Real Time BOD Monitoring for Wastewater Process Control

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Abstract: This is a preliminary investigation of a method for the timely monitoring of wastewater biochemical oxygen demand (BOD). Many ecological and economic pressures support the use of BOD measurement methods fast enough to prevent process upsets. Since the standard laboratory procedure takes five days, and previously used fast tests are unsatisfactory for various reasons, tests were made on the Nissin Electric BOD-2000 instrument, which uses a yeast-based biosensor to measure soluble BOD in 30 min. It has been used successfully in the pharmaceutical and food industries. An initial attempt was made to place the instrument in field service. This attempt was unsuccessful, so the present study concentrated on comparing its operation in the laboratory with the results of the standard five-day BOD test (BOD_5) procedure. The two types of tests were compared for samples from Terminal Island Treatment Plant (TITP), Bureau of Sanitation of the city of Los Angeles, using various combinations of filter porosities and wastewater sources in an attempt to establish a measurement routine that would not suffer from clogging problems that plagued the field test. Under these conditions the results from the instrument are excellent, and we briefly discuss further work needed to bring it into field use. This test is believed to be the first effort to assess the capability of this technology in a wastewater application in the United States.

INTRODUCTION

Biochemical oxygen demand (BOD) is currently considered to be the most important parameter of wastewater quality, but the standard laboratory procedure to measure it takes five days from sample collection to result (*Standard* 1992). This is far too slow to use for wastewater treatment plant process control. BOD loadings often change on a time scale of hours, and excessively large loadings can cause process upsets when plants are not prepared for them. Rising standards for environmental protection make it desirable to monitor the BOD of primary influent fast enough to allow plant operation to adopt to influent changes.

Faster tests for related parameters have been available for years, but they are not fully satisfactory by current standards. The chemical oxygen demand (COD) test requires hazardous mercuric sulfate ($HgSO_4$), and total organic carbon (TOC) only measures the content of organic compounds, not other substances that contribute to BOD (*Standard* 1992). Thus, this test is not correlated well enough with BOD_5 to substitute for it.

Accordingly, several instrument manufacturers are now offering devices to perform rapid monitoring of wastewater BOD, but little experience with the technology has accumulated yet. For example, Harita et al. (1985), did a brief series of tests on wastewater from several sources such as the influent at a wastewater plant, and the effluent from several types of industries, but did not do prolonged tests on any of them. The Nissin Electric BOD-2000, made by the Central Kegaku Corporation (CKC), is a device that has already been widely used in Japan in the food, pharmaceutical, and wood pulp industries. This instrument uses a biosensor consisting of a dissolved oxygen (DO) electrode and a membrane impregnated with a yeast, *Trichosporon cutaneum*. The solution to be tested is aerated, and the consumption of oxygen by the yeast is proportional to the concentration of metabolizable compounds in the solution, so that the DO electrode current decreases with increasing BOD. This technology derives from research extending back to the middle 1970s (Karube et al. 1977) and is sufficiently well established that it is specified by Japanese Industry Standard K 3602 to measure BOD in several industries. A microprocessor provides data handling and control of measurement cycles that include calibration with three standard solutions and cleaning the cell with a rinsing solution between measurements. The BOD-2000 is the subject of this study, but several types of respirometers are also available for rapid monitoring of soluble BOD.

The ARAS sensor BOD instrument, made by Lange, a German firm, is very similar to the BOD-2000 except that it uses different microbes. The bacterium and yeast used in the biosensor are less of a health hazard to humans, and are supposed to respond to a wider range of nutrients than the yeast in the BOD-2000. This instrument has been demonstrated at the Terminal Island Treatment Plant (TITP), but requires operators to insert each sample separately, and has been considered unsuited for a process control application in its present form. The BIOX-1010 (*Biox-1010* 1994), manufactured by STIP, another German firm, and distributed in the United States by Cosa Instruments, relies on the respiration of a bacterial population from the wastewater living on plastic carriers in the instrument's bioreactor. This instrument is currently under evaluation at TITP, since it is designed for continuous online monitoring of a wastewater stream. It consumes much more electricity than the BOD-2000, but does not need biomembranes or reagents. Still another instrument is the Anatel BioMonitor, which compares the respiration of activated sludge to the respiration of a mixture of activated sludge and the wastewater being tested. It would be viewed as the most realistic quick simulation of the metabolic activity of a secondary treatment system. Anatel Corporation has offered to arrange a test at TITP, but this has not yet been finalized. The time required for the different measurement methods varies from a few minutes to half an hour.

