludge represents a significant operation and maintenance cost, and directly affects the quality of the sludge cake produced by the dewatering device. It is therefore important, from both cost and performance considerations, to optimize the addition of chemicals for sludge conditioning. A variety of tests including capillary suction time (CST), specific resistance, solids concentration, etc., are available to measure the effectiveness of a particular conditioning option. Unfortunately, none of these test procedures have been adapted to on-line measurement. The result is that, as the characteristics of the incoming sludge change, there is no method of automatically adjusting the flow rate of conditioning chemical to compensate for these changes.

The key to increased control of the conditioning process lies in a better understanding of fundamental intrinsic sludge properties such as rheology. Rheological measurements are sensitive to changes in the physical properties of sludge, and existing equipment can be adapted for on-line measurement of rheological properties. Process research conducted at the Wastewater Technology Centre (WTC) has shown that direct measurement of the rheological properties of sludges can be used to control chemical conditioning. This work has been developed and commercialized in the form of a sludge conditioning controller by Zenon Environmental Inc. The paper discusses the rationale behind the control strategy, describes the commercial controller and presents results from the demonstration study.
BACKGROUND

Rheology can be defined as the study of the properties and behaviour of matter in the fluid state. Most single-phase fluids exhibit Newtonian behaviour in that the rate of viscous flow is proportional to the shear stress. The addition of solid particles to the fluid interferes with the free flow of the dispersion medium to a degree that is dependent on the rate of shear. Sewage sludge behaves in this manner and is referred to as a dispersed system.

The rheology of sewage sludge is further complicated by the fact that most sludges are also thixotropic, meaning they possess an internal structure which breaks down as a function of time and shear rate. A flow curve or rheogram (Figure 1) of a typical sludge, showing the curves produced by a rotating viscometer during the increasing and decreasing rate of shear cycles, indicates that the rheology of the sludge has been altered during the initial (increasing) phase of the test. The displacement of the two curves is referred to as a hysteresis loop and is a measure of the degree of thixotropy exhibited by the sludge.

The relationship between sludge rheology and polymer addition was established during a sludge characterization study at the WTC (Campbell et al., 1978). Figure 2 shows a typical set of rheograms for a polymer conditioned anaerobically digested sludge. As the polymer dosage increased, the shear stress also increased for any given shear rate. At some polymer dose, which was specific to the sludge, a peak appeared in the initial portion of the rheogram. It was observed that the polymer dosage at which this phenomenon occurred, correlated well with the dosage which produced efficient performance during concurrent pilot-scale dewatering trials. These observations formed the basis for selecting rheological properties as a means of automatically controlling polymer addition. This assumes that rheograms describe fundamental sludge properties. As the amount of polymer in a system is increased, the nature of the sludge particles or flocs changes and subsequently the interrelationship between the dispersed particles (sludge flocs) and the fluid also changes. This, in turn, is reflected in changes in the characteristics of the flow curves or rheograms as shown in Figure 2.

The development of the sludge conditioning controller has evolved through a number of stages. The background work conducted by the WTC included a series of bench-scale batch experiments, operation of a pilot-scale continuous flow conditioning system and testing of an experimental control system on a 0.5 m belt filter press. The objectives of these three phases were to determine the sensitivity of rheological measurements to changes in sludge characteristics and to develop and test an algorithm capable of controlling polymer addition. Details of this work are available in the literature (Campbell and Crescuolo, 1982, 1983, 1985). The rationale on which the control algorithm is based is illustrated by the flow diagram in Figure 3. A reference rheogram is developed and stored in the computer memory. During operation a new rheogram is produced and its characteristics compared with those of the one stored in the memory. Based on this comparison, the algorithm determines what action should be taken by the polymer pump. The entire process is then repeated at pre-selected time intervals.

Fig. 1 Typical Rheogram Illustrating Thixotropy

Fig. 2 Rheograms of Polymer Conditioned Sludge
At the conclusion of phase three, it had been demonstrated that the control strategy developed by the WTC was successful and patents were filed by Canadian Patents and Development Ltd. on behalf of the Canadian Government. The main drawback of the initial experimental system was that the viscometer and computer were too sophisticated and expensive for routine use at a treatment plant. While the rationale behind the control strategy had been shown to be valid, the practical application of the technology depended on the development of an instrument which was not only rugged enough for installation at a sludge dewatering site but was also sufficiently inexpensive to be economically attractive. At this point the WTC entered into a co-operative program with Zenon Environmental Inc. Under the "Program for Industry/Laboratory Projects" (PILP), Zenon received financial support to develop a commercial prototype controller based on the WTC research. The development of the controller was carried out by introducing Zenon designed components to the original WTC test facility one at a time. This enabled each element of the system to be tested independently of the other components. Details of the development and testing of the Zenon sludge conditioning controller (SCC) are available in the literature (Campbell et al., 1986).

