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Environmental Protection Technology Series

TOC, ATP AND RESPIRATION RATE AS CONTROL PARAMETERS FOR THE ACTIVATED SLUDGE PROCESS

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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TOC, ATP AND RESPIRATION RATE AS CONTROL PARAMETERS FOR THE ACTIVATED SLUDGE PROCESS

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Several control strategies were evaluated during the course of this study to demonstrate the benefits of automatic control of wastewater treatment plants. Improved control of wastewater treatment plants increases plant reliability and thus reduces environmental contamination.

Francis T. Mayo, Director
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ABSTRACT

This research was conducted to determine the feasibility of using TOC (Total Organic Carbon), ATP (Adenosine Triphosphate), and respiration rates as tools for controlling a complete mix activated sludge plant handling a significant amount of industrial waste. Methods were developed for determination of ATP in sludge with MLSS concentrations up to 10,000 mg/l using a JRB analyzer.

Control methodology was centered on using a modified F/M ratio. This parameter was determined by calculating aerator organic loading based on wastewater TOC concentration and microorganism concentration and/or activity by TOC and ATP of the activated sludge. Process control decisions were based on 5 to 7 determinations per day.

Respiration rates were used to indicate the need for increased or decreased sludge aeration time. When respiration rates were held between 8 to 20 mg O_2/g/hr, and other parameters were in an optimum range, regulatory permit requirements were met.

Process control decision making was aided by the use of a programmable calculator. Process control information was set up so that operators could input plant data and receive printed out instructions for process settings. Functional programs included return rates, mode changes, wasting rates, respiration rate, and corrected settlometer volume.

This report was submitted in fulfillment of Grant No. R 802983-01-1 by the City of Hillsboro under the sponsorship of the U.S. Environmental Protection Agency. Work was subcontracted to Stevens, Thompson & Runyan, Inc. This report covers a period from July 25, 1974 to July 24, 1975.

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ACKNOWLEDGMENTS

We wish to acknowledge the laboratory effort of Mr. Jerry Schulz, Lab Technician. Mr. Schulz was mainly responsible for the ATP analysis phase of the project. The data could not have been collected without the support of the operation personnel at the plant and city administration for the City of Hillsboro. The assistance given by Mr. Joseph F. Roesler of the U.S. Environmental Protection Agency is gratefully acknowledged.

SECTION 1

INTRODUCTION

BACKGROUND INFORMATION

The Hillsboro, Oregon westside plant is a complete mix activated sludge plant handling industrial waste from a dog food processing plant, a vegetable and fruit juice processing plant, and a meat processing plant, in addition to domestic waste.

Problems at the Westside plant were evident soon after operation began in that the effluent quality would not meet effluent standards set by the Oregon Department of Environmental Quality (DEQ). The cause of the early operating difficulty was traced to large and random variations in plant loading. At times, the incoming organic loading varied as much as 500 percent due primarily to industrial wastes. As a consequence of this variation, the activated sludge process was in a nearly constant upset condition.

The difficulties were overcome by a program with three major elements:

1. Financial and regulatory measures were initiated to reduce industrial waste loading. A stronger industrial waste ordinance was enacted mandating charges in proportion to the amount of load imposed on the plant. A concentrated sampling program provided the basis for measuring loading.

2. Operation control was improved by fixing responsibility for plant performance with specific individuals during each shift.

3. A plant process control program using F/M by TOC and respiration rate to define aerator feed points was initiated. This was done to enable plant operators to implement changes rapidly enough to improve or maintain effluent quality with wide variations in waste loading.

OPERATION PROBLEMS

Most of the operation problems that occurred at the Westside plant were related to the industrial load. The problem was identified as erratic loadings due to soluble organic material which caused frequent upsets in the secondary portion of the plant. These shock loads intensified due to a short flow time between the industry's effluent line and the primary clarifier.

The first method employed was to correct the problem using Primary Clarifier No. 2 as a holding tank to reduce some of the peaks. Other remedies that were tried were: utilizing chemical flocculents, variations in DO, dilution, maintaining a constant F/M by the moving average method and upgrading the pretreatment of industrial wastes. None of these schemes solved this problem, but did indicate that the proper solution required an immediate indication of organic loading. This led to the use of the TOC (Total Organic Carbon) analysis as a rapid method of determining changes in the organic content of the primary effluent and final effluent, and the microorganism content of the mixed liquor and return activated sludge. These data together with results from a Mallory settlometer, and respiration rates (oxygen uptake) were the parameters that were used in the control strategy development and evolution.

SECTION 2

CONCLUSIONS

1. The use of TOC information for plant control using samples of primary effluent and return sludge was particularly effective in plant control. Loading variations from industrial sources requires the rapid control response possible using TOC.

2. The ATP procedure allows very little variation to obtain repeatable results, therefore, compared to TOC is not as useful as a process tool.

3. "Modified" F/M described as the F/M ratio of primary effluent (PE) TOC entering the aeration basin to return sludge (RAS) TOC entering the aeration basin was found to be an effective process control parameter.

4. Aerator effluent respiration rate (AE-RR) was used to determine at which point return sludge and/or primary effluent should be added to the aeration basin. Unadjusted high AE-RR (>20) for short periods of time resulted in poor effluent. To reduce AE-RR, the proportion of the aeration capacity used for sludge reaeration was increased when in the contact stabilization mode. When in plug flow, the number of quadrants for aerating mixed liquor was increased.

5. AE-RR is controlled in conjunction with mode changes by RAS rate change. Increased RAS will result in a decrease in AE-RR.

6. The use of the 5-minute corrected settlometer test (CSV_5) is a valid measure of sludge quality. High values (800-1000 ml/l) indicate a "young," slow-settling, active biomass. Conversely, low values (200-300 ml/l) indicate "matured," fast-settling, but less active and responsive, biomass. A CSV_5 of 400 to 500 ml/l is an optimum value.

7. State standards for effluent quality were usually met when both of the following conditions existed:

   a. The CSV_5 is maintained between 400 and 500 ml/l.

   b. The AE-RR is maintained between 8.0 and 19.0 mg O_2/g/hr.

8. The settling rate observed by the CSV_5 can be controlled on a long-range basis by a calculator sludge wasting program which uses RAS TOC and five-minute CSV_5 as inputs. A tendency for the settling rate to increase with increasing sludge age was observed. Significant changes occur in days to weeks. That tendency is opposed by one or both of the following:

   a. A relative increase in the organic loading rate.

   b. A relative increase in the sludge wasting rate.

SECTION 3

RECOMMENDATIONS

1. Investigate transferrability of the developed process control procedures to another treatment plant.
2. Pursue the possibility of automating existing control loops and relate this to economic feasibility.
3. Investigate feasibility using tighter process control to meet impending stringent permit requirements with the goal of forestalling plant expansion.
4. Investigate potential use of ATP to predict changes in the bacteria which lead to filamentous bulking.
5. Investigate methods of automating the respiration rate determination at the Hillsboro plant.
6. Find a means to submit the existing data collected during the course of this study to computer programming for statistical analysis.

SECTION 4

NATURE AND SCOPE OF THE STUDY

INTRODUCTION

The objective of the study was to investigate, evaluate, and demonstrate a new practical method of process control of an erratically loaded activated sludge sewage treatment plant. Three variables, Total Organic Carbon (TOC), Adenosine Tri-Phosphate (ATP), and Respiration Rate (RR), have been suggested for use in control of a wastewater treatment plant. The use of each of these three control variables was demonstrated at the City of Hillsboro Westside Treatment Plant. Simultaneously, the use of an adjustable aerator volume and a modified F/M control strategy were investigated. All control actions were manually implemented, although potentially they could be completely automated.

During the course of the study, the basic control strategy used was modified F/M with a flow pattern of contact-stabilization, return sludge aeration or plug flow depending on sludge conditioning needs.

PLANT DESCRIPTION

The Westside Treatment Plant is a 2 mgd (0.09 m^3/s) plant, treating both domestic and industrial wastes. Figure 1 shows a plan view of the plant giving major flow lines and unit process components.

The plant commenced operation in March 1971. It has a hydraulic capacity of 2 mgd (0.09 m^3/s) dry weather flow and a complete mix aeration tank divided into four quadrants which provides a great deal of flexibility in terms of sludge conditioning time. Sparged turbines provide mixing and aeration. Industrial wastes constitute about 12 percent of the hydraulic flow and 40 to 80 percent of the organic load. An additional food processing industry discharges through vibrating screens at the plant site to an adjacent spray irrigation field.

The plant effluent is discharged to the Tualatin River from November 1 to May 31. From June 1 to October 31 the effluent is irrigated on the city's 280-acre (113 ha) farm and another 200-acre (81 ha) site operated by a local farmer.

The present NPDES waste discharge permit calls for 20/20, BOD/SS during the period of the year when the flow is going to the river and zero discharge in addition to the above requirements when effluent is used for irrigation.

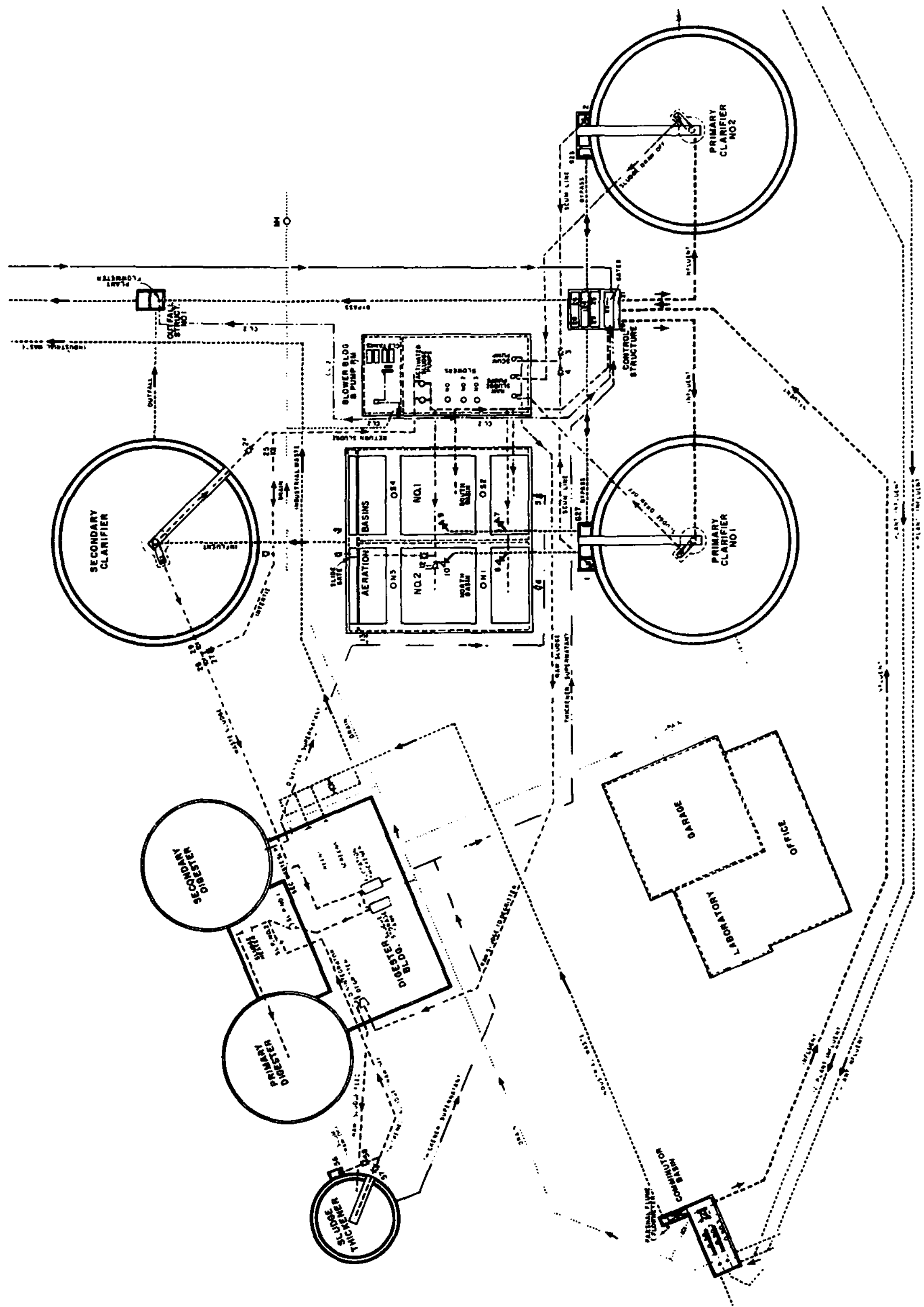


Figure 1. Plant layout.

Figure 2 depicts the aeration and clarifier relationship with the associated piping showing the versitility of the major flow lines schematically.

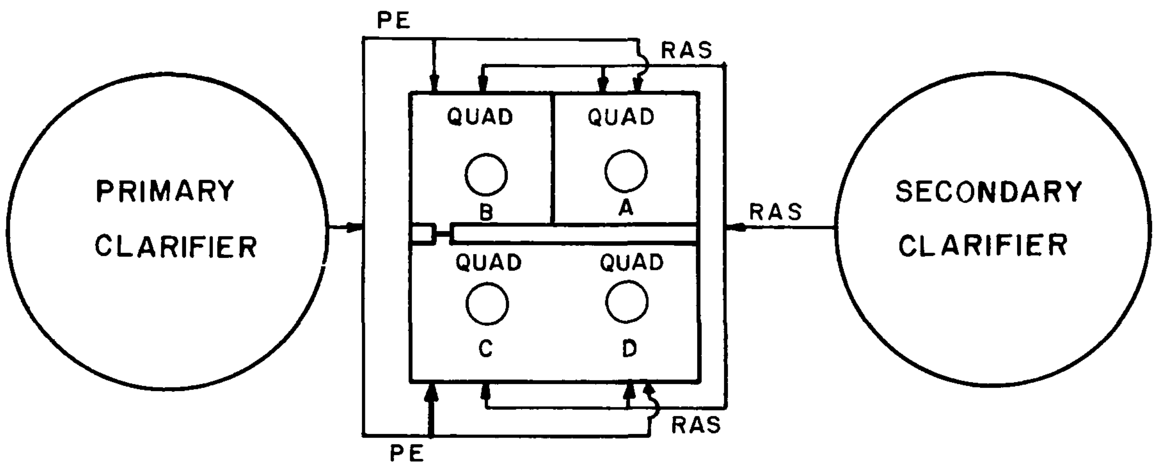


Figure 2. Aerator-clarifier relationship.