FIELD TESTING

Initial field experience with the BOD-2000 was unsatisfactory. In April 1994 it was set up at TITP, which receives 60% of its influent flow from industries that produce unpredictable discharges. The instrument was installed in a rainproofed

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metal cabinet, and most tests were done on primary effluent, since this contained fewer solids than the primary influent. However, there were very frequent problems with slime building up in various small tubes, and in hot weather the BOD-2000 went offline or gave clearly erroneous values, such as less than 10 mg/l or more than 500 mg/l. By August it was clear that no further useful information could be obtained from this setup, and it was relocated to the laboratory trailer at TITP.

As might be expected, the correlation coefficient and regression line between the BOD_5 values from the standard laboratory method and the corresponding readings recorded by the instrument under these conditions showed no significant relationship. Fig. 1(a) is the time series plot and Fig. 1(b) is the corresponding best line regression fit. In Fig. 1(b) the horizontal coordinate of each point is a BOD-2000 instrument reading (BOD_{CKC}), and the vertical coordinate is the corresponding BOD_5 value.

A few plausible results were obtained while the equipment

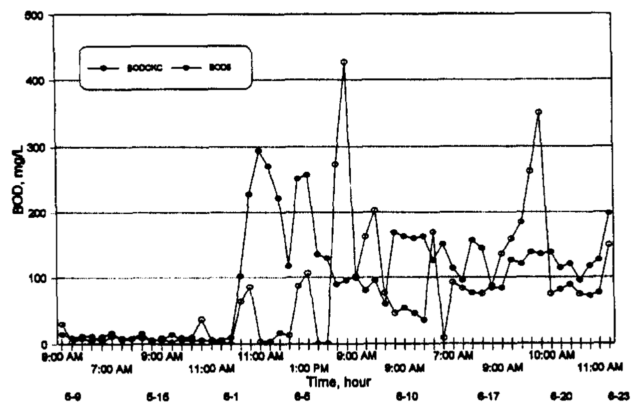

FIG. 1(a). Time Series for Instrument Data and BOD_5 Data

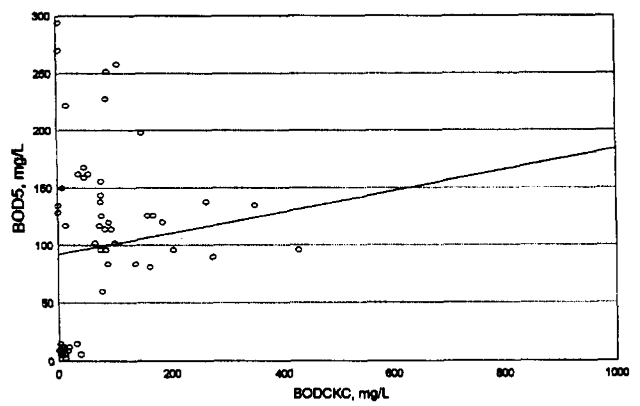

FIG. 1(b). Relationship between Instrument Data and BOD_5 Data

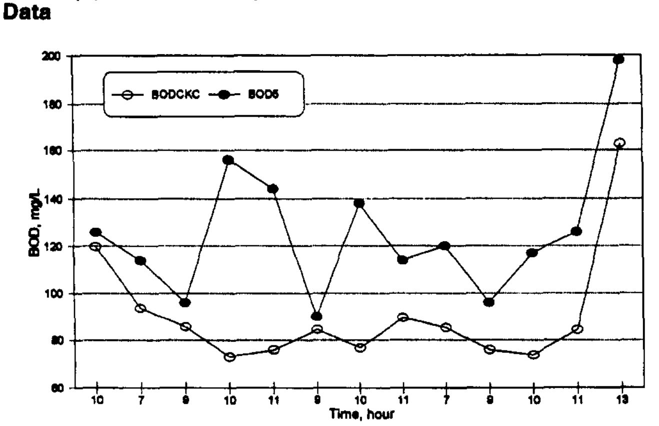

FIG. 2(a). Time Series of Selected Instrument Data and BOD_5 Data

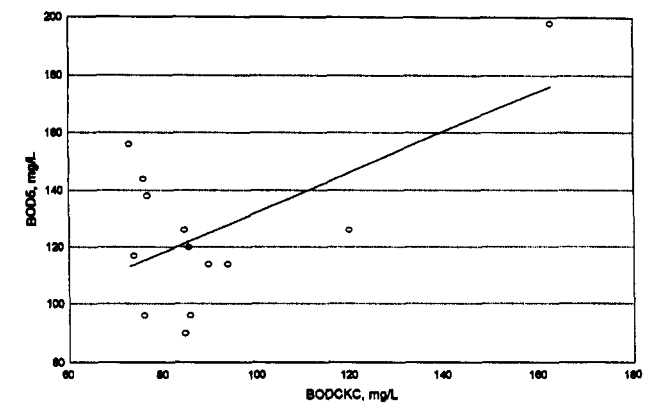

FIG. 2(b). Relationship between Selected Instrument Data and BOD_5 Data

