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Project Summary

Automation of Sludge Processing: Conditioning, Dewatering, and Incineration

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This study developed and tested automated control strategies for municipal wastewater sludge processing. The strategies were applied to three unit processes—chemical conditioning with lime and ferric chloride, vacuum filtration, and incineration. The project was conducted at the St. Paul, Minnesota, Metropolitan Waste Control Commission (MWCC) Seneca facility, a 24-mgd plant with parallel sludge processing trains.

Several strategies were developed for controlling lime and ferric chloride addition and filter cake production rate. Each strategy was evaluated during approximately 500 hr of operation.

Automated strategies were also developed for controlling incinerator hearth temperatures and air input. The strategies were designed to maintain the lowest possible furnace burning zone and to minimize excess air. The test data show a moderate cost reduction for automated control.

On-line sensors were used to collect data and implement control strategies. Performance data for these sensors are summarized, and the digital data acquisition and control system is described.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully described in a separate report of the same title (see Project Report ordering information at back).

Introduction

The costs for solids handling and disposal at a conventional secondary treatment facility are usually 30% to 50% of the operating and maintenance (O & M) budget. The solids handling processes at a St. Paul, Minnesota, Metropolitan Waste Control Commission (MWCC) treatment facility were studied to determine the impact of improved process control on these costs. The primary goal was to process the greatest volume of sludge possible at the least cost. Process control can be accomplished by manual or automated means, but the complexity and interaction of sludge dewatering and incineration processes limit manual control to simplistic schemes. In addition, the variable nature of the raw sludge requires considerable control flexibility. Thus automatic digital control techniques were used.

Study Objectives

The overall study objective was to model and eventually control the three unit processes for sludge treatment—conditioning, dewatering, and incineration—to achieve near-optimum performance for a particular operating goal. This goal will change throughout the year and may vary from maximizing the volume of liquid sludge processed to maintaining specified limits for particulates in the stack discharge. The original reasoning was that if adequate models could be generated, it would be relatively easy to prepare an algorithm to minimize the total cost for any given operating scheme. Though the overall project objective was not met, the project demonstrated that considerable cost savings could be generated by using automated process control schemes even when they are less than optimum.

Facility Operations

All of the work described was conducted at the Seneca Wastewater Treatment Plant on the Minnesota River in Eagan, Minnesota. This facility has a design capacity of 90,840 m^3/day (24 mgd).

Approximately 10% of the influent flow is from industrial sources. The treatment scheme consists of screening, grit removal, primary sedimentation, complete-mix activated sludge, final sedimentation, and chlorination.

The solids processing operations include floatation thickening of waste-activated sludge, vacuum filtration, and incineration. Ferric chloride and lime are used to condition the sludge before dewatering. All of the primary and waste-activated sludges generated at Seneca are processed along with sludges hauled from other MWCC facilities. During 1980, the plant processed approximately 215,745 m^3 (57 million gallons) of liquid sludge, of which approximately 93,490 m^3 (24.7 million gallons) were hauled to the plant.

Because of the variable nature of the raw sludge, the conditioning and filtration processes are extremely difficult to operate at a steady output rate with a cake of uniform burning characteristics. The measured daily variation was 14% to 25.5% for cake solids and 53% to 68% for volatile solids. Filter yield varied by a factor of three.

Because of the lack of cake storage capacity at Seneca, the incinerator must burn the cake as produced, maintain hearth temperatures below 1100°C (2000°F) to protect the furnace structure, and meet air pollution standards. These goals are difficult to achieve given the variable nature of the filter output.

The total operating cost for sludge dewatering and incineration at Seneca, including chemicals, energy, and labor, was $166/metric ton ($151/ton) or approximately 47% of the total plant operating budget for 1981.

Chemical Conditioning Control

To control chemical conditioning, it is necessary to know the impact of chemical addition on the dewatering characteristics of sludge. The two most common methods of estimating sludge dewaterability are capillary suction time (CST) and specific resistance (SR).