Aeration and mixing is accomplished by four sparged air mixers, one in each quadrant. Three positive displacement blowers with a maximum combined capacity of 1380 cfm supply air to the mixers.

The aeration tanks are separated by a concrete wall and each half of the aerator has a volume of 182,700 gal. (694 m^3). The aeration tanks may be visualized as being divided into four quadrants. Quadrants C and D (on the same side) have no physical boundary, but do have separate feed lines for primary effluent and return sludge. A concrete wall separates Quadrants A and B from Quadrants C and D. There is a 24-inch (0.6 m) sliding gate valve between Quadrants B and C and a wooden baffle separates Quadrants A and B.

Two variable speed pumps are used for return sludge flow. One pump has a range of 350 gpm to 1200 gpm (22 to 76 l/s), and the other has a range of 50 gpm to 700 gpm (3 to 44 l/s). Because of discharge line hydraulics, combined output with both pumps on line yields a maximum pump rate of 1400 gpm (88 l/s). During the plant's operating experience, the demand for return sludge seldom exceeds 600 gpm (38 l/s).

The final clarifier is 60 feet (18.3 m) in diameter, 10 feet (3.1 m) deep at the outer wall and 13 feet (4.0 m) deep in the center. The design overflow rate is 707 gal./sq. ft./day (28.8 m^3/m^2/day) with a surface area of 2,826 sq. ft. (262 m^2).

The plant was placed in operation in March 1971. The raw BOD entering the plant varies from a minimum of 21 to a maximum of 680 mg/l, and daily average flows vary from 0.6 to 1.5 mgd (0.026 to 0.066 m^3/s). Extreme peak winter flows have exceeded 3 mgd (0.132 m^3/s). During the period of January 1972 to June 1973, average monthly BOD removals varied from 38.3 percent to 89.6 percent. In July 1973, when process control using a modified F/M ratio and varying modes of aerator volume commenced, the plant performance improved and the average daily BOD removals varied from 90.5 percent to 98.3 percent.

Plant personnel kept aerator effluent respiration rates within the desirable range by changing the sludge conditioning time (time MLSS has air but no new food) and contact time (time MLSS in contact with primary effluent). These changes are accomplished by the valving in the aerator basin.

INDUSTRIAL WASTE

Because industrial waste loading is so relevant to the necessity of this study, the Table 1 is presented to outline types and quantities.

Table 1. INDUSTRIAL WASTE LOAD

Source of Waste	Average Flow gpd (m^3d)	Time of Travel from Industry to Plant
Carnation (pet food)	50,000 (190)	12 min.
Haley's Food (chili beans)	50,000 (190)	26 min.
Kummers (meat packer)	10,100 (38.4)	Several Hours

The industrial waste loading on the plant is discontinuous and the flow values given above are estimated yearly averages. Flow and loading varies on an hourly, weekly, and seasonal basis making predictable control based on history essentially impossible.

CONTROL ELEMENTS

As evidence increased that the variable industrial load was contributing to plant upset, the need for a rapid means of defining loading and process response became more evident. TOC, ATP, and RR were methods selected to measure loading and biological response to loading for plant control.

Influent strength was measured by TOC to define instantaneous aerator loading. By running the test at 3 to 4 hour intervals over a 24-hour period, the change in organic load was recognized rapidly enough to make process changes. This value was used as a measure of food or "F" in the F/M ratio.

Both TOC and ATP were used to define the relative quantity of biomass or "M" for F/M ratios. The calculative procedure is defined later in this report, however, the essential use of the results was to determine a return rate that would maintain the instantaneous F/M at the desired value.

The primary effluent and return sludge feed points in the aeration tank allows variable aeration times for adjusting sludge quality. Respiration rates on the aerator effluent (AE-RR) are used in conjunction with loading rates to determine which feed points and aeration tank modes are called for. As a general rule, as respiration rates trend toward 20 mg O_2/g MLSS/hr. the amount of sludge aeration time is increased. When the trend is toward 8 mg/g/hr., aeration time is decreased. This concept is discussed in a later section titled, "Sludge Conditioning Time."

A modified sludge settling test calling for a sludge concentration of 2 g/l is used to indicate relative sludge quality and provide information on setting sludge wasting rates. The test procedure is defined in Section 7.

Loading Ratio Control

Process control by manual feed forward TOC to determine and control a modified F/M has not been used broadly on a full scale plant. The modified F/M is defined as the ratio of primary effluent TOC on an instantaneous weight basis to the instantaneous weight of the RAS TOC at the theoretical mixing point. In Phase II of the study, ATP of the RAS was measured instead of TOC. In the first case, a control regime was established whereby:

$$\text{RAS pump rate, gal/min} = \frac{\text{PRI-TOC x plant flow, mgd x 694}}{\text{RAS-TOC x F/M ratio}}$$

where PRI-TOC = Primary effluent TOC
RAS-TOC = Return activated sludge TOC
F/M ratio = Desired F/M ratio

gpm x 0.063 = l/s

In the above equation the desired F/M was determined by correlating past plant performance with values during good and poor operation. It has varied in the past between 0.15 and 0.35 with best values near 0.22.

Where ATP values were used, RAS-ATP was substituted for RAS-TOC in return rate calculation. During the course of this study, the return sludge pump rates varied from the minimum of 50 gpm (3.2 l/s) to a maximum of 700 gpm (44.1 l/s).

SLUDGE CONDITIONING TIME

The method whereby the sludge conditioning time is varied is outlined in Figure 3. The aeration tank is divided into four quadrants. Both the primary effluent flow (PE) and the return sludge flow (RS) can be directed into any one of these quadrants. By varying the placement of these flows, the sludge conditioning time can be varied between contact stabilization and plug flow. The total aeration time will depend on the existing primary and return flows and tank volume in use.

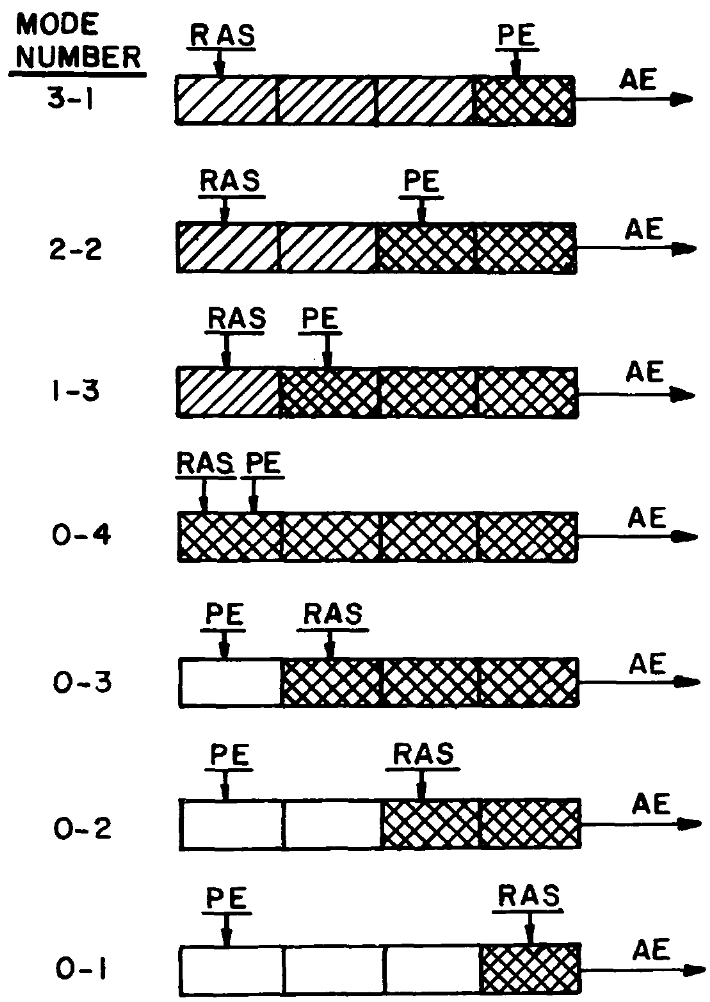
To illustrate this process, consider the situation where both the return sludge (RS) and the primary effluent (PE) are brought into the fourth quadrant. This allows for (0) units of reaeration or stabilization time and (1) unit of contact time. This is defined as mode 0-1. At the other extreme, consider the situation where the return sludge enters the first quadrant, while the primary effluent enters the fourth quadrant. In this case, the return sludge flows through three quadrants before contacting the primary effluent. Since the return sludge flow is significantly less than the primary flow, it spends more time in transit, increasing the conditioning or stabilization time. This is defined as 3-1 inasmuch as 3 quadrants are used for reaeration and 1 for mixed liquor. Similarly, other sludge conditioning times can be accomplished by appropriate placement of flows. (Reaeration or stabilization is defined as that condition where return sludge is aerated prior to mixing with primary effluent.)

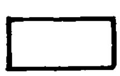
The purpose of changing modes is to keep the Aeration Effluent Respiration Rate (AE-RR) between 8 and 20 mg O_2/g/hr. An AE-RR that is too high indicates the need for more aeration time, and conversely, low values require less aeration time.

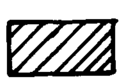
An increase in aeration time, in this study, is defined as sludge residence time in a quadrant receiving only return sludge. The aeration time would then be decreased by adding primary effluent, increasing the hydraulic through-put.

Information elsewhere in this report shows the phenomenon of aerator respiration rate changes correlated with increases in return sludge respiration rate. This increase indicates that unoxidized food recycling from the secondary clarifier in the return sludge builds up over a period of time and requires additional stabilization time prior to the addition of "new" food in the primary effluent. As residence time in the aerator is increased, the respiration rate tends to decrease.

Operators were instructed when to change modes by a program in a programmable calculator that contains a collection of decision-making rules based on past response of the process to various respiration rates and mode changes. Inputs to the calculator program are "Present Mode," "How Many Hours in this Mode," and "Present AE-RR." The calculator printed out instructions to stay in the present mode or change to another mode.



 Primary Effluent only; mixer on, air off.

 Return Activated Sludge only; mixer on, air on. The detention time through these quadrants equals the RAS detention time and the number of quadrants used is identified by the first mode number.

 Mixed Liquor; mixer on, air on. The detention time through these quadrants equals the ML detention time and the number of quadrants used is identified by the "last mode number."

Figure 3. Mode change description.

Process Control Scheme

The relationship of control loops and parameters adjusted is summarized in Figure 4. Four loops were identified and operated throughout the course of the study using input to the programmable calculator and the output results were then implemented manually.

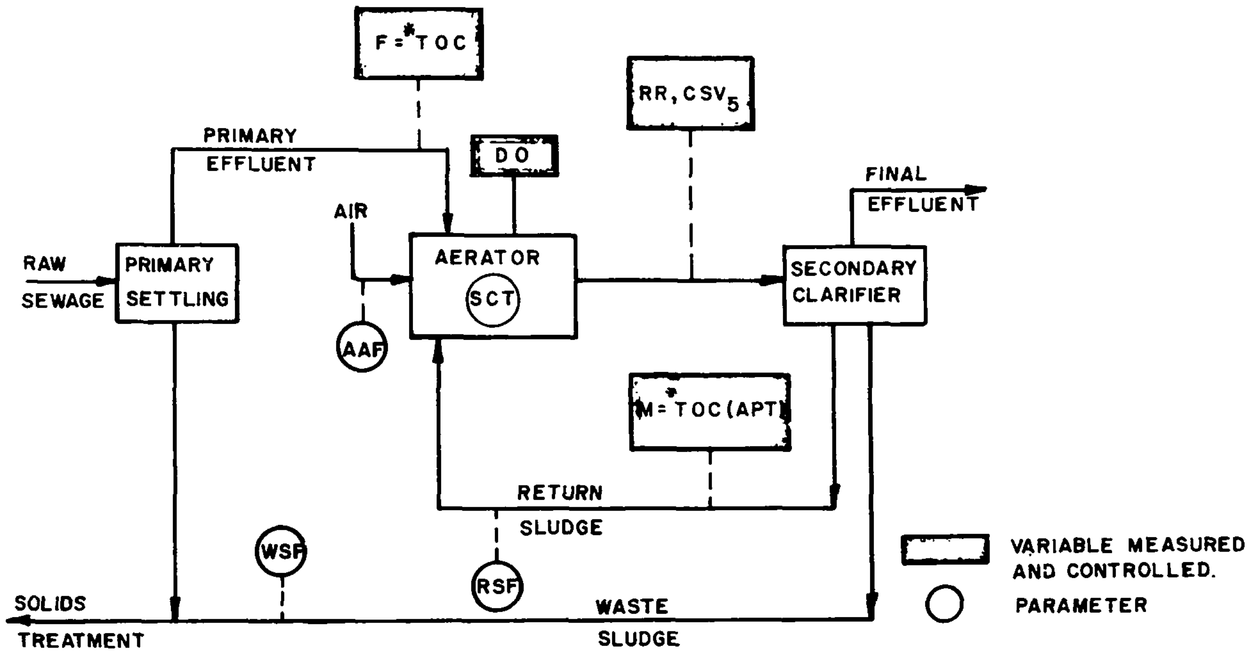


Figure 4. Process control schematic.