received enhanced surveillance, but even these results were unreliable. Figs. 2(a) and 2(b) show the results for the best 13 values from four months of field data, recorded on June 11, 17, 22, and 27. One hardly needs to compute a correlation coefficient to see that there is no stable relationship between the laboratory and the instrument values.

LABORATORY TESTING

Results were more satisfactory when the BOD-2000 was tested under controlled laboratory conditions. In order to assess the reliability of the instrument, each sample of wastewater was tested repeatly. Thus, the results of the standard tests are compared in the following figures and tables to averages of the instrument readings for the same samples. In addition to maintaining an ambient temperature within the instrument's operating range, the staff also cleaned the instrument and sometimes replaced the tubing that was most subject to clogging.

Filtered Tests

Since filtering reduces clogging, a number of tests were made with samples filtered through plastic membranes with small pore sizes, to see whether it would distort the results. In each set of tests the filtered samples were used in the BOD_5 test as well as the instrument.

Filter No. 4 has a pore size of 3 μm, and Figs. 3 and 4 show the results of using this filter on, respectively, primary influent and primary effluent. As in the Field Testing section, the (a) part of each pair shows the time series plot and the (b) part shows the regression comparing the BOD-2000 readings and BOD_5 values.

Likewise, Fig. 5 shows the results of using Filter No. 1,

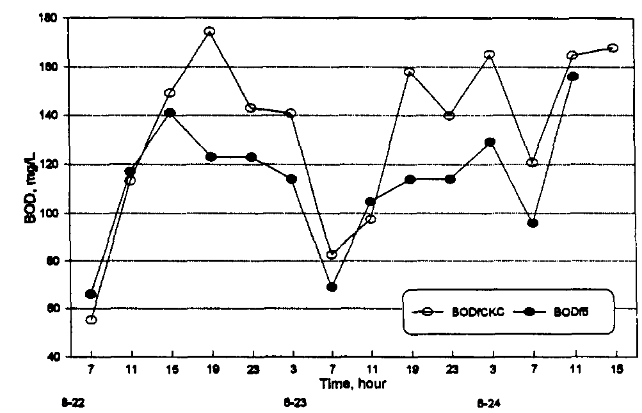

FIG. 3(a). Time Series for Instrument Data and BOD_5 Data Using Filtered Primary Effluent Samples (Filter No. 4)