COMMERCIAL PROTOTYPE

The SCC, shown in Figure 4, consists of two major subsystems: the sampling system and the central control panel. One sampling vessel is required for each independent polymer dosing unit while the central control panel is configured to handle up to four sampling systems.

The sampling system consists of a ten litre tank, the feed and drain pinch valves (5 cm diameter, air operated), three spray rinsing nozzles and the measurement head assembly. The
measurement head includes the rheology sensor and its drive motor (sensor head), a signal conditioning amplifier and a level sensor. A local control station is provided near the vessel which allows for manual operation of the feed, drain and spray solenoid valves.

The sample piping is designed to fill the vessel from the bottom. This minimizes the shear to the conditioned sludge. The pinch valves provide an unobstructed flow path when open and positive shut-off when closed. This arrangement effectively eliminates clogging of the sample piping. The vessel itself is constructed of stainless steel. It has a conical bottom to facilitate rinsing. The three rinse nozzles are arranged around the vessel at the level of the rheology sensor. The fan spray pattern from each nozzle provides excellent cleaning of the probe and sufficient overspray to rinse the level sensor and the vessel walls. The level shut-off sensor operates on the basis of conductivity. The probe itself is a piece of stainless steel rod. The lack of moving parts and simple design make it very resistant to fouling.

The central control panel houses the custom microcomputer and associated hardware. The computer sequences the fill, measurement and drain operations for each sampling vessel. It also receives the raw rheological measurements and calculates the parameters of interest and output control signal for the appropriate polymer pump controller. The operator interface is on the front of the control panel. This includes a series of push buttons to toggle between manual and automatic control modes, increase or decrease the desired setpoints, and check the status of the system and each sampling vessel. System parameters are shown on a two-line LCD display as are any alarm messages.

The system can operate in two modes. The manual mode allows the operator to directly control the polymer dosing pump. In automatic (normal) mode the SCC tracks changes in the dewaterability of the sludge to keep the press operating at optimal conditions. During automatic operation, flocculated sludge is allowed to flow under gravity into the bottom of the sample vessel. The sample is taken from the top of the flocculator or from a header pipe just before the sludge is introduced to the press. In either case, care is required to ensure that the take-off point will provide a representative sample of fully conditioned sludge.

Once the vessel fills, the rheology sensor is rotated in the sludge and its output is transmitted to the central control panel. After the measurement cycle is completed, the sample is allowed to drain out and the vessel is thoroughly rinsed for thirty seconds.

Because sludge characteristics vary with time, it may be necessary to redefine the optimal setpoints occasionally. This can be done in one of two ways. When the 'tune' button is pushed the system uses the next five sample results as representative of optimal operation and chooses setpoints from this data. This is useful when starting up a press or when changing sludges. A setpoint adjustment is also provided which allows the operator to make minor adjustments to the operating setpoints of the press without 'tuning' the press.

The control program incorporates a 'minimum seeking' algorithm. Meeting the requirements is a necessary but not sufficient condition of being at the optimal dose. Thus, even if all of the conditions are met, the polymer dose is decreased by a small preselected increment. At steady state the dose will tend to cycle around the minimum value which meets the setpoint requirements. The computer examines the data from each run to determine possible control actions and also to verify that the sample is acceptable. From the data collected the computer decides if the measurement system is operating properly (i.e., the rheology probe is turning in the sludge or is badly fouled). It also monitors the time to fill the vessel and the initial rate of emptying in order to detect possible plugging conditions. If any of these conditions persist over several samples, the operator is notified of the problem by an alarm.

DEMONSTRATION STUDY

The final phase of the program involved demonstrating the operation of the SCC at a full-scale sludge dewatering facility and determining the actual cost savings. The site selected was the Guelph Water Pollution Control Plant which currently operates two, 2 m Komline Sanderson belt presses on anaerobically digested sludge. Zenon installed an SCC on one of the presses and the WTC monitored the process. Some instrumentation already existed at the plant but additional sensors were also installed. All of the sensors were then connected to a data logging system. The instrumentation package included sludge and polymer flow meters, feed sludge and filter effluent suspended solids probes and an HP data logging system.

The demonstration study was designed such that the SCC could be installed and debugged on one
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press. This press would be operated for a period of time under manual control and the performance monitored by the data logging system. The system would then be operated under automatic control, the performance monitored and compared with the manual operation. Although side-by-side testing of the two presses was an option, it was decided to use only one press for the study in order to eliminate the inherent differences between two different presses.