Control Loops

1. Food to biomass ratio F/M (F = TOC PE M = RAS TOC or RAS ATP)
2. Respiration rate of aeration tank effluent (RR)
3. 5 min. corrected settling volume of aeration tank effluent (CSV_5)
4. Dissolved oxygen in aeration tank (DO)

Key Parameters Adjusted

1. Returned Sludge Flow (RSF)
2. Waste Sludge Flow (WSF)
3. Sludge Conditioning Time (SCT)
4. Aerator Air Flow (AAF)

Other Control Elements

Aerator air was controlled between 1-4 mg/l in each quadrant containing sludge in either a contact or reaeration (or stabilization) mode.

Waste sludge was normally removed from the bottom of the secondary clarifier at a fixed rate of 58 gpm (3.6 l/s) and thickened in a flotation thickener. The number of minutes of wasting per day at the fixed rate was determined on results of the settling test, loading and RAS-TOC. The specific calculation is defined in Section 6.

A programmable calculator was used to provide information storage, computation and process control direction. Many of the control parameters were preprogrammed into the calculator and used in conjunction with periodic series of tests run during the course of a day. These results were input into the calculator and the readout gave the operator specific instructions on the required process change based on test results.

PHASES OF THE PROJECT

Work under this grant commenced on July 25, 1974, and continued through July 24, 1975. During this time period, a number of refinements in technique and control were implemented. The study was divided into three basic phases preceded by a period of gathering background data. The phases and times of implementation are shown on Table 2.

Table 2. PHASE IDENTIFICATION

Phase	Date	RAS and Modified F/M Control
I	7/25/74 to 12/31/74	Controlled by TOC, ATP monitored
II	1/01/75 to 6/26/75	Controlled by ATP, TOC monitored
III	6/26/75 to 7/24/75	Controlled by TOC, ATP monitored

Because one of the objectives of this study was to compare TOC and ATP, control decisions for RAS rates were made based on results of one parameter while data was collected simultaneously on the other. Food (F) was measured in all cases using TOC of the primary effluent.

Chemical and Biological Analysis During Study

The testing program consisted of: a series of tests performed five to seven times per day, Cl_2 residual, DO, pH, SVI, microscopic examination of the bacteria in the aerator, depth of final clarifier sludge blanket, and calculation of the pounds of waste activated sludge.

The TOC test series consisted of a TOC reading on the primary effluent, mixed liquor, return activated sludge flow and final effluent. In addition, other tests were used to monitor the process including settlometer, final effluent turbidity, MLSS concentration, and plant flow. These tests were performed by the operator on duty.

Data Collection

During the course of the study, a series of tests were run on samples collected by plant personnel 5 to 7 times daily. Collection times are shown on Table 3.

Table 3. SAMPLE COLLECTION TIMES

Time ($\pm$1 Hr)	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
12:00 midnight			X	X	X	X	X
4:00 a.m.			X	X	X	X	X
8:00 a.m.	X	X	X	X	X	X	X
10:30 a.m.	X	X	X	X	X	X	X
1:30 p.m.	X	X	X	X	X	X	X
4:00 p.m.	X	X	X	X	X	X	X
8:00 p.m.	X	X	X	X	X	X	X

Determinations were made on samples collected or instantaneous readings were recorded for the following parameters at each of the times given in Table 4. During each sample period the following information noted on Table 4 was collected and recorded.

Table 4. MAJOR INFORMATION RECORDED

Information Categories	Comments
Time of Day	Time of sample collection ($\pm$1 Hr from time noted on Table 3)
Plant Flow, mgd	From plant flowmeter
Primary Effluent TOC, mg/l	Dohrmann Envirotech Model 50 TOC Analyzer
RAS TOC, mg/l	Dohrmann Envirotech Model 50 TOC Analyzer
Aerator Effluent TOC, mg/l	Dohrmann Envirotech Model 50 TOC Analyzer
Sludge Blanket Surface Depth, ft	Measured with a lighted blanket finder 2 to 4 times per day
Mixed Liquor Aeration Time, Hrs	Calculated by the Tektronix Model 31 calculator

Table 4 (Continued). MAJOR INFORMATION RECORDED

Information Categories	Comments
RAS Aeration Time, Hrs	Calculated by the Tektronix Model 31 calculator
Final Effluent Turbidity, Jackson Units	Approximated by Spectronic 70 Spectrophotometer from 7/25/74 to 2/20/75. A Hach 2100A Turbidometer was used for the balance of the study.
SVI	Determined 2 to 3 times daily
5-Minute Corrected Settlometer	Determined 3 to 4 times daily approximately at alternate sample times
Final Effluent TOC, mg/l	Dohrmann Envirotech Model 50 TOC Analyzer
Mode of Operation	Aerator mode defining feed points for PE and RAS
Calculated Modified F/M Ratio	Determined by relationship of PE-TOC and RAS-TOC or RAS-ATP
Present RAS flow, gpm	Observed reading from RAS propeller meter
New RAS flow, gpm	Calculated setting as determined by program to maintain desired modified F/M
Lbs Solids Wasted/Day	Calculated amount of sludge to waste. Readout is in minutes to waste per program
Aeration Effluent Respiration Rate mg O_2/g/hr	Determined by YSI DO meter and concentration of AE
RAS ATP, mg/l	JRB-ATP photometer
Aerator Effluent ATP, mg/l	JRB-ATP photometer

SUMMARY OF PHASES

Phase I - TOC Control While Monitoring ATP

From the initiation of the study until December 31, 1974, RAS rates and modified F/M were determined by TOC of PE and RAS. The method of calculation is described in Section 5.

During this period, optimum ranges were defined for several of the basic determinations and parameters. These were first approximations and were refined later.

The major emphasis was on perfecting technique in gathering background information. Considerable time was spent on refining the ATP sample preparation and testing procedure which had to be revised from that provided by the supplier of the ATP equipment.

Emphasis was placed on finding the best operating ranges for respiration rate, settleability, RAS-TOC, and confirmed to be bracketed as follows:

1. Settleability measured by the adjusted settlometer at 5 minutes: less than 600 ml/l (see Section 7 for description of this test).

2. Aerator effluent respiration rate (AE-RR) between 8 and 19 mg O_2/g MLSS/Hr.

3. RAS-TOC: less than 5,000 mg/l.

The range and average of some of the other key data points is in Table 5.

Table 5. PHASE I RANGE AND AVERAGE DATA

Operation Parameter	Monthly Average Range	Monthly Average
PRI TOC mg/l	118 - 189	171
RAS TOC mg/l	2,589 - 4,010	3,500
AE TOC mg/l	750 - 883	914
CSV_5 ml/l	497 - 619	575
Flow and Performance Parameter		
Fin. Eff. JTU	8.4 - 17.1	12.6
Fin. TOC mg/l	42 - 68	61
Fin. BOD mg/l	15 - 40	30
Fin. SS mg/l	19 - 40	29
Flow mgd	0.71 - 1.43	0.91

Digester supernatant recycling from the anaerobic digesters influenced plant loading in addition to external loads. Raw suspended solids were recorded as high as 4,000 mg/l and 420 mg/l in the primary effluent in September 1974. A liquid sludge hauling program was implemented late in 1974 that resolved this situation.

The following data summarizes the comparison before and after control of supernatant.

Table 6. EFFECTS OF DIGESTER SUPERNATANT ON PROCESS

	Raw		Pri			Fin	
	SS	BOD	SS	BOD	TOC	SS	BOD
Nov. 1974 w/super	1,205	586	178	219	184	29	28
Dec. 1974 w/o super	251	229	124	161	118	18	15

Phase II - ATP Control While Monitoring TOC

The JRB-ATP photometer was used to analyze for adenosine triphosphate (ATP). During Phase I, the procedure was perfected and plant operators were instructed in correct sample collection, preparation, and determination.

The RAS rate change was made using the ATP determination 89 percent of the time in January 1975 and 98 percent of the time from February through April 1975 (see discussion later in this section). Simultaneous data was collected for ATP and TOC and a set of confidence limits established allowing a decision on which parameter was used. These limits are also discussed later in this section.

Industrial waste loading fluctuated widely during the course of Phase II and the annual winter high flows necessitated diversion of a portion of the primary effluent around the secondary units to prevent hydraulic washout. The decision to divert is based on the amount of the solids in the secondary clarifier under the assumption that it is preferrable to preserve the biomass and divert chlorinated primary effluent than to spend 10-14 days reestablishing the growth. Approximately 86 percent of the flow received secondary treatment between February 1, and April 30, 1975.

During this phase, ATP was used as a control parameter for adjustment of RAS to maintain a constant F/M. The use of this different parameter combined with too frequent mode changes led to loss of control of the process. The apparent reason was the tendency to make corrections too rapidly without allowing the process to reach a new equilibrium point. The two major changes being made were adjustment of return rates and trending from plug flow to contact stabilization.

Table 7. PHASE II RANGE AND AVERAGE DATA

Operation Parameter	Monthly Average Range	Monthly Average
PRI TOC mg/l	84 to 168	121
RAS TOC mg/l	3,300 - 3,760	3,522
AE TOC mg/l	675 - 1,067	834
CSV_5 ml/l	408 - 773	534
Flow and Performance Parameter		
Fin. Eff. JTU	7.0 - 19.5	10.5
Fin. TOC mg/l	40 - 85	56
Fin. BOD mg/l	10 - 45	21
Fin. SS mg/l	13 - 120	33
AE ATP*	5.0 - 6.7	5.8
RAS-ATP*	17.2 - 20.3	19.1
Flow mgd	0.92 - 1.8	1.4

*Four month's data.

Phase III - TOC Control While Monitoring ATP

This phase was carried out during the last month of the grant period. A revised mode change schedule was implemented that allowed more time for the process to stabilize following mode adjustment.

During this period, the primary effluent TOC exceeded 200 mg/l (17 times in 21 determinations) between July 10 and 12, 1975. A maximum value of 427 was recorded at 4:00 p.m. on July 12, 1975. In spite of this shock industrial load, the process was held in control and plant effluent stayed within acceptable limits.

Table 8. PHASE III RANGE AND AVERAGE DATA

Operation Parameter	Monthly Average Range	Monthly Average
PRI TOC mg/l	106 to 284	154
RAS TOC mg/l	2,844 - 4,593	3,793
AE TOC mg/l	646 - 1,131	964
CSV_5 ml/l	505 - 923	700
Flow and Performance Parameter		
Fin. Eff. JTU	2.8 - 16.9	5.1
Fin. TOC mg/l	31 - 89	49
Fin. BOD mg/l	6 - 34	13
Fin. SS mg/l	2 - 52	13
Flow mgd	0.62 - 1.8	0.83

SECTION 5

DISCUSSION OF RESULTS

APPLICATION OF TOC

To meet the objectives of this study, it was necessary to define TOC control procedures, gather baseline information for comparing TOC to ATP control and document some of the reasons for success of the application of TOC control prior to the study period.

Even though successful results were obtained early in the TOC control strategy application, problems still existed from time to time in maintaining continuous control for a variety of reasons. Three causes for plant upset were identified: shock loads to the process when sludge condition was not prepared for rapid increases, lack of a defined wasting program and unexplained influx of filamentous organisms which seem to be correlated with lowered wastewater temperatures.

Influent Load Monitoring By TOC

An improvement in the ability of the system to withstand shock loads was evident between August 1974 and September 1974, when for two five-day periods the PE-TOC averaged 228 mg/l. In August, the secondary clarifier lost a significant amount of solids resulting in a final SS of 275 mg/l on the 5th day. Essentially the same loading in September resulted in a peak final SS of 61 mg/l, but the SS was only 22 mg/l on the 5th day. These data are shown on Table 9. The ability of the plant to handle high loads in September was correlated with the improved sludge quality as measured by both the corrected settleability and respiration rates. This added credence to the necessity of holding settling below 600 ml/l in 5 minutes and respiration rates below 20 mg O_2/g/hr.

Table 9. TOC CONTROL COMPARISON

Day of Week	Aug. 1974	PE-TOC mg/l	Fin SS mg/l	AE-RR mg/g/hr	Sept. 1974	PE-TOC mg/l	Fin SS mg/l	AE-RR mg/g/hr
T	6	192	20	17	10	207	34	12
W	7	221	24	28	11	200	35	12
T	8	235	44	32	12	261	61	15
F	9	210	80	39	13	271	26	13
S	10	284	275	57	14	199	22	11

A typical range for PE-TOC over a 24-hour cycle, when excessive industrial loading was not evident was, 84 to 148, compared to a typical range of 114 to 219 mg/l when industrial loading was evident.

Plant upset was most frequently experienced when the PRI-TOC averaged 190 mg/l or above for more than 48 hours. In July 1975, changes were incorporated into the wasting and mode adjustment programs in conjunction with modified F/M control to reduce the possibility of these upsets.

Initially, adjustment of RAS rates to maintain a fixed modified F/M was practiced. As more experience was gained, the target modified F/M was allowed to vary with the RAS TOC which resulted in better control during sustained shock loads. This is covered more thoroughly in Section 6.

RAS-TOC

The TOC of the return sludge was used as a measure of "M" in the modified F/M ratio. The initial approach in the early phases of the study was to hold F/M constant by varying the return rate proportionately as the primary effluent load changed. In July 1975 a new program was put into use whereby the modified F/M used to control the return rate was varied as the observed AE-RR changed. This change was made in an effort to reduce the necessity for frequent mode changes after observing apparent process instability when modes were adjusted during prolonged high loading periods. Early in the study wasting was done at a constant rate from the return sludge line with the variable being hours of wasting. Experience with the system led to the derivation of a family of curves shown on Figure 5. These data were programmed into the printing calculator and wasting was practiced each day starting on day shift. These conditions held true in the range of RAS-TOC between 4000-6500 mg/l.