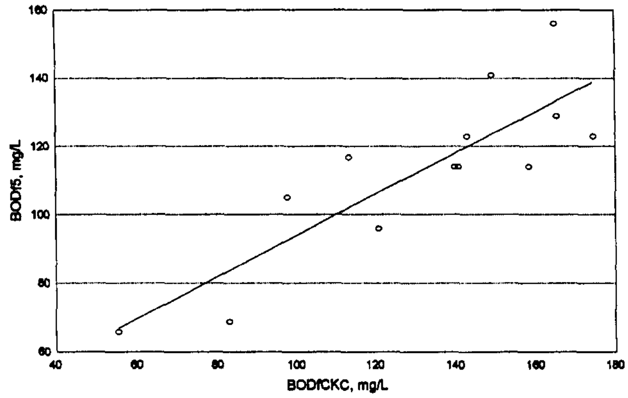

FIG. 3(b). Relationship between Instrument Data and BOD_5 Data for Filtered Primary Effluent Samples (Filter No. 4)

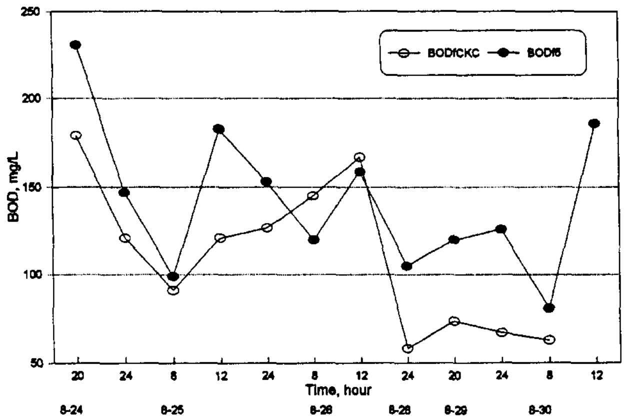

FIG. 4(a). Time Series for Instrument Data and BOD_5 Data Using Filtered Primary Influent Samples (Filter No. 4)

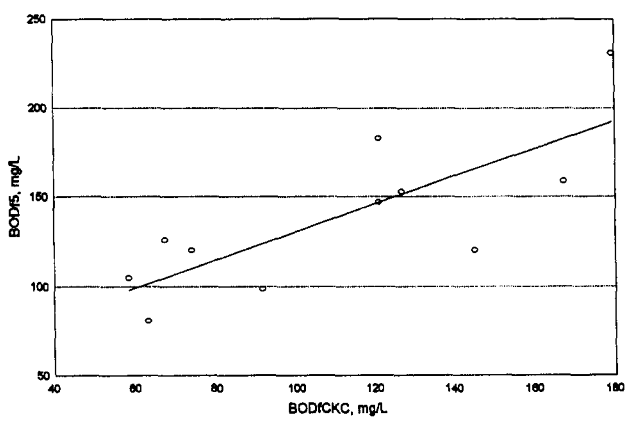

FIG. 4(b). Relationship between Instrument Data and BOD_5 Data for Filtered Primary Influent Samples (Filter No. 4)

with a pore size of 1 μm on primary influent, and Fig. 6 shows the results of using Filter No. 0.45 (pore size 0.45 μm) on primary effluent.

Comparison Tests

For comparison with the filtered tests, a set of tests were made with unfiltered primary effluent, as shown in Fig. 7. Another comparison was provided by making tests on solutions prepared from reagents with known BOD values, and these results are shown in Fig. 8.

Summary of the Results

Table 1 lists the correlation coefficients for this experiment series, using either all the data, or the data sets with a few doubtful points discarded.