Ideally, an on-line measurement would produce a signal that could be used to vary the chemical dose and maintain the desired dewatering characteristics. Unfortunately, neither CST nor SR is directly measurable on-line. However, a correlation was sought between CST or SR and other parameters (Table 1) that could be measured on-line.

Rheological data were analyzed and yielded a relationship between sludge SR (after conditioning with ferric chloride and lime) and several other sludge parameters. This analysis indicated the feasibility of using on-line data to measure SR and CST.

Because the conditioning process at Seneca uses both ferric chloride and lime, two control systems and hence two models were required. Since others have demonstrated that SR adequately describes sludge dewatering characteristics for vacuum filtration, this parameter was selected for study. Initial attempts at determining the SR of ferric-conditioned sludge yielded extremely long filtration times, and in most cases, no cake was formed. Since the laboratory data demonstrated a strong relationship between the SR of lime-conditioned sludge (SRL) and the CST of lime-conditioned sludge (CSTL), the CST of the ferric-conditioned sludge (CSTF) was used to characterize ferric conditioning.

The CST model was constructed with a total of 124 data sets collected over a 7-month period. A number of relationships were developed to gauge the potential for success and the need for additional data. Multiple linear regression analysis techniques were used to analyze the data.

The modeling efforts resulted in the following equations for predicting the CST of ferric-conditioned sludge ($R = 0.82$).

$$\begin{aligned} CST2 = 66 - 0.104\,(ORPD) \\ - 1.8\,(PF) + 6.0\,(SSR) \\ + 0.05\,(ORPF) - 3.5\,(PHD) \end{aligned} \quad (1)$$

The addition of the last two variables did little to improve the goodness of fit. Thus for model CST2, 67% of the variability in the actual CST is explained by the independent variables. The unexplained variability may be related to the measurement precision of the field monitors or to one or more of the important (but unknown) parameters that were not monitored.

Three control schemes were considered for $FeCl_3$ addition: pH (PHD) control, CST control, and sludge mass ratio control. Tests demonstrated that both the pH and the ORP sensors responded to a change in $FeCl_3$ dose, but that no universal setpoint would maintain constant dewatering characteristics. Thus the feedback approach required additional parameters to make the strategy responsive to sludge conditioning needs.

Previous experience had demonstrated that the $FeCl_3$ dose required for good vacuum filtration increased as the raw sludge solids decreased. To reflect this physical characteristic, the control scheme was modified to calculate and maintain PHD based on the raw sludge solids concentration.

$$\text{PHD setpoint} = K_2 + K_1\,(SSR) \quad (2)$$

and

$$\text{PHF setpoint} = PHR - \text{PHD setpoint} \quad (3)$$

Test results demonstated that this strategy could control PHF. However, the ability to maintain PHF at the setpoint did not insure proper conditioning, as over- and under-dosing resulted when raw sludge characteristics other than SSR changed. Proper conditioning required manual entry of new values for K_1 and K_2. The control system was thus reduced to a semi-automated scheme requiring periodic judgments by the operators.

CST uses a cascade control to adjust the ferric pump. The inner loop controls the pH of ferric-conditioned sludge by adjusting pump speed. The pH setpoint is generated by a CST controller.

The model receives inputs from process sensors and predicts a CST value. If the prediction differs from the desired value, a new pH setpoint value is calculated. To avoid coupling problems, the CST control model is recalculated infrequently, thereby appearing constant to the pH controller.

Evaluation of the on-line CST control proved a constant CST setpoint to be unworkable, as the $FeCl_3$ pump ramped to maximum or minimum speed if the desired CST value was not attained. Thus a variable CST setpoint was initiated based on raw sludge solids.

$$\text{CST setpoint} = K_3\,(SSR) - K_4 \quad (4)$$

The variable CST setpoint provided a degree of flexibility in the control strategy, but the constants K_3 and K_4 required adjustment during control runs because of changes in sludge properties not totally reflected in solids con-