Later RAS-TOC, along with CSV_5 and mode of operation, was used in the determination of amount of sludge to waste. (More information on this subject is presented in Section 6 - Operation Procedures.) RAS-TOC was found more sensitive than secondary clarifier sludge blanket level, and more convenient than RAS-SS as indication of biomass buildup for input to the wasting-time calculator program. RAS-SS could theoretically be used in place of RAS-TOC since they were found to correlate at the Westside Plant as follows:

(RAS-SS, g/l) x (371) + 250 = RAS-TOC, mg/l

APPLICATION OF ATP

Limited work to date has been done on the application of ATP to process control; therefore, one of the objectives of this study was to test the capability of using ATP values to determine the modified F/M for process control.

ATP has been recognized as one means to identify the viable fraction of the sludge mass. The premise was made that by varying the proportion of viable mass as measured by ATP in proportion to the load measured by PE-TOC the modified F/M would bear a closer relationship to actual "live" mass per unit of available food.

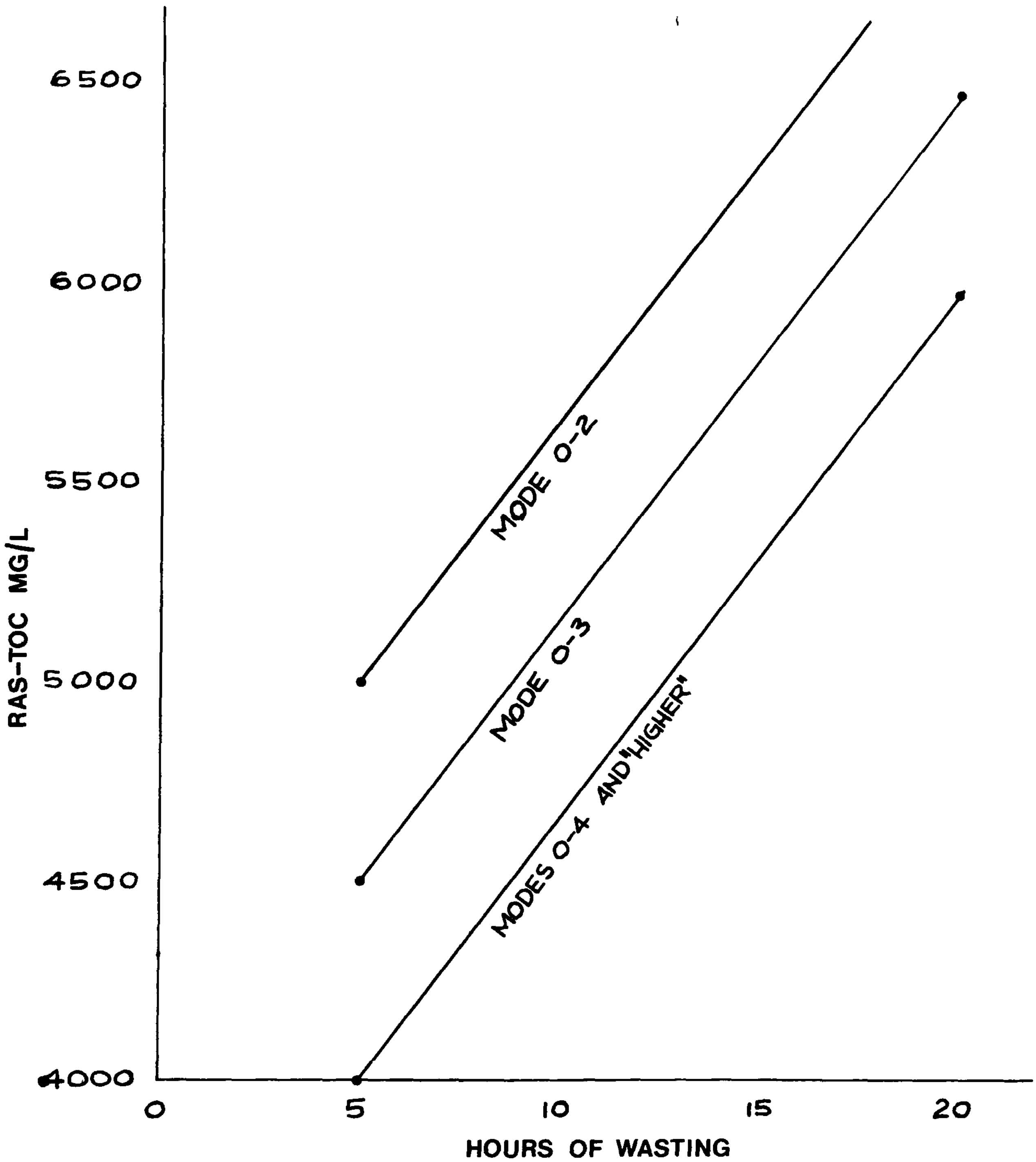


Figure 5. Relationship of RAS-TOC to wasting time.

The return rate using ATP values was established as follows:

$$\text{RAS pump rate, gal/min} = \frac{\text{PRI-TOC} \times \text{plant flow, mgd} \times 694}{\text{RAS-ATP} \times 187.5 \times \text{F/M ratio}}$$

where PRI-TOC = Primary effluent TOC
RAS-ATP = Return activated sludge ATP
F/M ratio = Ratio varied from 0.15 to 0.35 during the study
(RAS TOC = RAS-ATP x 187.5)
gpm x 0.063 = l/s

ATP was correlated with TOC in order to establish the working limits. (The term 694 was a conversion factor to obtain an expression in gallons per minute to coincide with the RAS meter readout.)

Determination of Correlation of RAS, ATP and TOC

The basis for establishing correlation for the modified F/M using ATP was done in November preparatory to beginning actual control.

On December 24, 1974, the return rate control commenced according to the results of RAS-ATP tests. The printing programmable calculator was programmed to determine mathematically the return rate from the usual data, plus the RAS-ATP. Because the laboratory ATP procedure is relatively involved compared to TOC, a method was instigated to prevent setting the return pump from faulty ATP determinations. Boundaries were defined on the plot of RAS-ATP, and RAS-TOC, and when the RAS-ATP for a particular RAS-TOC fell outside of this boundary, the calculator program assumed that the ATP determination was faulty and calculated the return rate from the RAS-TOC in the usual way.

The RAS ATP-TOC pairs used were taken between November 5 and November 21, 1974, and the calculator program is based on 83 pairs of data from those 16 days.

The boundaries, as defined, include about 90 percent of the points. This means that the return rate would be set according to ATP 90 percent of the time. The calculator was programmed to print out which parameter is being used each time.

The best-fitting line was drawn by visual inspection after the 83 points were plotted. These data are presented on Figure 5.

Referring to Figure 5, the procedure used for incorporating the RAS ATP into the return rate determination is illustrated by the following two cases:

1. RAS TOC = 3,000
   RAS ATP = 20.00

2. RAS TOC = 3,000
   RAS ATP = 30.00

In case (1), the ATP is within the boundaries. The ATP determination was assumed to be accurate, and the return rate was calculated according to the previously described formula.

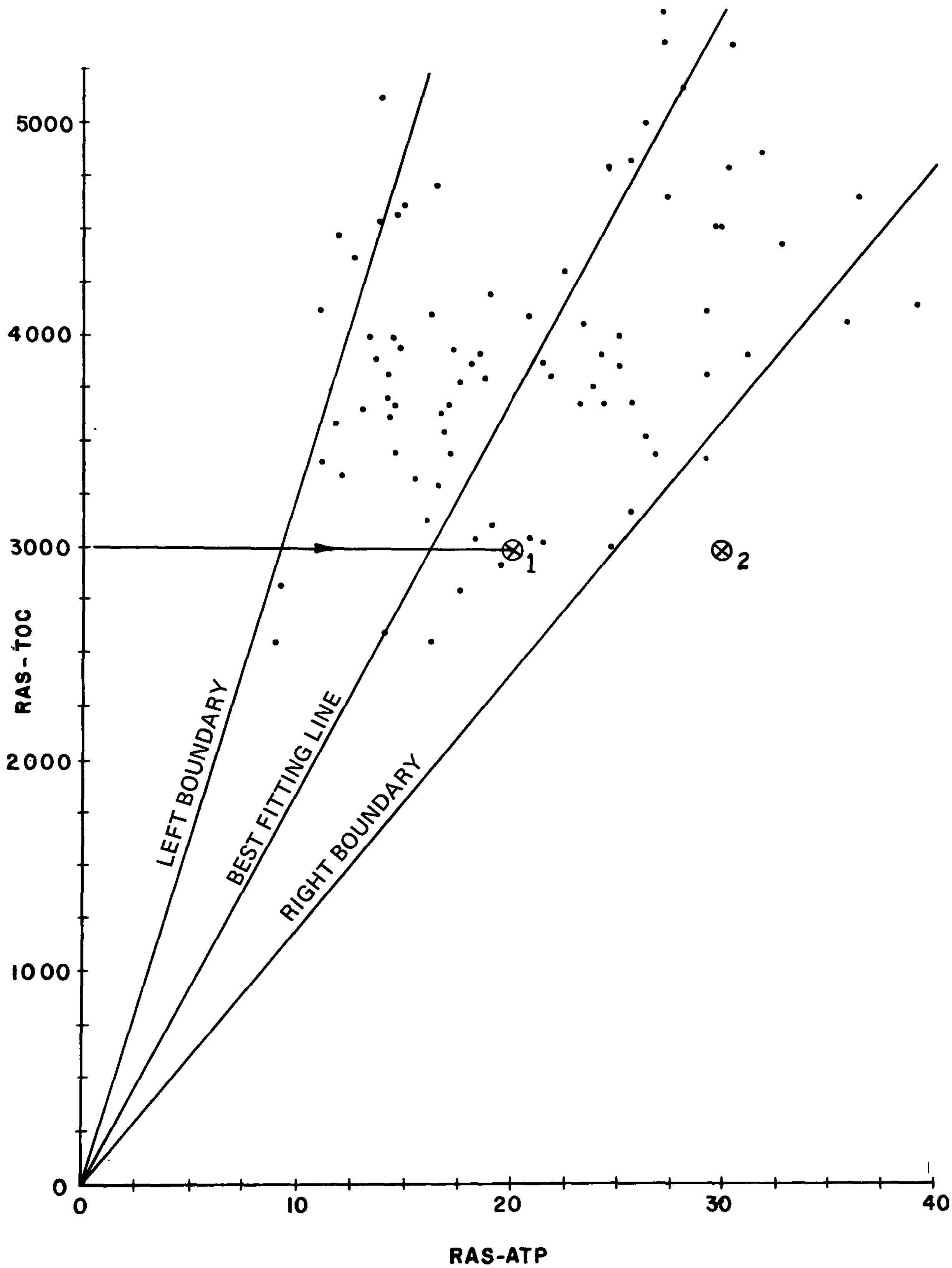


Figure 6. Line of best fit for RAS ATP/TOC correlation.

In case (2), the ATP is outside of the boundaries. The ATP laboratory determination was then considered to be in error, and the return rate was set using TOC.

Observations on the ATP Testing

The procedure, although difficult, was performed by operation personnel around the clock. Standards were made up by the chemist or technician. Because the calculation to obtain the results in mg/l involved comparing the raw number from the photometer with the scope of the standard curve, a program was established on the programmable calculator.

An explanation of the RAS-SS/TOC/ATP relationships in Figure 7 can be hypothesized as follows: Normally the RAS-SS concentration was maintained around 8 to 9 g/l corresponding to 3,300 to 3,500 mg/l TOC. Data for higher points on Figure 7 were most likely taken soon after a period of increased growth which led to the higher values. Increased growth means increased proportion of viable biomass, thus the "stretching out" and nonlinearity of the RAS-ATP curve.

Since the degree of "stretching out" of the ATP curve was more than anticipated, the RAS rate calculator program was not set up to benefit the process from this ATP-derived information. Instead, the greater ATP values, than would be predicted by a linear relationship, led to calculated RAS flow rates which at times exceeded the hydraulic capacity of the secondary clarifier for proper operation.

Presumably, a larger range of F/M values could be used with the ATP data in an RAS rate formula to derive maximum benefit from the viable biomass information. But due to the greater difficulty of the ATP laboratory procedure compared to the TOC procedure, and because TOC information seems to be entirely satisfactory in this type of operational program, ATP shows more promise for research than as a control tool.

ATP Determination by Operation Personnel

Following the period of perfecting technique for operation of the JRB-ATP Photometer and establishing a correlation between TOC and ATP, it was necessary to train operation personnel running the routine samples inasmuch as sampling and determinations were necessary on all three shifts. This was accomplished by using a cassette tape-slide projector combination and recording the essential steps in sequential fashion. This unique method made the instructions available on a 24-hour basis to each of the operators involved.

Difficulty was encountered during the early stages of the project in obtaining repeatable results and this was traced to sample preparation techniques. Much helpful information was obtained from Harold Bond, EPA National Ecological Research Lab, Corvallis, Oregon.