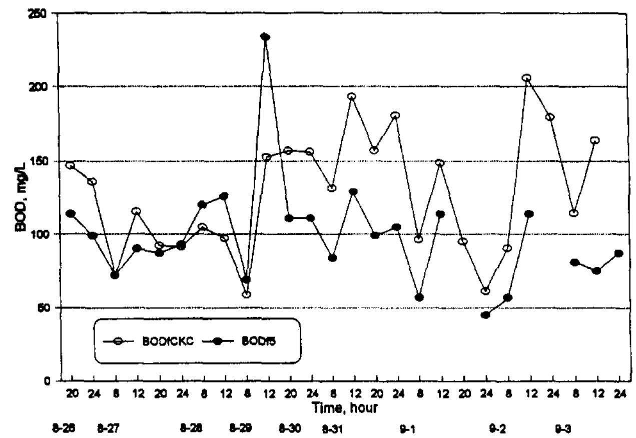

FIG. 5(a). Time Series for Instrument Data and BOD_5 Data Using Filtered Primary Influent Samples (Filter No. 1)

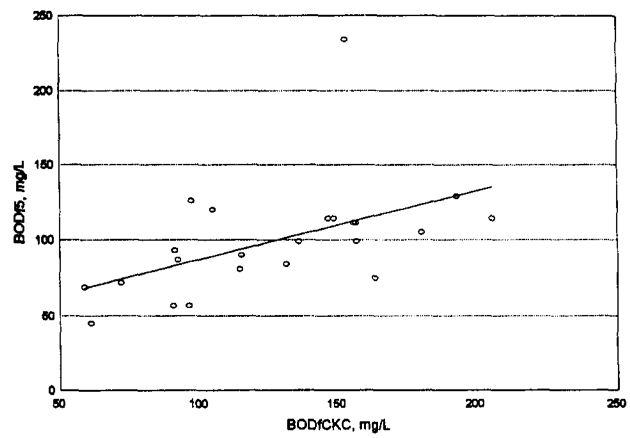

FIG. 5(b). Relationship between Instrument Data and BOD_5 Data for Filtered Primary Influent Samples (Filter No. 1)

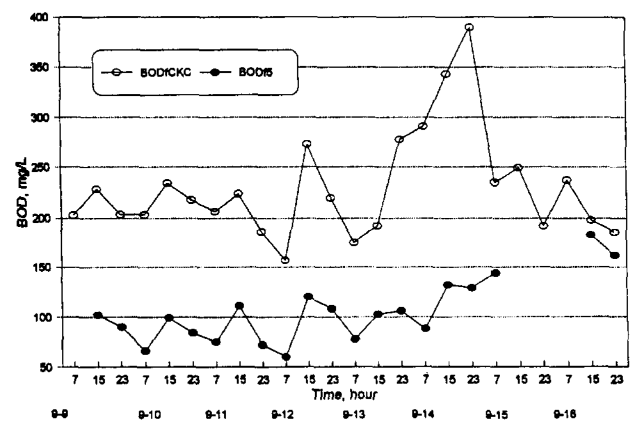

FIG. 6(a). Time Series for Instrument Data and BOD_5 Data Using Filtered Primary Effluent Samples (Filter No. 0.45)

It is evident from the results that under controlled laboratory conditions, for all the combinations of filtering and source that were used, excellent correlations were obtained between the instrument readings and BOD_5 values obtained using the standard laboratory method on samples filtered the same way. For the tests on laboratory solutions with known concentrations, the correlations are nearly perfect.

It is apparent that there are systematic differences between the BOD-2000 and the BOD_5 results, and the finer the filter the greater the divergence. This difference probably results because the standard procedure relies on the metabolic activity of the microorganisms in the water, but the filtering removes many of them. By contrast, since the BOD-2000 biosensor has