Table 1. *Sludge Modeling Parameters*

Symbol	*Definition*
SSR	*Suspended solids concentration in raw sludge, % solids*
PHR	*pH of raw sludge*
PHF	*pH of ferric-chloride-conditioned sludge*
PHL	*pH of lime-conditioned sludge*
PHD	*Differential pH*
ORP	*Oxidation—reduction potential*
ORPR	*ORP of raw sludge, mv*
ORPF	*ORP of ferric-chloride-conditioned sludge, mv*
ORPL	*ORP of lime-conditioned sludge, mv*
12	*Shear stress of lime-conditioned sludge, 12 rpm, dyne/cm^2.*
30	*Shear stress of lime-conditioned sludge, 30 rpm, dyne/cm^2.*
60	*Shear stress of lime-conditioned sludge, 60 rpm, dyne/cm^2.*
CST	*Capillary suction time*
CSTR	*CST of raw sludge, sec*
CSTF	*CST of ferric-chloride-conditioned sludge, sec*
CSTL	*CST of lime-conditioned sludge, sec*
SRL	*Specific resistance of lime-conditioned sludge × 10^{-11} m/kg*
SSL	*Suspended solids concentration in lime-conditioned sludge, % solids*
TL	*Temperature of lime-conditioned sludge, °C*
PF	*Ferric chloride feed, % by weight of dry sludge solids*
PL	*Lime feed, % by weight of dry sludge solids*
VAC	*Vacuum in form zone, in. Hg*
VAT	*Submergence of filter drum, in.*
DRUM	*Rotational speed of filter drum, rph*
TPH	*Wet cake production rate, ton/hr*
SSF	*Total solids concentration in cake, % solids*
FLOW	*Raw sludge flow, gpm*
CLOTH	*Operating hours since media acid cleaned, hr*
SR3	*Specific resistance of conditioned sludge calculated from the yield equation, m/kg*

tent. Though the predicted CST closely followed the CST setpoint value, significant deviations between the setpoint pH and the measured pH remained.

These problems were related to the fouling of the pH electrodes and changes in the sludge characteristics. Although short-term control was achieved using the model, a suitable setpoint for all sludges was not developed. Eventually, dose limits of 7% to 13% $FeCl_3$ were implemented to eliminate severe excursions.

The $FeCl_3$ dose ratio control strategy is defined as follows:

$$\text{Ferric chloride mass flow} = K_5\,(\text{sludge mass flow}) + K_6\,(\text{SSR-4}) \quad (5)$$

This control strategy uses a selected ferric chloride dose (K_5) and reflects changing sludge characteristics through K_6. The advantages of the dose ratio strategy are that sensor maintenance is eliminated and a given $FeCl_3$ dose is maintained. Disadvantages are that there is no feedback adjustment, that the accuracy of the sludge solids analyzer is critical, and that a steady-day tank ferric chloride concentration is required.

A number of control schemes for lime addition were considered during the course of the project, but the filter yield dropped off dramatically when the pH of the lime-conditioned sludge decreased much below 12.0. Thus the only strategy used for the test runs was control of pH to 12.0 or above. Although this strategy did not address the initial intent of controlling the SR of the conditioned sludge, it had two major advantages: It was simple and it worked.

Vacuum Filter Control

Control Strategies

Initial filter control strategies were designed to reduce the variation in cake yield and maximize the production rate by stabilizing and controlling filter operating parameters.

Analyses of vat level adjustments on filter operation indicated that low vat levels and higher drum speeds improved cake quality because of the lower moisture content. However, to reduce the risk of vacuum loss and promote efficient cake release, most operators maintained the vat at high levels.

Under manual control, the vat level varies in response to any change in the filtration rate. For any reasonable combination of parameters, the vat level reaches an equilibrium value between the lower limit and the vat overflow. Any change in dewatering characteristics destroys this equilibrium, and the vat level changes to a new point.

A cascade algorithm is used to control the vat level. The internal loop consists of a flow controller that adjusts the sludge pump motor speed. The external loop provides the flow setpoint.

Only two variables that influence the cake production rate are adjustable: vat level and filter speed. Form zone vacuum is usually maintained at the highest value possible.