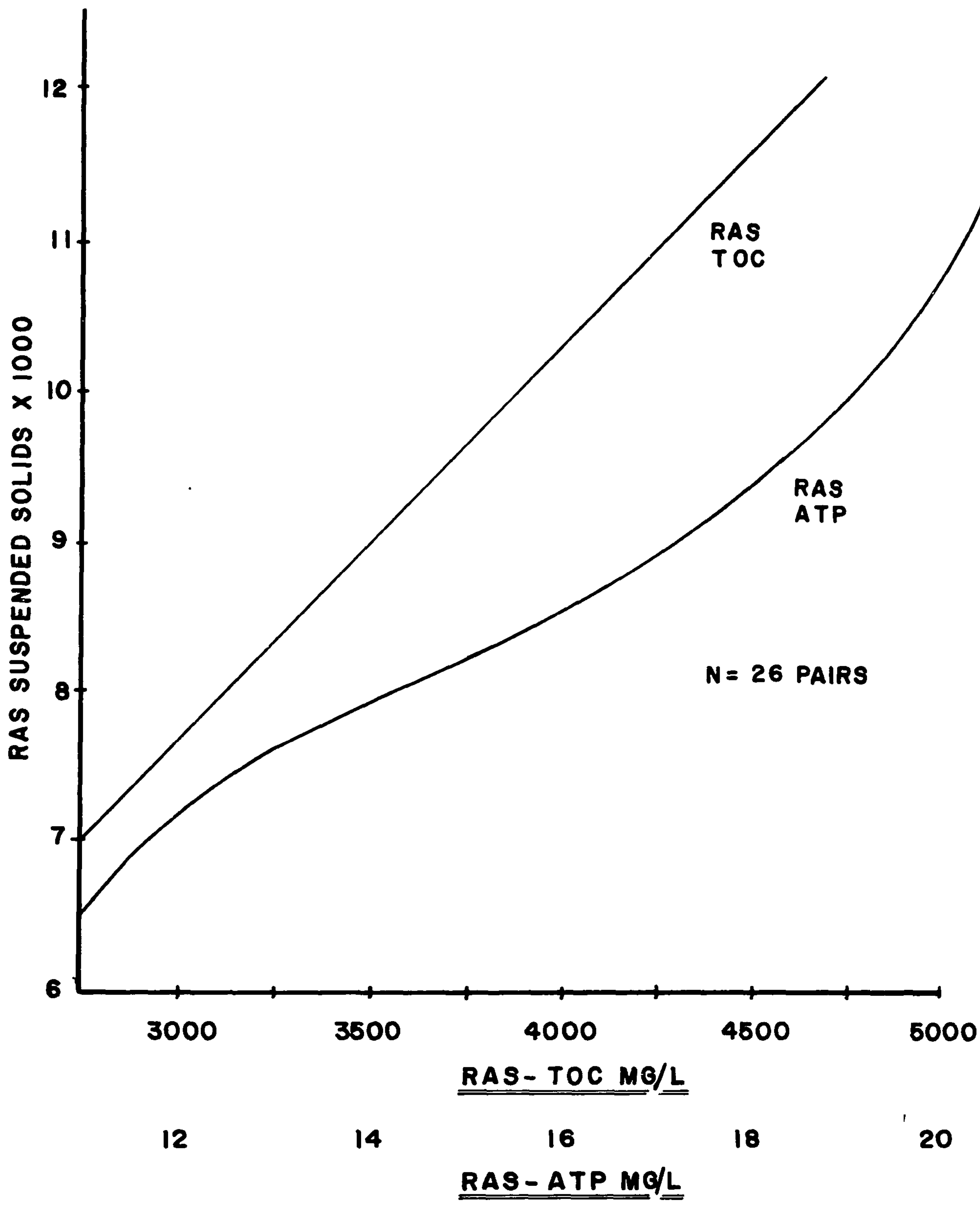


Figure 7. Relationship of RAS-SS to ATP and TOC.

APPLICATION OF RESPIRATION RATES

The observation and control of respiration rates proved to be a key factor in plant operation, being integrally associated with two control loops in the process control scheme. These two loops tie RR with RAS rate and RR with mode change.

Historically, it has been noted that the best treatment occurred when RR was maintained between 8 and 19 mg O_2/g solids/Hr. Operation for more than 12 hours at RR > 20 produces poor settling sludge and cloudly effluent.

This measurement is taken on the aerator effluent as flow passes out of the aerator into the secondary clarifier influent line. The method for determination is given in Section 7.

Relationship of RR and RAS Rate

Within hydraulic limits, an increase in return rate was observed to cause a decrease in RR. A program was written for the programmable calculator which allows the operator to enter the present AE-RR rate. This value is considered in conjunction with the other input items and a readout is given, providing the operator with the new setting in gpm. The complete list of input items are:

1. Influent flow
2. Most recent PE-TOC
3. Present RAS rate
4. Most recent RAS-TOC
5. Present aerator mode
6. Present AE-RR

Relationship of RR and Mode Changes

The configuration of the Hillsboro plant aerator-clarifier relationship was described in Section 4 and shown in Figure 2. The ability to regulate the feed points and aeration time is the other major factor in respiration rate control. Mode change criteria was revised three times during the course of the study and in July 1975 a scheme was developed which limited the frequency of changes to prevent undue internally-caused shocks to the process. These criteria are discussed in the Section 8.

The interrelationship of RAS-TOC has been observed to have a marked effect on sludge quality and RR. When the RAS-TOC exceeded 5,000 mg/l, the process trended toward instability. A rapid rise in RAS-TOC and RAS-ATP generally resulted after industrial shock loads. The most immediate corrective action was toward longer sludge aeration times which is affected by mode changes that favor this condition. The RR is used to indicate the progress of stabilizing excess food that is carried through the aeration-sedimentation cycle and back to the aerator. There appears to be detrimental effects to the system when apparently unoxidized food is recycled concurrently with incoming loads.

SECTION 6

OPERATION PROCEDURES

USE OF PROGRAMMABLE CALCULATOR DURING THE STUDY

The use of programmable calculator was initiated at Hillsboro in June 1974, and has been in continuous use since that date. The first piece of equipment to be used was a Monroe 1775 with a card reader for data input. This unit was replaced with a Tektronix Model 31 calculator utilizing keyboard program language input and alphanumeric printout. The Model 31 can be programmed by plant personnel and the most difficult program to date was completed in less than six hours.

The operator used all of the following on a routine basis to carry out the required operation procedures in connection with the control strategy:

1. Determination of settlometer mixing ratios.
2. AE respiration rate and aeration time.
3. RAS rate.
4. Wasting time required for process control.
5. Cost of polymer for flotation thickener.
6. Aeration mode.
7. AE-ATP in mg/l from standardization curve.
8. RAS-ATP in mg/l from standardization curve.

Practical Use of Calculator

There are many advantages to the use of the calculator in its present capacity, not the least of which is uniformity of data transmittal and handling. The following list summarizes a few of the main features of the concept.

1. Operation instructions are uniform, as an example, RAS pump settings are established by the preplanned program and after evaluation of the program parameters printed into the calculator programs, a readout telling what the new setting should be in gpm is printed out.

2. Arithmetic errors are reduced materially.

3. The time factor for making calculations is essentially eliminated.

4. Information on basic operation instructions are available 24 hours a day.

5. Elements can be built into the system for eventual plant automation.

6. Complicated procedures, such as determining the slope of the standardization curve to obtain a readout in mg/l for the ATP test, were accomplished quickly, allowing results to be applied immediately for the process control.

7. Certain unit cost information is immediately available and useful in process control. As an example, cost information on polymer use per dry ton for flotation thickening is included in the sludge wasting program, keeping the awareness of cost efficiency before the operator.

MODE CHANGE CRITERIA

As discussed earlier, changing aeration modes to maintain the desirable respiration rate was an integral part of the control strategy.

Three mode change criteria were used during the course of this study, each one being a refinement of the previous one and each was instituted following an evaluation of operation experience.

The reader is referred to Figure 2 for the configuration of quadrants and feed points.

Mode Change Criteria - 7/25/74 to 10/20/74

Instructions for determining the aerator mode of operation:

1. A respiration rate should be run on the AE two or three times each shift (a few hours apart) and

if the present respiration rate comes out:	the mode should be (until the next RR is run):
Greater than 25	2-2 unless today's base mode (see below) is a higher
Between 20 and 25	1-3 mode; in that case, don't go below the base mode.
Less than 20	Same as the base mode.

2. If yesterday's respiration rate average was:

If yesterday's respiration rate average was:	today's base mode is:
Greater than 25	3-1
Between 20 and 25	2-2
Between 15 and 20	1-3
Between 12 and 15	0-4
Less than 12	0-3

Table 10. MODE NUMBER DEFINITION

Mode Number*	PE Feed Point	RAS Feed Point
3-1	Quad. D	Quad. A
2-2	Quad. C	Quad. A
1-3	Quad. B	Quad. A
0-4	Quad. A	Quad. A
0-3	Quad. A	Quad. B

*The first digit refers to the number of quadrants in which RAS aeration is taking place.

The second digit refers to the number of quadrants in which ML aeration is taking place.

Mode Change Criteria - 10/21/74 to 7/22/75

1. The shift supervisor was responsible for making mode changes. If no shift supervisor was on duty, the person on duty who had been employed at the plant the longest was responsible.

2. The objective was to keep the AE-RR within the range 12 to 15 as much as possible.

3. The principle was:

   a. If the AE-RR was less than 12, move in the direction from 3-1 toward 0-3 one or more modes. This tends to decrease the aeration time and increase the AE-RR or, it provides less RAS stabilization time and increased AE-RR.

   b. If the AE-RR was greater than 15, move toward 3-1 one or more modes. This increased the aeration time and decreased the AE-RR or, provided more RAS stabilization and eventually decreased the AE-RR.

4. In general, when the AE-RR was:

   a. Far out of range (less than 8 or more than 19), movement of one mode once per shift until the AE-RR returned within to 12 to 15.

   b. A little out of range (8 to 12 or 15 to 19) the operato considered the following before making a decision:

(1) The trend of the AE-RR.
(2) The PE TOC and its trend.
(3) The usual daily trends, especially for that day of the week.

Table 11. MODE CHANGE INSTRUCTIONS 10/21/74 - 7/22/75

Mode Number	PE Feed Point	RAS Feed Point	Keep the DO at 1 to 4 mg/l in Quadrants	Keep the Air Valve Off at Quadrants
3-1	D	A	All	--
2-2	C	A	All	--
1-3	B	A	All	--
0-4	A	A	All	--
0-3	A	B	B, C, D	A
0-2	A	C	C, D	A, B
0-1	A	D	C	A, B, C

Mode Change Criteria - 7/23/75

Near the end of the study in May and June 1975, a series of upsets occurred leading plant personnel to review the operation procedure. The sludge was typically bulky a portion of the time and as is the case with bulking sludge, good treatment was achieved as long as solids could be kept from overflowing the secondary clarifier weirs. The system was very unstable during high flow periods of the day consequently treatment efficiency fluctuated markedly depending on hydraulic loading.

Persistent upset conditions generally lead to frequent adjustments in process control which, in turn, generate further swings of the pendulum perpetrating further upset. Plant personnel reviewed the trend which was developing in an effort to pinpoint internal causes of upset inasmuch as similar situations had been handled successfully in the past.

Process instability appeared to be related to something associated with the way changes were being made in response to directions given operators by the existing calculator program. It was determined that personnel were carrying out the directives as printed out for a given situation.

Following the review of both data and operation procedures, it was decided to revise the mode change criteria to allow less frequent changes. The rationale behind this move is discussed in more depth in Section 8 titled "Discussion of Interrelated Parameters."

Table 12 outlines the calculator program elements involved in the change criteria.

Table 12. AERATION MODE-CHANGE DIRECTION FOR CALCULATOR PROGRAM (Instituted 7/23/75)

If the present mode is:	and if the present AE R.R. is:	and if the process has been in the present mode:	then:
0-2	<16.0	(all cases)	stay in 0-2
0-2	16.0 - 26.0	<8.0 hours	stay in 0-2
0-2	16.0 - 26.0	>8.0 hours	move to 0-3
0-2	>26.0	(all cases)	move to 0-4
0-3	< 8.0	>72.0 hours	move to 0-2*
0-3	< 8.0	<72.0 hours	stay in 0-3
0-3	8.0 - 19.0	(all cases)	stay in 0-3
0-3	19.0 - 26.0	<12.0 hours	stay in 0-3
0-3	19.0 - 26.0	>12.0 hours	move to 0-4
0-3	>26.0	<8.0 hours	stay in 0-3
0-3	>26.0	8.0 - 12.0 hours	move to 0-4
0-3	>26.0	>12.0 hours	move to 1-3
0-4	< 8.0	<24.0 hours	stay in 0-4
0-4	< 8.0	>24.0 hours	move to 0-3
0-4	8.0 - 22.0	(all cases)	stay in 0-4
0-4	22.0 - 30.0	<24.0 hours	stay in 0-4
0-4	22.0 - 30.0	>24.0 hours	move to 1-3
0-4	>30.0	<8.0 hours	stay in 0-4
0-4	>30.0	>8.0 hours	move to 1-3
1-3	<18.0	(all cases)	move to 0-4
1-3	18.0 - 40.0	(all cases)	stay in 1-3
1-3	>40.0	<12.0 hours	stay in 1-3
1-3	>40.0	>12.0 hours	move to 2-2
2-2	<20.0	(all cases)	move to 1-3
2-2	20.0 - 40.0	(all cases)	stay in 2-2
2-2	>40.0	<12.0 hours	stay in 2-2
2-2	>40.0	>12.0 hours	move to 3-1
3-1	<20.0	(all cases)	move to 2-2
3-1	>20.0	(all cases)	stay in 3-1

*Program will not allow a move to mode 0-2 unless AE-RR daily average has been below 8.0 for three consecutive days.

WASTING CRITERIA

The secondary clarification at the Hillsboro plant allows waste sludge to be drawn either from a "sludge pocket" under the sludge collection arms or from the RAS line.

Sludge is wasted to a flotation thickener at a constant rate of 58 gpm (3.6 l/s), through a positive displacement pump. The amount to be wasted was found to be a function of settleability and RAS TOC. The settleability factor was determined from the CSV_5 results and RAS TOC was previous days average.