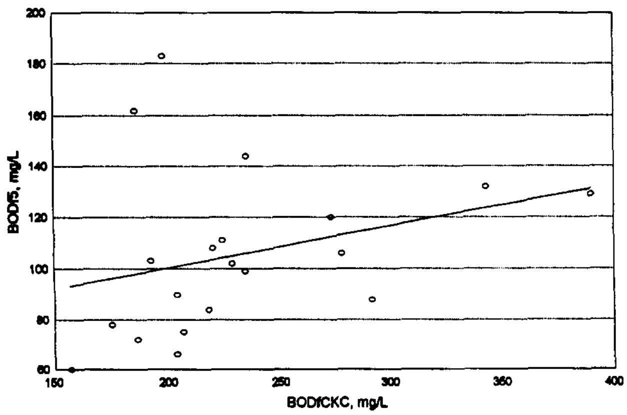

FIG. 6(b). Relationship between Instrument Data and BOD_5 Data for Filtered Primary Effluent Samples (Filter No. 0.45)

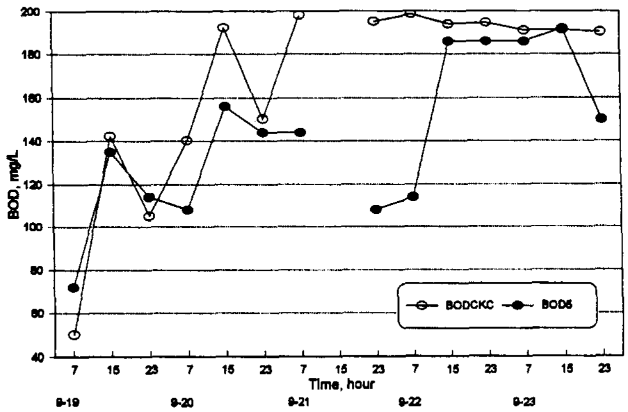

FIG. 7(a). Time Series for Instrument Data and BOD_5 Data Using Primary Effluent Samples (Unfiltered)

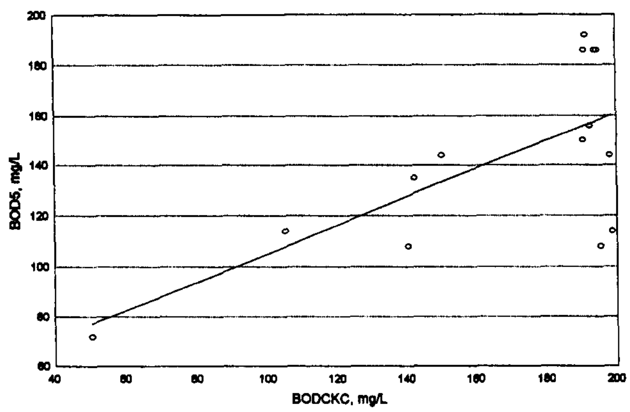

FIG. 7(b). Relationship between Instrument Data and BOD_5 Data for Primary Effluent Samples (Unfiltered)

its own yeast cells, the instrument can be used even on sterilized solutions of nutrients. However, an anomaly was observed in the data for filter No. 0.45 because total BOD_5 and soluble BOD_5 were sometimes measured for this filter, and also for filters No. 4 and No. 1 in primary influent. Total BOD_5 was greater than BOD_{CKC} for filter No. 1 and No. 4, as expected, but smaller for filter No. 0.45. This casts doubts on the validity of the other results for filter No. 0.45, even though in all other respects the results for this filter appear plausible.

Further measurements to resolve this anomaly would be desirable. Limited laboratory time at TITP prevented obtaining comprehensive sets of measurements of total BOD_5 during the experiments reported here, although this is the parameter that ultimately is to be estimated from the instrument measurements. Thus, the total BOD_5 data corresponding to the data in

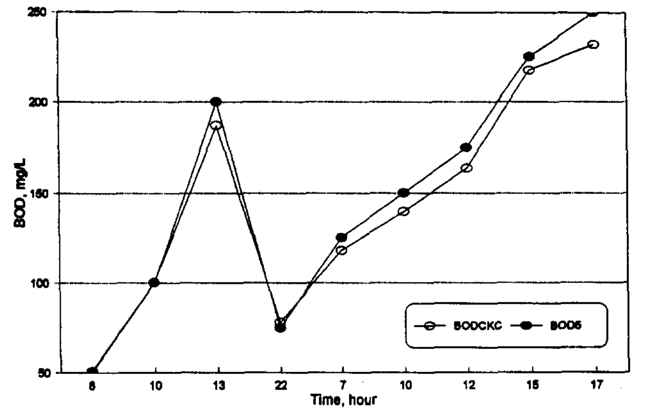

FIG. 8(a). Time Series for Instrument Data and BOD_5 Data Using Reagent Solutions with Known BOD Concentrations