When automated control of the vat level and drum speed was initiated, the vat level setpoint was a function of the cake thickness.

$$\text{Vat level setpoint} = K_7 - K_8 \times (\text{thickness in inches}/100) \quad (6)$$

Because attempts at thickness measurement were not successful, the cake thickness was calculated from the production rate, drum speed, and cloth area.

By judicious choice of the constants K_7 and K_8, reasonable setpoint values for a wide range of sludge characteristics can be established. The control action also reduces the chance of filter upsets by increasing the level setpoint when lower cake production rates (thin cakes) occur because of low sludge solids or filter media blinding.

Drum speed control used a cake production setpoint adjusted as a function of raw sludge solids concentration:

$$\text{Cake production setpoint} = K_9 + K_{10}\,(\text{SSR}) \quad (7)$$

A filter recovery mode was added, which decreased the drum speed to a fixed value whenever cake production fell below a predetermined value, and an upper limit was placed on the drum speed to prevent filter failure as a result of cake discharge problems. The upper limit also facilitated the use of a constant cake production setpoint without frequent upsets.

Evaluation of Automated Vacuum Filter Control

Approximately 2800 hourly average data sets were generated for automated and manual filter control. These data sets fell into three main categories: Data from filter No. 1 under computer control, data from filter No. 1 under manual control, and data from filter No. 2 under manual control.

Performance data for the three modes show that filter No. 1 under computer control processed more sludge with lower chemical doses. If it is assumed that the average raw sludge solids did not vary for the three categories, then the computer control mode also produced a drier cake.

Although the wet cake yield was essentially constant, the variability of chemical feed was considerably greater in the manual modes, especially for lime. These data show that control of the lime dose was the major advantage of the computer control mode.

In incineration operation, the ratio of water to volatiles is important to fuel consumption and steady hearth temperatures. Although all attempts to estimate cake moisture by direct and indirect methods were unsuccessful, this ratio varied more with manual operations and was directly related to the chemical feed rates. Control of the chemical feed systems would provide a reasonably conditioned sludge without large excursions in cake moisture and volatile content. Table 2 summarizes the average filter performance by mode.

Incinerator Control

Control Strategies

Since the input to the incinerator can vary, even with automated control of the dewatering train, some control action is necessary to maintain steady incinerator operation. The primary objective for instituting new incinerator controls was to minimize the use of auxiliary fuel while burning all cake produced and meeting stack discharge standards.

A series of tests was conducted to determine whether the Seneca incinerators could be operated at rates near capacity and still meet the stack discharge standard. The final control strategy was based on these tests.

This strategy used the calculated incinerator load as a feedforward signal. This signal was delayed for each burning hearth to account for process deadtime. The temperatures on the controlled hearths (Nos. 3, 5, and 6) were used as feedback signals to temperature controllers. Fuel flow was in turn regulated by the air flow rate. The temperature controllers received their setpoints from a temperature adjustment supervisory program. The output from the temperature controller was combined with the delayed loading signal at adjustable ratios to throttle air valve positions. A burner sequence program could start or stop the burners individually if necessary. The temperature control program also prevented imbalances between hearths.

Furnace pressure was controlled using three signals—furnace load, furnace draft, and atmospheric air damper position—to calculate the position of the induced-draft fan damper.

The air for drying, burning, and cooling was provided through an atmospheric air damper on hearth No. 7 and the return of the center shaft cooling air.

The atmospheric air damper was adjusted to maintain a fixed oxygen level in the stack gas, and the incinerator load was used as a feedforward trim. Hearth temperatures are used as a second trim to detect conditions such as too much cooling air entering the incinerator.

In addition to the on-line sensors, visual observations are also required. For example, dark smoke indicates insufficient combustion air. Cake volatile solids data are manually entered.