The criteria for wasting time (WT) for various daily averages of RAS TOC and CSV_5 is based on an assumed RAS SS of 10.0 g/l. Actual wasting time (WT) is calculated by modifying "X" from Table 13 as follows:

$$WT = (X) \left(\frac{10}{6 + 0.4\,(RAS\ SS)} \right) Hrs$$

Table 13. WASTING CRITERIA

<table>
<tr><th></th><th>Mode 1-3 to 0-4</th><th>Mode 0-3</th><th>Mode 0-2</th></tr>
<tr><td>RAS-TOC mg/l
7000

6000</td><td rowspan="2">X = 15 Hrs
for $CSV_5 < 500$

X = 10 Hrs
for $CSV_5 > 500$</td><td>X = 15 Hrs
for $CSV_5 < 500$

X = 10 Hrs
for $CSV_5 > 500$</td><td rowspan="2">X = 10 Hrs
for $CSV_5 < 500$

X = 5 Hrs
for $CSV_5 > 500$</td></tr>
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for $CSV_5 < 500$

X = 5 Hrs
for $CSV_5 > 500$</td></tr>
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for $CSV_5 < 500$

X = 5 Hrs
for $CSV_5 > 500$</td><td rowspan="3">X = 5 Hrs
for $CSV_5 < 500$

X = 0 Hrs
for $CSV_5 > 500$</td></tr>
<tr><td>4000</td><td rowspan="3">X = 5 Hrs
for $CSV_5 < 500$

X = 0 Hrs
for $CSV_5 > 500$</td></tr>
<tr><td></td><td rowspan="3">X = 5 Hrs
for $CSV_5 < 500$

X = 0 Hrs
for $CSV_5 > 500$</td></tr>
<tr><td></td><td rowspan="3">X = 0 Hrs
all cases</td></tr>
<tr><td>3000</td><td rowspan="2">X = 0 Hrs
all cases</td></tr>
<tr><td>2000</td><td>X = 0 Hrs
all cases</td></tr>
</table>

Although the wasting program was in a continuous state of refinement prior to and during the study, the same principles, discussed in Section 8, were applied. At the beginning of the study only RAS-TOC and CSV_5 were used as input parameters to the wasting-time calculator program. During the course of the study it became evident that the aeration mode must also be input to prevent loss of long-range process control, indicated by increasing CSV_5 values or a slower sludge settling rate.

The final, very successful, wasting program consisted of a calculator program containing the criteria of Table 14. Sludge was wasted to a flotation thickener at a constant rate through a positive displacement pump from the "sludge pocket" at the bottom center of the secondary clarifier.

The sludge concentration from this location was related to the RAS concentration by a formula based on actual data. The amount to be wasted is a function of three parameters, all averages of the previous day: RAS-TOC, aeration mode, and CSV_5. The daily wasting time (WT) was found by modifying the X hours from Table 14 by the previous formula which corrected for the concentration and the clarifier exit location of the material wasted.

RAS FLOW CONTROL CRITERIA

As noted earlier, the objective in varying RAS was to hold the modified F/M within a predetermined range of values which in turn affects the AE-RR and thus the condition of the biomass and quality of the effluent.

Initially the goal was to maintain a constant value as determined by the ratio between PE TOC as a measure of F and RAS TOC for M. As more data was collected and reviewed it became evident that the system could not be controlled when high loading forced respiration rates to corresponding high values. Consequently, an empirical equation was written to allow the modified F/M ratio used in RAS rate control to be varied in order to help hold respiration rates within the desired range. Holding RR below 20 by altering the mode has improved effluent quality at the Hillsboro plant.

As shown in Figures 2 and 3, the aerator configuration can be approximated as four quadrants with the capability of introducing return sludge and/or primary effluent to each quadrant. By trending toward contact stabilization when it is desired to reduce RR and trending toward plug flow and less quadrants in use for mixed liquor when an increase in RR is indicated, the process can be held in balance.

This control relationship is displayed in Figure 8.

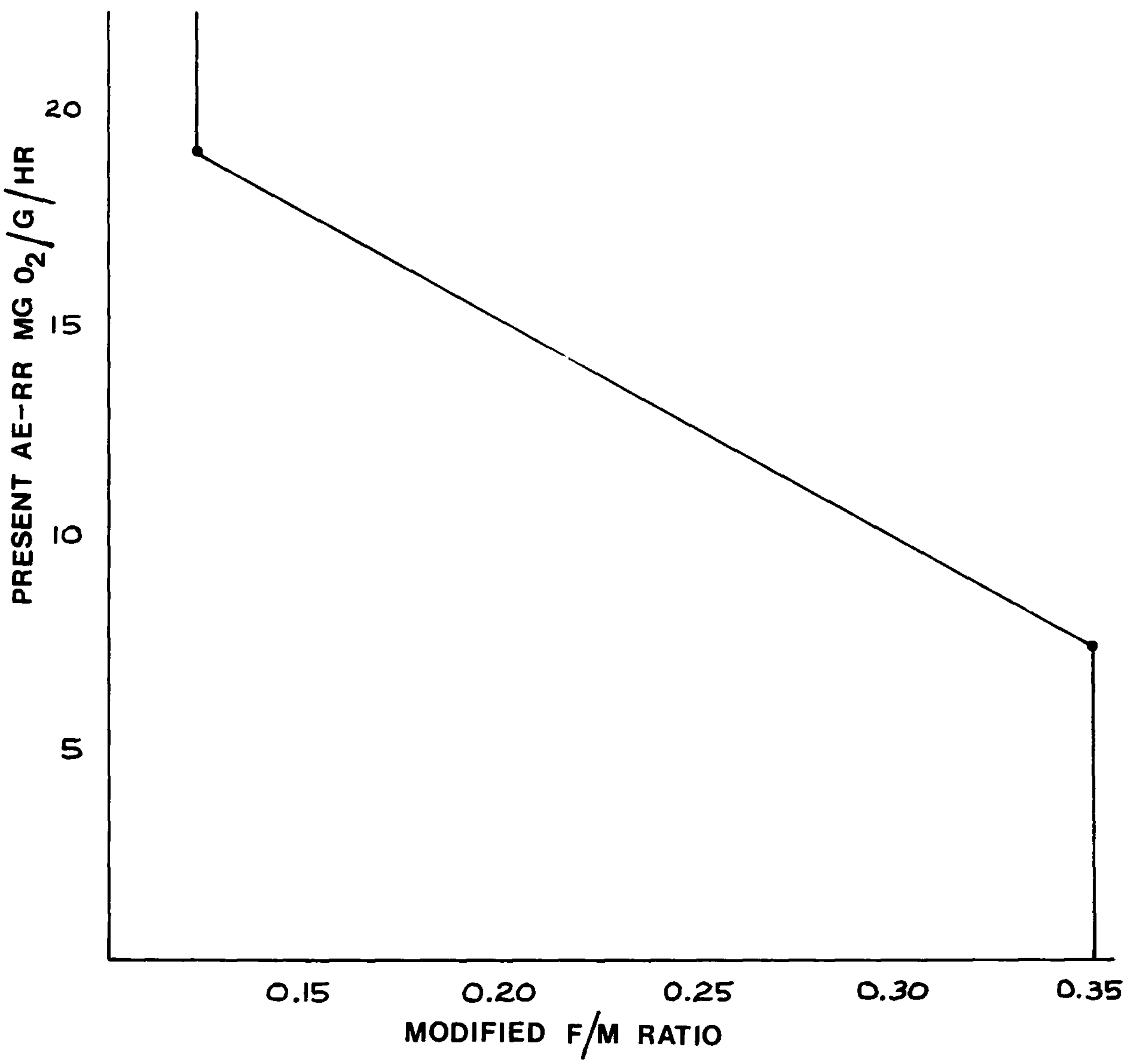


Figure 8. Respiration rate--modified F/M relationship.

SECTION 7

EXPERIMENTAL PROCEDURES

The major instruments used during this study were the Dohrmann-Envirotech Model 51 TOC Analyser and the JRB ATP Photometer. In order to apply these units to the goals of this research specific procedures were developed. Particularly in the case of the ATP Photometer, considerable time was spent perfecting a procedure that would yield repeatable results and be adaptable to use by operators on 24-hour shifts.

The following outlines procedures that were used by shift personnel as frequently as seven times a day in order to obtain the required operation information for process control.

TOC ANALYSIS

TOC Analyser As A Process Tool

As a process tool, the Dohrmann-Envirotech TOC Analyser has proven to be a reliable instrument and capable of being used by as many as 10 different individuals in a week performing as many as 135 determinations. The unit is calibrated daily requiring approximately 20 minutes. The only major expenses have been associated with repair or replacement of the pyrolysis tube.

Gas and chemicals cost about $3.00 per day.

Equipment and Procedures

Samples

1. Aerator Effluent (AE), Return Activated Sludge (RAS), Primay Effluent (PE), and Final Effluent (FE).

Sample Preparation

1. AE - Dilute 250 ml of AE to 500 ml with distilled water. Place the sample in a blender and blend it at top speed (liquify) for 90 seconds.

2. RAS - Dilute 50 ml of RAS to 500 ml with distilled water. Place the sample into a blender and blent it at top speed (liquify) for 90 seconds.

3. PE - Run full strength. No blending necessary.

4. FE - Run full strength. No blending necessary.

5. None of the samples were acidified prior to analysis.

Equipment and Reagents

1. Envirotech Model DC-50, Total Organic Carbon Analyzer.

2. Compressed Gasses

   a. Ultra pure helium

   b. Hydrogen

   c. Compressed air

3. Osterizer Blender

4. 50 Microliter Syringe

5. Manganese dioxide

6. Potassium Biphthalate MW 204.23

Reagent Instructions

1. MnO_2 - Changed daily.

2. Potassium Biphthalate - Dissolve 0.6375 g in distilled water and dilute to 1 liter. (Standard stock solution.)

Calibration

1. Sample Size - 30 microliters.

2. Sample - 300 mg/l potassium biphthalate TOC standard.

3. If necessary, after analyzing the standard with the TOC analyzer, set the span so the display reads 300.

Sample Analysis - Procedure

1. Set TOC analyzer in Organic Carbon Mode for all samples.

2. Sample Size - 30 microliters.

3. Push the "Baseline" button.

4. Move the boat into the pyrolysis zone.

5. When the baseline has stabilized, somewhere less than a reading of 20, move the boat to the heat sink.

6. Push the "Operate" button.

7. Using a well mixed sample, withdraw at least 50 microliters of sample being careful not to trap air bubbles in the barrel.

8. Invert the syringe and tap it gently to remove any trapped air, if present.

9. Eject all but 30 microliters of sample and wipe off the syringe.

10. After the boat has been in the heat sink for at least 45 seconds, remove it to the injection septum.

11. Inject the 30 microliters sample carefully into the MnO_2 in the boat.

12. Push the "Start" button.

13. Move the boat immediately into the vaporize zone.

14. After approximately 2 1/2 minutes, a signal will sound. Move the boat into the pyrolysis zone at this time.

15. After approximately another 2 1/2 minutes, the signal will sound again indicating the end of the integration period. The number in the display is the concentration of TOC in mg/l. (Except AE and RAS samples, multiply the AE by 2 and the RAS by 10 to determine TOC in mg/l.)

16. If more samples are being run at this time, push the "Baseline" button. If the display is stabilized at less than 20, withdraw the boat to the heat sink and repeat the procedure starting with No. 5. If the "baseline" is greater than 20 or has not stabilized, repeat the procedure starting with No. 4.

17. If no more samples are to be run, withdraw the boat to the heat sink and leave in this position until the next use.

ATP ANALYSIS

Inasmuch as very little information was available on sample preparation and procedural technique for use of the JRB ATP analyser in conjunction with plant process control, it was necessary to develop this as part of the study.

<u>Procedural Observations</u>

1. The temperature of the Tris buffer must be maintained at 100 degrees Celsius before and after the sample has been injected into the buffer.

2. The best boiling time for the samples must be determined to insure complete lysing of the cells. If the samples are boiled for too great a time period, the ATP will begin to be destroyed.

3. After the samples have been boiled, distilled water must be added to the system to bring the volume back to 10 ml.

4. When storing the samples for later analysis, they must be cooled and frozen immediately after being boiled to prevent loss of ATP from the system.

5. The samples must be thawed slowly and in an ice bath. They must also be maintained in an ice bath until analyzed.

Conclusions Drawn from Observations

1. The greatest temperature reached in the buffer in the test tube was 98 degrees Celsius. If a higher temperature is necessary, as has been indicated, a different solution needs to be used for heating the buffer. This temperature did not change after 30 minutes of being in a boiled water bath.

2. Contrary to JRB's instruction manual, the boiling time of the sample does appear to be important. The ATP concentration of samples analyzed after having boiled for 5 to 10 minutes was fairly constant. However, after 15 minutes, the ATP concentration was found to be 10 to 15 percent greater. More testing indicated 15 minutes to be the best boiling time.

3. The thawing rate and the temperature the samples are thawed at also affect the system. Samples thawed in an ice bath had 2 to 5 percent greater ATP concentrations than samples thawed in a warm water bath. Furthermore, samples kept in an ice bath lost 10 to 15 percent of their ATP after 1 1/2 hours while samples kept in the open at room temperature lost 20 to 30 percent of their initial ATP concentration during the same time period.

4. When samples were analyzed without freezing prior to analysis but rather immediately after boiling them, AE ATP concentrations of about 10 ppm and RAS ATP concentrations of about 35 ppm were obtained.

Procedural Problems

Certain errors were identified during the early stages of procedural development and these are identified below.

1. Not injecting the samples directly into the boiling Tris-buffer but rather getting it onto the sides of the test tubes.

2. Not allowing the buffer to become hot enough before injecting the samples. This results in a slow killing of the bacteria and considerably low ATP readings.

3. Boiling the samples unnecessarily long which might result in incorrect readings.

4. Mislabeling the samples for storage.

5. Using incorrect volumes and dilutions for the samples.

6. Letting the samples sit too long before fixing them for analysis.

7. Leaving the sample out to cool allowing possible sample contamination. Air-borne bacteria may then consume a significant portion of the ATP before the sample analysis is performed.

Equipment and Procedures

Reagents

1. Tris Buffer (Tris [hydroxymethyl] amino methane hydrochloride)

   Avg. M.W. = 147.7

   Dissolve 2.954 g in distilled water and bring the volume up to 1 liter. Adjust the pH to 7.75 with HCl. Sterilize in an autoclave at 121 degrees Celsius for 15 minutes.

   2.954 g/l = 0.02m

2. Adenosine 5' - Triphosphate

   1 mg - preweighed vial (Sigma Chemical Co.)

   Dissolve the contents of the vial in sterilized Tris buffer and bring the volume up to 10 ml. Keep the sample frozen.