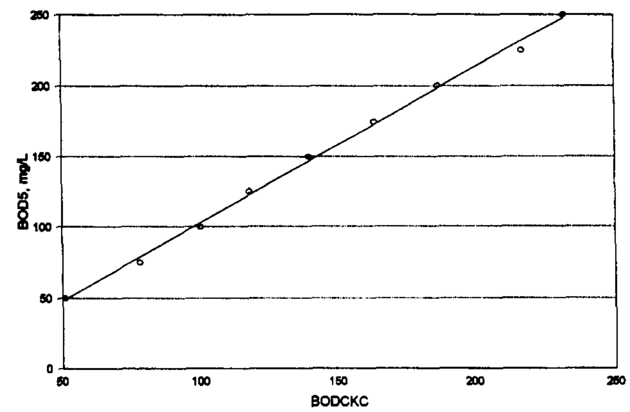

FIG. 8(b). Relationship between Instrument Data and BOD_5 Data Using Reagent Solutions with Known BOD Concentrations

Figs. 3, 4, and 5 are not plotted here. The data presently available leave open the possibility that some of the differences result from using primary influent in some measurement series and primary effluent in others. Only the No. 4 filter was used on both primary influent and primary effluent. The rest were done only with one source or the other.

Stability of BOD-2000 Instrument Readings

Since each sample was tested repeatedly in the instrument, Fig. 9 presents representative plots of actual sample series. This time series plot provides more information than would be obtained by calculating standard deviations for the averages, since it shows whether systematic trends or random noise are causing the deviations. Evidently, the results are generally stable, with small random fluctuations and only a slight tendency to drift, perhaps because there was some settling of fine particles or fermentation occurring during test repetitions that lasted several hours. A few gross deviations are attributed to mistakes.

COMMENTS

Under laboratory conditions the BOD-2000 produces excellent measurements of soluble wastewater BOD. However, a number of further considerations arise if this technology is to be used for process control in a wastewater treatment plant.

Since the 30 min needed for a measurement are negligible compared with the time scale of hours over which influent BOD changes, the instrument could be used to guide plant operation if it were kept in the laboratory and used to test grab samples of influent composited over the periods between equally spaced measurements made a few times a day (probably four or five times a day would be adequate).

TABLE 1. Summary of Correlation Analysis between Instrument Data and BOD_5 Data for Figs. 3–8

		Sample		Period	Filter	All Data		Screened Data	
Tests (1)	Figure (2)	Source (3)	Type (4)	Days (5)	Number (6)	Number (7)	Correlation (8)	Number (9)	Correlation (10)
Filtered	3(b)	Primary effluent	Grab	3	4	13	0.853	13	0.853
	4(b)	Primary influent	Grab	6	4	11	0.780	11	0.780
	5(b)	Primary influent	Grab	9	1	23	0.450	22	0.639
	6(b)	Primary effluent	Grab	8	0.45	19	0.300	14	0.764
Unfiltered	7(b)	Primary effluent	Grab	5	Not applicable	14	0.681	12	0.882
Reagent solution (known BOD concentration)	8(b)	Laboratory	Not applicable	Not applicable	Not applicable	9	0.999	9	0.999