Table 2. *Average Filter Performance by Mode—Complete Sets*

Parameter	*Filter No. 1 Computer*	*Filter No. 1 Manual*	*Filter No. 2 Manual*
Sludge feed, L/s (gpm)	*5.6 (89)*	*5.7 (90)*	*4.5 (71)*
Cake yield, mt/hr (ton/hr)	*4.8 (5.3)*	*5.2 (5.7)*	*4.4 (4.8)*
Cake solids, %	*20.5*	*20.8*	*20.3*
Volatile solids, %	*56*	*48*	*50*
$FeCl_3$, % of sludge solids	*11.2*	*11.5*	*12.9*
CaO, % of sludge solids	*18.3*	*24.3*	*26.0*
pH of ferric cond. sludge	*4.9*	*4.8*	-
pH of lime cond. sludge	*12.0*	*12.1*	-
lb H_2O/lb volatile	*6.9*	*8.0*	*8.1*
Vat level, cm (in.)	*43 (17.1)*	*53 (21)*	*37 (14.8)*
Drum speed, rph	*15.3*	*15.3*	*13.3*

Tests were conducted to characterize the dynamic response of the process to variations in temperature and gas flow. The tests demonstrated that three distinct zones should be maintained to maximize fuel efficiency: cake drying on hearth Nos. 1, 2, and 3, complete combustion on hearth Nos. 4 and 5, and ash cooling on hearth Nos. 6 and 7. The tests further determined that the above zones could be maintained by operating as follows:

Furnace draft	0.4 cm (0.15) H_2O
Shaft cooling air	100% return to hearth No. 7
Ambient air	0-20% open as required
Hearth 6 burner ..	Off
Hearth 5 burner ..	100% capacity
Hearth 3 burner ..	Control to 650°C (1200°F)

By eliminating burning on the upper hearths, the thermal efficiency was increased, and overall thermal efficiencies of approximately 4420 kJ/kg (1900 BTU/lb) water evaporated could be obtained. Typical values fell in the range of 4200 to 5800 kJ/kg (1800 to 2500 BTU/lb).

The control strategy was organized into two areas—temperature and gas flow. The recommended temperature profile appears in Table 3. As previously demonstrated, these temperatures could be maintained without firing hearth No. 6, only the burners on hearth Nos. 3 and 5 were used regularly.

Gas flow through the furnace was divided into draft and oxygen control. The draft setpoint was manually entered, and the controller adjusted the position of the induced-draft fan damper.

Gas flow through the furnace was controlled to maintain a manually entered value for flue gas oxygen concentration. Tests indicated that all shaft cooling air should be returned to the furnace before opening the atmospheric air damper. This goal was accomplished by using two independent controllers. Subsequent tests demonstrated that sufficient oxygen was usually obtained without opening the atmospheric air damper.

Evaluation of Automated Solids Processing

Tests were conducted to operate process train No. 1 by computer and process train No. 2 by hand. In one such test, the initial setpoints for process train No. 1 were as follows:

Parameter	Setpoint
Wet cake yield	5.4 mt/hr (6TPH)
$FeCl_3$ dose	11% of dry sludge solids
pH of lime-conditioned sludge	12.0
Incinerator draft	5 mm (0.2 in.) H_2O
Flue gas O_2	7.4%
Hearth 2 temperature	565°C (1050°F)
Hearth 4 temperature	980°C (1800°F)

The performance data for the two dewatering trains during the 11-hr test No. 2 are summarized in Table 4. As in other tests, the vacuum system limited the performance of both trains. During the ninth hour of the test, both filters lost vacuum, were shut down, and were restarted manually.

Filter No. 1 produced a cake with a higher volatile solids content, primarily because of the reduced lime dose. The $FeCl_3$ dose in train No. 2 was lower than normal because the actual discharge capacity of the chemical feed pump was only 45% of its nominal capacity.

The fuel efficiencies of the two process trains are summarized in Table 5. The total energy used per mass of water fed was significantly lower than normal for both trains, but because of the higher volatile content, furnace No. 1 was more efficient.

The improvement in the efficiency of furnace No. 1 can be attributed to setting an upper temperature limit for hearth No. 4. Initially this limit was 980°C (1800°F), and it was changed to 950°C (1750°F) at 1610 hr.