   ATP conc. = 100 mg/l

3. Firefly Extract

   FLE-50 from Sigma Chemical Co. - premeasured vials.

   Add approximately 15 ml sterile Tris buffer to the vial of firefly extract. Cap the vial, shake to mix the contents and refrigerate the sample for at least 12 hours before use. Do not shake up the vial after it has been in the refrigerator and is ready for use. The solids which have settled out may cause unreliable readings in the ATP determination. Use only the clear supernatant.

Preparation of Glassware

1. All glassware was washed with soap and water and rinsed at least 5 times after the last trace of soap was noticed.

2. The glassware was then soaked in a 10% solution of HCl.

3. This was followed by 5 rinses in tap water followed by 5 rinses in distilled water.

4. All glassware was heat dried in a drying oven and then cooled to room temperature before use.

Equipment

1. Autoclave

2. Heating mantle

3. Sand

4. Scintillation vials

5. ATP photometer - JRB Inc.

6. Ice bath

7. Automatic pipet with disposable tips

Procedure

1. Samples

    a. Aerator effluent diluted 1:2 with distilled water.

    b. Return activated sludge diluted 1:10 with distilled water.

2. ATP Standards

    a. 100 mg/l.

    b. 9.9 ml sterile Tris buffer + 0.1 ml "A" = 1 mg/l.

    c. 18.0 ml Tris buffer + 20 ml "B" = 0.1 mg/l.

    d. 5 ml Tris buffer + 5 ml "C" = 0.05 mg/l.

    e. 9 ml Tris buffer + 1 ml "C" = 0.01 mg/l.

    Keep Standard "A" frozen until needed. Thaw slowly in an ice bath. Retain Standards "C", "D" and "E" for the calibration of a standard curve. Make them fresh daily or more frequently if needed.

3. Sample Preparation

    a. Fill the heat mantle with sand.

    b. Place 9.5 ml sterile Tris buffer into one scintillation vial and 9.8 ml sterile Tris buffer into another vial. Each vial should be pre-marked (etched) at the 10 ml mark.

    c. Place the vials into the sand and turn the heat mantle on high.

d. Place a boiling stone into each vial and heat to boiling.

e. When the buffer in each vial is boiling, add 0.5 ml of RAS to the vial with 9.5 ml buffer, and add 0.2 ml of AE to the vial with 9.8 ml buffer.

f. Let the samples continue to boil for 6 minutes.

g. Remove the vials from the sand and place them into an ice bath immediately.

h. When the samples have been cooled, bring the volume back to 10 ml in each vial with distilled water.

4. Sample dilution.

AE	=	1:2 initial dilution
	=	1:50 sample dilution
	=	1:100 final dilution
RAS	=	1:10 initial dilution
	=	1:20 sample dilution
	=	1:200 final dilution

Sample Analysis

1. ATP Photometer

a. The photometer was allowed to warm up for at least 30 minutes prior to use.

b. The attenuator control was set at 0.0.

c. The high voltage control was set at 6.0.

d. The zero control was set at 5.09. This gave an average of 18 CPM "noise" when the photometer was run without a sample.

2. Sample Preservation

a. All samples, including the standards, were left in an ice bath during the analysis procedure.

b. AE and RAS samples were usually discarded after analysis. However, occasionally these samples were frozen so they could be analyzed at a later date.

c. Standards were kept in the refrigerator until needed. They were prepared fresh daily except the "A" standard which was frozen and thawed as needed to prepare new standards.

d. Sterile Tris buffer was kept in small volumes. After the buffer flask had been opened and used, any remaining buffer in that flask was discarded if not needed.

e. Firefly extract was kept in the refrigerator until needed.

3. Sample Analysis

a. Using the automatic pipet, inject 0.5 ml of firefly extract into a scintillation vial. Swirl the vial to disperse the liquid over the bottom of the vial.

b.

(1) Place the sample in the light chamber and place the cap on the chamber.

(2) Put the timer on 6 seconds.

(3) Pull out the slide and push the start button.

(4) At the end of the integration period (6 seconds), record the number in the display as the background reading.

(5) Push in the slide and remove the vial from the chamber.

(6) Push the reset button.

(7) Push the 60 second timer.

c.

(1) Using the automatic pipet with a clean pipet tip, withdraw 0.5 ml of one of the samples (well mixed - either AE or RAS) or standards.

(2) Inject this sample in the vial containing firefly extract. At the same time the sample is injected into the vial, push the foot starting switch.

(3) Swirl the vial to mix the contents.

(4) Place the vial into the light chamber and place on the cap.

(5) Pull out the slide.

(6) At the end of the integration period, record the number in the display as counts per minute for the sample.

(7) Push in the slide and remove the vial.

(8) Push the reset button and repeat this procedure for all samples.

4. Determination of ATP Concentration*

a. For each series of samples, a calibration curve was determined from the three ATP standards, 0.1 mg/l, 0.05 mg/l and 0.01 mg/l.

b. If the background readings were extremely high or differed considerably (higher) from readings obtained for other samples analyzed with the same firefly extract, the vials were discarded (rewashed).

c. The reference points for all samples were determined by subtracting the background reading from the counts per minute for that sample.

d. The slope of the standard curve was determined.

e. Using the 0.1 mg/l standard as a reference point and the slope of the curve, the counts per minute for the unknown samples were converted to concentration (mg/l) and multiplied by the appropriate dilution factor to determine actual ATP concentration in the sample.

f. As the ATP standard curve changes slowly with time for the same firefly extract, the standards should be run several times at various intervals if there are many unknown samples to be tested at the same time.

The calibration method is as follows:

Slope (1) was found by running determinations on the known (K) concentration of the three standards. The unknown (U) was analyzed and Slope (2) compared with Slope (1) using the programmable calculation. See Figure 9.

$$\text{Slope (2)} = \frac{CPM(K) - CPM(U)}{ATP(K) - ATP(U)}$$

$$ATP(K) - ATP(U) = \frac{CPM(K) - CPM(U)}{\text{Slope (2)}}$$

$$ATP(U) = ATP(K) - \frac{CPM(K) - CPM(U)}{\text{Slope (2)}}$$

*For this study, a program was written for the programmable calculator which determined the ATP concentration of the samples. By entering the background and counts per minute for each sample and the standards, the ATP was read out in mg/l.

The assumption is made that Slope (1) equals Slope (2), then:

$$ATP(U) = ATP(K) - \frac{CPM(K) - CPM(U)}{Slope\ 1}$$

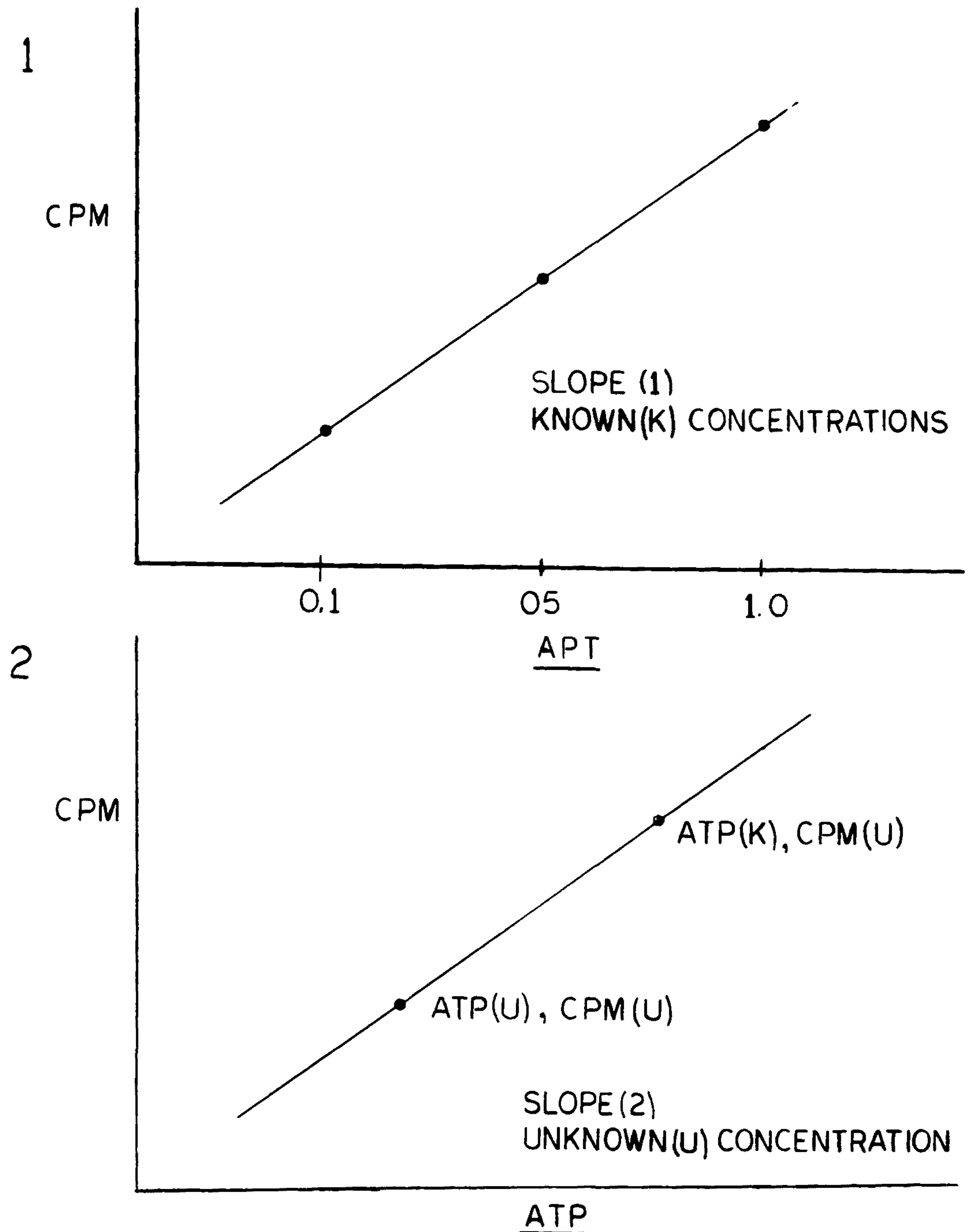


Figure 9. ATP standardization curves.

RESPIRATION RATE ANALYSIS

Respiration Rate (RR) Procedure Use

The procedure used for this study was perfected over a period of time prior to commencement of this study and has been found to yield repeatable results.

As described earlier, plant operators made these determinations 4 to 7 times daily using the following equipment and procedures.

Equipment and Procedures

Sample

1. Aerator Effluent

Equipment

1. International Centrifuge Model HM-S - Use the same speed for all samples. (Set on maximum speed.)

2. Gooch Crucibles

3. Whatman GF/A Filters 2.1 cm

4. YSI Model 51A with self-stirring BOD probe and Meter

5. Analytical Balance

Necessary Determinations

1. AE Suspended Solids Concentration (g/l)

   a. Direct weight determinations made daily and a daily "factor" determined.

   b. Determined indirectly by centrifuge for every respiration rate using the "factor."

2. Oxygen uptake during a 3-minute period.

AE Concentration (g/l)

1. Factor

   a. Centrifuge two 40 ml samples of AE for 15 minutes at a set speed.

   b. Determine the average ml of sediment in the two tubes and record this number.

   c. Determine the weight of a crucible and filter.

d. Place the crucible on a suction apparatus, wet down the filter and apply suction.

e. Filter 5 ml of AE through the filter.

f. When all the liquid has passed through the filter, remove the crucible and dry it in a drying oven for 1 hour.

g. Remove the crucible and cool to room temperature in a dessicator.

h. Determine the weight of the crucible and dry residue.

i. To determine the daily factor:

(1) Wt. of residue in grams = (H)-(C).

(2) $\frac{\text{Wt. of residue (g)}}{\text{ml filtered 5 ml}} \times \frac{1000\ \text{ml}}{1} = \text{Wt. of residue (g/l)}$

(3) $\frac{\text{Wt. of residue (g/l)}}{\text{ml of sediment in 40 ml tube}} = \text{Factor } \frac{\text{(g/l)}}{\text{ml}}$

2. Indirect Determination

a. Centrifuge two 40 ml samples of the AE being used for the respiration rate for 15 minutes at the set speed.

b. Determine the average ml of sediment in the tubes.

c. The AE concentration is approximately equal to the factor $\left(\frac{\text{(g/l)}}{\text{ml sediment}}\right)$ times the (ml sediment) = g/l

Oxygen Uptake

1. Aerate a well mixed sample of AE by pouring some AE (about 500 ml) into a 1 liter jar, capping the jar and shaking it for about 1 minute.

2. Pour the aerated AE into a 300 ml BOD bottle.

3. Insert the BOD probe, adjust the temperature, set the scale on DO and turn on the probe stirrer.

4. When the DO concentration is declining at a constant rate (approximately 2 minutes after pouring sample into BOD bottle), begin the readings.

5. Take an initial reading of DO and then once per minute for the next 3 minutes.

6. Run the data (AE concentration g/l) and the DO readings through the calculator which is programmed to determine the respiration rate.

RESPIRATION RATE DETERMINATION

1. The calculator program is set up to calculate the respiration rate in mg/l O_2 per AE per hour. This is done by determining the O_2 depletion over a 3-minute period, extrapolating this depletion for an hour period and dividing the O_2 depletion by the AE concentration in g/l.

2. Calculation:

$$\text{AE RR} = \frac{(3a + b - c - 3d)(6)}{e}$$

where a = first DO reading
b = second DO reading
c = third DO reading
d = fourth DO reading
e = AE suspended solids concentration (g/l)

CORRECTED SETTLOMETER TEST

Use of Settlometer

A 2 l Mallory Settlometer with a procedure developed by plant lab personnel was used to determine sludge settleability. Most applicable results were obtained when the 5-minute value was used based on a sample containing 2 g/l of solids. The solids were blended from Aerator Effluent (AE) and Return Activated Sludge (RAS) according to the following procedure.