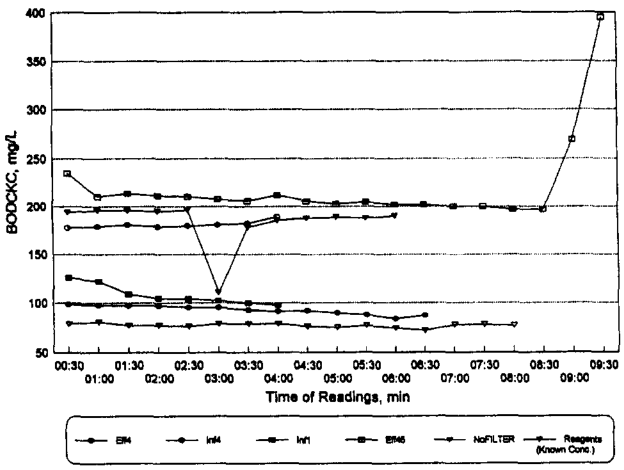

FIG. 9. Stability of BOD-2000 Instrument Readings

More automated operation clearly would be desirable to eliminate the need for plant operators to collect samples frequently. As the operation of the biosensor makes it impossible in the foreseeable future to extend the instrument's operating temperature range, it will have to be located where it is protected from excessive temperatures. Thus, although it is capable of collecting samples with its own pumps, doing so in wastewater treatment plants will require piping or tubing from the influent stream to the instrument location. Hence, there must be provisions for preventing clogging, such as filtering, washing with sodium hypochloride (NaOCl) or other disinfectants, ultrasonic cleaning, or any other suitable technology.

Testing for the sensitivity of response to salinity changes is another prerequisite for operational use in a wastewater system such as that in Los Angeles. Relatively large fluctuations of salinity have been detected in Los Angeles wastewater over the past several years with the variation of rainfall from drought to flood conditions. The biosensor's sensitivity to variations in temperature and pH have been addressed in the system design, which uses a constant temperature bath for the flow cell and tubes leading into the cell, and mixes the sample with a phosphate buffer at a pH of seven, but salinity variations have not been prevented.

Toxins in wastewater are also a concern. Toxicity sufficient to cause a sudden change in biosensor response could be detected during the calibration phase of each measurement cycle. A modest change in the programming of the microprocessor would allow the instrument to detect and report such events.

When a technology is not merely well established but mandated in governmental regulations, compelling reasons must exist if it is to be replaced with a newer one. That is the case for replacing the five-day BOD test with an instrument that provides results in a few minutes. The National Pollution Discharge Elimination System (NPDES) permit compliance for BOD_5 discharge requires monitoring of the plant final effluent based on the five-day BOD test of 24-h composited samples. Thus, from a legal standpoint, in the near future, results from a BOD analyzer will not be admissible for the NPDES permit compliance. Since the correlation between instrument readings and BOD_5 is so good, it is reasonable to hope that the regulatory agencies will change their policies to accept instrument monitoring of final effluent, but for now it is necessary to assume continued BOD_5 testing at the required rate.

A number of costs result from process upsets: notification of many regulatory agencies by telephone and in writing, greatly increased laboratory activity, overtime for many operators and technical experts, changes in plant operation requiring additional energy and supplies, and possible fines. Since the standard BOD_5 test cannot prevent process upsets, the cost of the testing plus the cost of occasional process upsets are actual costs of maintaining the current system. This must be compared with the costs of using a BOD instrument, continuing the legally required minimum of BOD_5 testing, and the costs of adapting plant operation at the first warning of conditions that could lead to a process upset. These observations imply that it is necessary to consider comprehensively the costs and advantages of integrating such instruments into plant operations.

CONCLUSION

The overall conclusion is that the BOD-2000 can produce good results for wastewater BOD hundreds of times faster than the standard BOD_5 test, and therefore shows promise for use in treatment plant process control, to prevent process upsets. The instrument might be used in this way now if it were kept in a temperature-controlled laboratory and used to test filtered samples of primary influent every few hours. This could be done if establishing such a process control were sufficiently urgent. Alternatively, a number of possible modifications have been identified that could be applied to field model BOD-2200 to obtain a system with better durability, and less of a labor requirement.

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