The results show that automated control of solids processing can yield economic savings. For Seneca, the annual savings are estimated to be $50,000 for chemicals and $48,000 to $127,000 for energy, depending on whether natural gas or oil is used.

Recommendations

Control Strategy for Sludge Conditioning

Changes in the raw sludge characteristics have a dramatic impact on the performance of a vacuum filter and, subsequently, the incinerator. Thus operators tend to include a significant factor of safety when selecting dose rates for chemical conditioning. This project demonstrated the need for an on-line method of identifying the dewatering characteristics of chemically conditioned sludge. However, since such a method is not presently available, the recommended control strategy is outlined as follows:

1. $FeCl_3$—Maintain a constant dose of 6% to 12% of dry solids. The specific dose is a function of the raw sludge variability and the operator time available to monitor filter operation.
2. Lime—Maintain a constant pH of 12 for Seneca after lime addition.

The above strategies require only three field sensors—raw sludge flow, raw sludge solids, and lime-conditioned sludge pH.

Control Strategy for Sludge Dewatering

The operating strategy is based on the assumption that the dry yield of sludge processing must be maximized. Because an on-line cake moisture analyzer was not found, the recommended strategy is based on maximizing the wet cake yield without exceeding the incinerator capacity. After selecting the wet cake yield setpoint the recommended strategy is as follows:

1. Yield—Adjust the drum speed to obtain the yield; however, to maintain a reasonable cake thickness, apply an upper limit of 18 rph. When the yield is below setpoint, the drum speed will increase to increase yield. As the drum speed increases, the cake thickness will decrease. To eliminate problems with a thin cake, the following equation is used to calculate a new vat level setpoint:

   $$\text{Vat level setpoint} = K_7 - K_8 \times (\text{thickness})$$

   Increased vat level will increase cake thickness.
2. Vat Level—The vat level is maintained by varying the raw sludge flow rate, which in turn causes the feed rate of $FeCl_3$ to vary.

To implement this strategy, the operator must enter the setpoint value for yield along with the constants K_9 and K_{10}.

Once the conditioning strategy is adopted, the dewatering strategy requires only three additional sensors—a belt scale to determine cake yield, a level detector to measure vat level, and a tachometer to determine drum speed.

Incinerator Control Strategy

The recommended incinerator control strategy is divided into the following two areas:

1. Temperature—Only the burners on hearth Nos. 3 and 5 are used in this strategy. Hearth No. 3 burners are operated to maintain a temperature of approximately 540°C (1000°F) on hearth No. 2, and the burners on hearth No. 5 are controlled to maintain a temperature of approximately 950°C (1750°F) on hearth No. 4. For the typical loading rates observed at Seneca, these setpoints make hearth No. 4 the main burning hearth.
2. Air Flow—The air flow strategy consists of maintaining the furnace pressure in the range of −0.38 to −0.51 cm (−0.15 to −.20 in.) H_2O. For cake loadings below approximately 4.1 wet mt/hr (4.5 wet ton/hr), the lower (absolute value) setpoint is sufficient. A lower limit of approximately 20% open should be established for the induced-draft damper. This limit will prevent problems associated with low draft values. The atmospheric air damper should remain closed, and all air not entering at the burners or through uncontrollable leaks should be provided as recycled shaft cooling air. The flow of recycled cooling air should be controlled to maintain the desired O_2 concentration on hearth No. 1. The O_2 setpoint should be determined from visual observation on hearth Nos. 1 through 4. Sufficient O_2 should be provided to minimize smoke generation.

During the test, it appeared that air may have entered through the sludge feed drop gate at the top of the incinerator. For this reason, the O_2 concentration should be determined on hearth No. 1 as opposed to the downstream location used during the tests. Also, a continuous measurement of opacity should be used to provide feedback for adjusting the oxygen setpoint or the filter yield or both.

The incinerator control strategy uses the standard temperature and pressure sensors found on most furnaces. In addition to these instruments, an oxygen analyzer is required on hearth No. 1.