Based on preliminary data collection carried out prior to the study, the program was designed on the assumptions that the sludge flow rate would range from 7 to 5 l/s, the feed solids concentration would range from 3 to 6% and a minimum polymer saving of 15% would be necessary for the city to justify purchasing the controller.

Immediately following hookup of the sensors, it became obvious that these assumptions were not valid. The sludge feed pump was an open impeller centrifugal type which produced extreme variations in flow rate. A typical plot of flow rate versus time is shown in Figure 5. The periods of zero flow represent time when flow to the press was stopped while the truck collecting the filter cake was emptied. The flow varied from approximately 2 l/s to 5 l/s with occasional fluctuations to 1 or 10 l/s. This results in polymer dosages (Figure 6) ranging generally from 5 to 12 kg/t but sometimes much higher. Initially, attempts were made to compensate for the varying flow by including a flow proportionate component in the algorithm but this was not successful. The problem was finally solved by the installation of a positive displacement sludge feed pump.

![Fig. 5 Variable Feed Sludge Flow Rate](image)

![Fig. 6 Polymer Dosage Under Variable Sludge Flow Conditions](image)

The second assumption regarding feed solids concentration was also proven to be false. Figure 7 shows a probability distribution of the feed solids concentration. The median concentration was 2.5%, but 20% of the time the concentration was less than 2%. At extremely low solids levels (i.e., less than 2%), the algorithm could not distinguish between low solids and insufficient polymer addition. Rather than simply specify a minimum operating range of 2% and sound an alarm for the operator when the solids concentration fell below that value, it was decided to increase the sensitivity of the controller down to a solids concentration of approximately 1%. This was accomplished by adding a second sampling port to the system for unconditioned sludge. By conducting rheological measurements on the unconditioned sludge it was possible to determine a relative solids concentration for the sample. This value was then used as a correction factor in the calculations following the measurement of the conditioned sludge. The final operating sequence was modified so that measurements were alternated between unconditioned and conditioned sludges.

With the modifications to the sludge pump and SCC in place, the system operated as expected. Figure 8 shows a test day where the solids concentration ranged from approximately 1.2% to 4%. The sludge feed rate throughout the day was relatively constant at about 6 l/s. In Figure 9, the response of the SCC is presented. As the solids concentration increased, the polymer flow rate increased; when the solids concentration decreased, the polymer flow rate also decreased accordingly. Data from other test days where the solids concentration remained constant, showed that the algorithm was continually searching for a lower polymer flow rate which would satisfy the setpoints. At the completion of the test program the data was
analyzed by performing an analysis of variance on the results from the manual and automatic operation periods. Without any adjustment of the data, the degree of scatter was such that there was no statistically significant difference between the two periods. Examination of the complete data set indicated that as the solids concentration decreased, the optimum polymer dosage (kg/t) increased, and that the phenomenon was most pronounced at levels less than 2%. This is shown clearly in Figure 10. The data set from the automatic control phase contained a significantly higher number of days with solids levels less than 2% than did the data set from the manual operation and thus skewed the polymer dosage for the automatic data set towards higher values. In order to compensate for this, data at less than 2% solids were deleted from both sets and the analysis repeated. Under these conditions the automatic operation showed a polymer saving of 12.5% over the manual operation.

![Fig. 7. Probability Distribution of Feed Solids Concentration](image)

![Fig. 8. Feed Solids Concentration Versus Time](image)

![Fig. 9. Response of SCC to Variable Solids Concentration](image)

However, because it was still believed that the results had been more positive than the above analysis indicated, the entire program was re-evaluated. It had been originally expected that the manual operation period could be directly compared with the automatic period. On closer examination this proved not to be the case. The program had actually consisted of three distinct phases. The first phase was before the constant flow pump had been installed. During this period, control of the polymer flow rate had been minimal. Essentially, the polymer flow rate was set at the beginning of the day and unless some major visible decrease in the performance of the press was noted, the flow rate was not changed throughout the day. Figure 11 shows the polymer flow rate for a typical historical operating day. In the second
phase, "manual" operation, the polymer flow rate was adjusted by the operator based on the information that was available to him from the instrumentation, i.e., computer readouts including polymer flow rate, polymer dosage, etc. In the third phase the polymer flow rate was controlled by the SCC. Figure 12 shows probability plots of polymer flow rates on an hourly basis. Comparison of phase 2 (manual with instrumentation) and phase 3 (automatic) show that both phases have approximately the same distribution of polymer flow rates based on hourly averages. The distribution for phase 1 (manual without instrumentation) is distinctly different. Instead of being relatively evenly distributed over a wide range of flow rates, approximately 93% of the data falls in the range of 36 to 48 l/min. This compares to a range of 21 to 48 l/min for the second phase and 24 to 57 l/min for the third phase. Thus, the second phase (manual) does not represent the typical manual mode of operation but rather manual operation utilizing a high degree of instrumentation. In order to evaluate the benefits that could be derived from the SCC it was necessary to compare phase 1 with phase 3. Although the first phase with variable sludge feed rate should not be considered as acceptable practice in terms of polymer dosage, it does represent actual current practice in controlling polymer flow rate.