Summary and Conclusions

The study demonstrated that automation of the sludge treatment facilities at the Seneca plant would yield annual savings on the order of $100,000 based on 1981 costs for conditioning chemicals and fuel. This estimate is based on implementation of the following control strategies:

1. Control of the chemical conditioning process consists of maintaining an $FeCl_3$ dose in the range of 6% to 12% (based on dry sludge solids) and adding sufficient lime to maintain a pH of 12.0.
2. The vacuum filter yield (wet weight/time) is controlled by adjusting the drum speed. Vat level is adjusted to maintain a cake thick enough to discharge properly. Level is maintained by varying raw sludge flow rate, which in turn varies the chemical feed rates.
3. The hearth temperatures are approximately 540°C (1000°F) on No. 2 and 950°C (1750°F) on No. 4. Temperature is controlled by manipulating the burners on hearth Nos. 3 and 5, respectively. Furnace pressure is maintained at −0.38 to −0.51 cm (−0.15 to −0.20 in.) by manipulating the induced-draft fan damper. The flow of recycled cooling air is controlled to maintain a setpoint oxygen concentration in hearth No. 1. Additional air is generally not required.

The following is a summary of the performance of the sensors used during this study:

Table 3. *Recommended Temperature Profile for Controlled Incineration*

Hearth No.	*Temperature, °C (°F)* Minimum	Average	Maximum
1	400 (750)	430 (800)	450 (850)
2	450 (850)	480 (900)	540 (1000)
3	650 (1200)	700 (1300)	760 (1400)
4	760 (1400)	870 (1600)	980 (1800)
5	590 (1100)	650 (1200)	700 (1300)
6	200 (400)	260 (500)	310 (600)
7	80 (180)	90 (200)	90 (200)

Table 4. *Dewatering Performance During Test No. 2*

Parameter	*Process Train No. 1 (Computer)*	*Process Train No. 2 (Manual)*
Hours	11	11
Sludge flow, L/s (gpm)	4.4 (70)	4.2 (66)
Raw sludge solids, %	4.1	4.1
$FeCl_3$, %	11	8.5
CaO, %	18	25
Yield, wet mt/hr (TPH)	4.7	4.4 (4.9)
Cake solids, %	20.5	21.2
Cake volatile solids, %	53.8	44.1

Table 5. *Incinerator Performance During Test No. 2*

Parameter	*Process Train No. 1 (Computer)*	*Process Train No. 2 (Manual)*
Hours	11	11
Gas use, sm^3/hr (SCFH)	184 (6,500)	218 (7,700)
Gas use, sm^3/wet mt (SCF/wet ton)	39 (1,250)	50 (1,600)
Gas use, sm^3/dry mt (SCF/dry ton)	184 (5,900)	240 (7,700)
Total energy, kJ/kg H_2O (BTU/lb H_2O)	4,885 (2,100)	4,885 (2,100)
Gas, kJ/kg H_2O (BTU/lb H_2O)	1,860 (800)	2,325 (1,000)

Acceptable		Questionable	Unacceptable
Vat level	pH	ORP	Viscosity
Temperature	Solids	Oxygen	Cake thickness
Rotational speed	Vacuum	Turbidity	Cake moisture
Rotational position	Cake weight		Tank level
Sludge flow			

Several studies were conducted at Seneca to determine whether commercially available sensors could provide a continuous measure of cake moisture. All those tested were unacceptable, as they failed to provide reliable estimates of cake moisture.

Even acceptable sensors require significant maintenance. The extreme is the conditioned sludge pH sensor, which required cleaning at least once per shift. Although the maintenance required for the other sensors was lower, both the raw sludge solids sensor and the belt scale require frequent calibration to assure success of the control system.

Control of sludge-handling processes should be designed to allow operator-entered setpoints to maintain operation without going to complete manual operation.

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The complete report, entitled "Automation of Sludge Processing: Conditioning, Dewatering, and Incineration," (Order No. PB 86-138 963/AS; Cost: $22.95, subject to change) will be available only from:
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