The method used was to take typical automatic control days and compare the observed polymer flow rate with what would have occurred historically. The median value from Figure 12 (i.e., 40 l/min), was selected to represent the historical polymer flow rate. Figures 13, 14 and 15 illustrate three typical automatic control days. In each case the actual polymer flow rate is shown along with what is assumed to be historical practice i.e., setting the polymer at 40 l/min and leaving it unchanged throughout the day. The area under the two curves was integrated, and the difference between the two areas was assumed to represent the savings due to automatic control. For the test day shown in Figure 13, the sludge solids were relatively consistent at approximately 3% with occasional fluctuations to 2.5% and 4%. The polymer flow rate under automatic control generally fluctuated around the 40 l/min chosen for manual operation, but did have some larger fluctuations which corresponded to changes in the solids concentration. The net effect was that the polymer savings were only marginal at 3.4%. In Figure 14, the solids concentration was very consistent throughout the day at about 2%. The automatic control fluctuated around the optimum dosage, always seeking to find a lower level which would satisfy the setpoints. The polymer savings on this day were 15.9%. For the test day shown in Figure 15, the solids concentration was extremely erratic throughout the day and ranged from 1.4% to 5%. It is this type of situation which best demonstrates the potential of the controller. The controller varied the flow rate from 18 to 40 l/min in response to the changing solids levels. In this case the controller showed a polymer saving of 28.7%.

In order to calculate the average polymer saving due to automatic control, the volume of polymer used for all of the automatic control days after the modifications to the SCC were complete, was determined from the data. The total volume of polymer that would have been used if the pump had been set at the median flow rate of 40 l/min for this entire time was also calculated. Under these conditions the polymer saving was calculated to be 24%. This result, combined with examination of the data, clearly shows that there is a distinct difference between the traditional manual and automatic modes of operation and that significant polymer savings can be achieved.
A number of other aspects were also investigated during the study. Suspended solids in the filter effluent, which was a combination of the filtrate and the belt wash water, was monitored continuously with a solids probe. The results were generally about 0.1% but ranged occasionally from 0.05 to 0.2%. No differences between operating modes were identified but the results of the probe were suspect. During periods of obvious underdosing under manual control, sludge squeezed out from the edges of the belts and fell into the drain area. After mixing with the washwater and filtrate, these solids appeared as extremely large, well flocculated aggregates and there was, based on visual observation, an increase in the solids loss from the system. Examination of the data from the probe never showed any corresponding increase in solids concentration. It is believed that the location of the probe was such that the very large solids resulting from overdosing were not sucked into the probe to be measured. The question of the impact of the controller on solids recovery remains unanswered.

Cake solids from the belt discharge were sampled by hand and measured on a regular basis. The results were similar to those for the filtrate solids in that no difference between operating modes was identified. The cake solids were relatively low at 17 to 19% and it was felt that with automated control of the polymer dosage, the operation of the belt press could be optimized to improve the cake dryness. This activity was outside the scope of the demonstration program.

A number of improvements to the sludge conditioning controller were implemented during the study. A second sampling port was added to increase the sensitivity of the instrument to low
solids concentrations. The spray pattern was also modified to improve the washing of the sensor and the inside of the sampling vessel.

**SUMMARY**

The sludge conditioning controller can operate without plugging or fouling over an extended period of time. During the entire study, a period of almost seven months, the sensor and sampling vessel were only cleaned manually two times.

Operation of the SCC results in a polymer flow rate versus time relationship which is distinctly different to that observed during manual operation without extensive instrumentation and data logging capabilities.

The average potential polymer savings with the SCC at the Guelph plant is estimated to be 24%, as compared to historical data.

Similar polymer savings can theoretically be achieved by a skilled operator who has a highly instrumented system complete with a data logger. The disadvantage with this approach is that the majority of the operators time will be spent making adjustments to the system, and the cost of an instrumentation package comparable to that used in Guelph is considerably more than the cost of an SCC.

Although confirming data from the study is not available, visual observation of the press throughout the study indicated that solids recovery was improved during periods when the SCC was operational.

Zenon Environmental Inc. are actively marketing the SCC under licence to Canadian Patents and Development Limited.

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