Equipment and Procedures

Samples

1. AE
2. RAS

Equipment

1. 2 l Mallory Settlometer
2. Stop Watch

Procedure

1. Determine AE and RAS concentrations in g/l using lab centrifuge and applying gravimetric/centfifuge calibration factor.

2. Determine the mixture of AE and RAS to be used in the settlometer as follows:

a. Dilution Method A

(1) ml of RAS $= \frac{2.0 \text{ g}}{\text{RAS g/l}} \times \frac{1{,}000 \text{ ml}}{1}$

(2) ml of AE $= \frac{2.0 \text{ g}}{\text{ML g/l}} \times \frac{1{,}000 \text{ ml}}{1}$

(3) If the sum of (1) and (2) is equal to or less than 2,000, add these volumes and make up to 2,000 ml with tap water if necessary.

(4) If the sum of (1) and (2) is greater than 2,000 use dilution method B.

b. Dilution Method B

(1) Determine ml of RAS and AE to be used by the following formula:

$$\text{ml of RAS} = \frac{(2{,}000)(\text{AE g/l} - 2)}{(\text{AE g/l} - \text{RAS g/l})}$$

and ml of AE = 2,000 - ml of RAS

(2) After settlometer has been filled, stir contents gently and reverse direction of stirring paddle to stop swirling motion.

(3) Time for 5 minutes and read sludge/water interface.

SECTION 8

DISCUSSION OF INTERRELATED PARAMETERS

INTRODUCTION

In May and June 1975, 60 to 90 days prior to the end of the study period, process trouble developed that required an analysis of several basic premises considered as determing factors in process control. This section summarizes the operating conditions during this period and presents the rationale for altering earlier procedures based on conclusions drawn from evaluating process response to conditions existing during the period under consideration.

The principle cause of plant problems was believed to be attributed to a too young, slow settling sludge. This resulted in poor quality effluent on a number of days when sludge bulking occurred in the secondary clarifier.

Prior to implementing a defined sludge wasting program, the plant frequently had process failure due to improper sludge maturity. However, between July 1974 and May 1975 the program had been successful in preventing sludge bulking for reason of a too "young" biomass. As an initial premise the use of RAS ATP in place of RAS TOC in the modified F/M ratio control program was suspected to be the principle cause of the failure.

Examination of previous data by plant personnel led to the theory that there appears to be a natural maturation process which causes changes to take place in the biomass during periods of limited food supply. These changes counteract the changes which take place during periods of abundant food supply. A biomass which is trending toward greater "maturity" has been observed at Hillsboro to have a faster settling rate as measured by the 5-minute corrected settlometer.

The biomass, if allowed to become very "mature", is also observed to be less active - its ability to quickly absorb organic material is reduced. Just the opposite is observed to happen during periods of heavy wasting or heavy organic loading. The "maturity" of the biomass, and therefore the settling rate of the floc, can be controlled by controlling the wasting rate. The degree of control is limited because the wasting rate is also used to control the quantity of biomass in the system. Furthermore, there is no easy way to predict which way the settling rate will trend except by experience, much less calculate the exact value, from the other process parameters. The way in which the food input, growth rates, wasting rates, quantity of biomass in the system, temperature, kinds of microorganisms present, etc., are related are obviously going to be infinitely complex.

Personnel at the Hillsboro plant therefore, use an information-feedback control method in which parameter values involved in the above relationships were chosen, based on experience and intuition, to derive the equations from which the actual wasting time is calculated. Control relationships are thus established whereby the parameters (RAS TOC, 5-minute corrected settlometer) are used as feedback information to calculate the control parameter (wasting rate) which, in turn, controls the feedback parameters. The equations were refined or adapted and after they were used for a time, refined again. A calculator program thus evolved which proved to be successful in controlling both the settling rate of the floc and the quantity of biomass in the system on a long-range basis, without knowing the complex relationships between the process parameters involved.

THE MAY-JUNE 1975 PROBLEM

It was assumed that a "too-young" biomass developed by too frequent and too many mode changes. The course of events was hypothesized as follows:

> Assume the aeration process is in 0-2. (The first digit refers to the number of quadrants being used for sludge conditioning in a contact stabilization mode of operation while the second digit refers to the number of quadrants in which ML is being aerated.) See Figure 10.

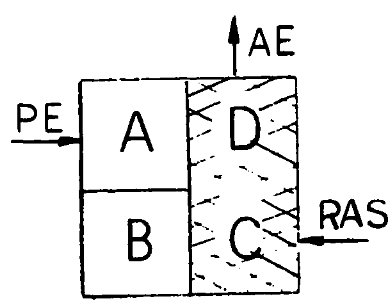


Figure 10. Mode 0-2.

Primary effluent is entering at Quadrant A. RAS at Quadrant C. Quadrants A and B contain only primary effluent, and Quadrants C and D contain mixed liquor.

Consider the transition when the mode is changed to 0-4:

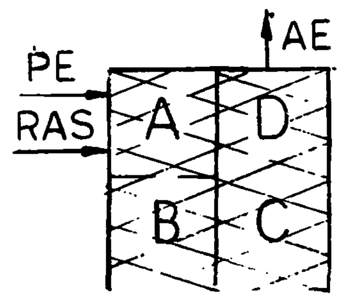


Figure 11. Mode 0-4

All quadrants are filled with mixed liquor. When the RAS feed point is moved from Quadrant C to Quadrant A for several hours or more until the new desirable equilibrium is reached, an undesirable situation is created. Until the mixed liquor is built up in Quadrants A and B, the F/M ratio in those quadrants is extremely high. This mode change appears to slow down the natural maturation process of the biomass, replacing the balance (between that process and a controlled growth) with wild new growth. This situation normally causes little harm to the activated-sludge process because of its short duration. However, during May, there were sufficient number of these situations to be in the principle cause of the "too-young" sludge problem.

The mode change from 0-2 to 0-4 was only an illustration. Actually, 0-2 to 0-3 and 0-3 to 0-4 would result in the same situation but to a lesser extent.

The foregoing is not the only problem with mode-change transitions. An additional problem occurs when moving from a noncontact stabilization mode to a contact stabilization mode. As an illustration, suppose the process was in mode 0-4 and the AE RR indicated insufficient aeration time. Other modes trending toward contact-stabilization can handle a much higher organic loading but only after the solids concentrations have stabilized. During the transition, for about 24 hours, it is actually equivalent to moving to a lower mode. Moving from 0-4 to 2-2 is similar to moving from 0-4 to 0-2 approximately the first 24 hours. See Figure 12.

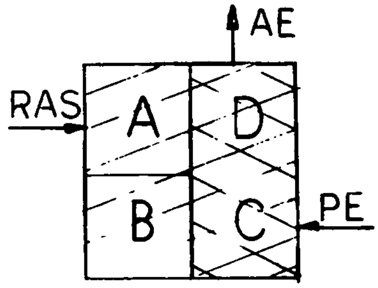
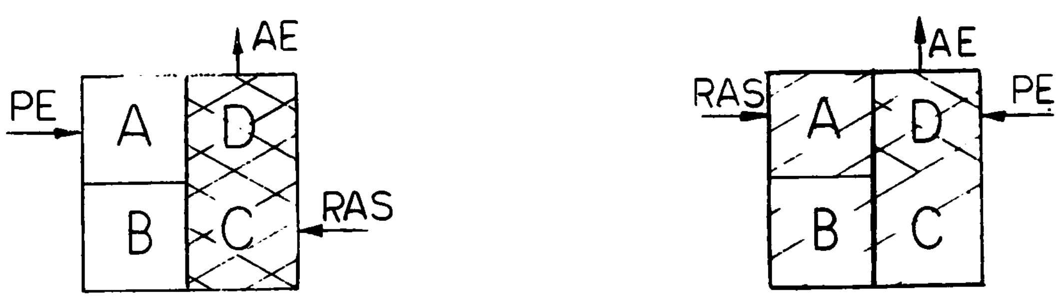


Figure 12. Mode 2-2.

By definition of the mode numbering and considering the transition, the contact time is reduced from the "sludge detention time through four quadrants" to "the sludge detention time through two quadrants." The RAS stabilization time, which is increased from zero to "the RAS detention time through two quadrants," eventually overcomes the problem by the overall ability to absorb and metabolize organic material. This is conjectured to be due to the prolonged period of RAS aeration, during which time the bacteria have metabolized the food sorbed during the time in the aeration basin and are ready to be fed again. In other words, a large pool of hungry bacteria is created which has the ability to metabolize a great quantity of food. But this is true only after the new equilibrium concentrations are reached in the aeration basin. It was observed that the AE RR rose even higher than the previous high value indicating to the plant operator that a "new" mode was needed. This problem seemed to be the root of the May/June difficulty because it caused plant operators, following the existing mode-change instructions, to make too-frequent multiple changes to new modes thus creating even more instability in the process.

In fact, moving from 0-2 to 3-1 in a short period of time combines both of these undesirable situations resulting in double trouble until the new equilibrium concentrations are reached.



MODE 0-2 MODE 3-1

Figure 13. Mode 0-2 and 3-1.

Table 14 shows the effects of excessive "mode shifting" during May 1975.

Table 14. MODE SHIFT FREQUENCIES

Date	Time	RAS TOC	AE TOC	Mode	CSV_5	Fin Eff. JTU	Sludge Surface	RR
5/12	1:30 p.m.	2980	460	0-2	530	13.5	6.5	20
5/12	5:30 p.m.	3930	708	0-4	510	10.3	7.0	23
5/13	5:30 p.m.	2730	772	1-3	500	14.0	7.0	23
5/13	9:00 p.m.	1770	728	2-2	500	20.0	7.0	27
5/14	10:30 a.m.	3250	550	1-3	540	10.0	7.0	9
5/14	1:30 p.m.	2990	858	0-4	480	13.0	7.0	11
5/15	5:30 p.m.	3200	756	0-3	430	19.0	7.0	9
5/16	5:30 p.m.	--	--	0-4	480	24.0	7.0	19
5/17	7:30 a.m.	--	--	1-3	550	17.0	7.0	19
5/18	10:30 a.m.	3870	866	0-4	550	17.0	7.0	8
5/18	4:30 p.m.	3280	706	0-3	900	22.0	--	8
5/19	11:00 a.m.	2970	830	0-2	510	23.0	7.0	6
5/19	5:30 p.m.	3150	722	0-3	610	25.0	5.5	16
5/20	1:30 p.m.	3090	656	0-2	600	19.0	7.0	12
5/20	5:30 p.m.	3630	830	0-3	610	19.0	7.0	26
5/20	8:30 p.m.	4200	662	0-4	660	20.0	7.0	22
5/21	1:30 p.m.	3370	644	0-3	670	14.0	7.0	10
5/22	1:30 p.m.	3180	984	0-2	750	14.5	7.0	13
5/22	8:30 p.m.	2930	804	0-3	670	21.0	7.0	18
5/23	12:00 a.m.	3590	826	0-4	650	21.0	6.0	13
5/23	8:30 p.m.	2330	962	1-3	670	10.0	7.0	15
5/24	8:00 p.m.	3600	1036	0-4	600	9.2	6.0	8
5/25	1:30 p.m.	3350	958	0-3	850	13.0	2.5	6
5/25	4:30 p.m.	3590	1000	0-2	850	14.0	2.0	4

Effective 7/23/75, the mode change rules were replaced by a calculator program which enabled plant operators to accurately make mode changes from a new, more elaborate set of rules discussed in Section 6 and displayed on Table 12. This set of rules involves "the number of hours in the present mode," and is designed to prevent too-frequent mode changes in one direction caused by not allowing sufficient time in the contact stabliization modes for solids concentrations to stabilize. Furthermore, it was designed to prevent moving oppositely too fast, as this is almost always observed to cause higher turbidity in the final.effluent (see Table 14). This was thought to be due to a large net move of sludge from the aeration basin to the secondary clarifier during mode shifts.

DISCUSSION

Conditions Prior to May 1975

With the foregoing presentation in mind it is possible to expand on some of the initial premises. In this regard two questions might be asked:

1. Why did the operation program fail to keep the biomass at the right "maturity" for good settling?

2. Why didn't the condition occur during a similar situation in 1974?

These two questions are related. During the period in May and June 1974 an entirely different set of mode-change instructions were being used. In fact, the activated-sludge process was never put into a mode less than 0-4, and mode changes were much less frequent than in May of 1975. That set of instructions was abandoned during October of 1974 because the plant was producing a poor quality effluent of high turbidity, but no evidence of a young, bulky sludge was observed. The main cause was, more probably. related to digester supernatant return due to insufficient hauling of sludge. The poor quality sludge resulted apparently because the process was in a "higher" mode than desirable to obtain the best quantity of biomass in the system. The mode-change program shown on Table 13 is a compromise between the two previous selections.

Another point to be considered is the wasting program which considers RAS-TOC concentrations before June 20, 1974, the wasting program maintained the RAS TOC below about 4,000 with the exception of May 1974, when the RAS TOC averaged between 4,500 and 5,000. A lower RAS TOC was maintained after that time because higher RAS TOC's were correlated with higher final effluent turbidities. The higher modes and higher RAS TOC's also result in more biomass in the system which may lead to a poor quality effluent.

Considering the capacitance of the system, increased biomass tends to prevent changes in the "maturity" of the biomass. Consequently, an increased biomass will tolerate a larger quantity of food entering the aerator without effecting the maturation rate significantly. On the other hand with a small amount of biomass in the system, the natural maturation process will be easily disturbed by a large quantity of food in the aeration basin and as a result new growth will begin to predominate.

It has been observed that when the settleability of the floc slowly decreases over a period of many days to weeks, conditions are normal and may be reversed by either temporarily decreasing the organic loading (which can seldom be done) or temporarily decreasing the wasting rate. But when settleability decreases rapidly, in a few days or less, conditions are extreme indicating that the natural maturation process is apparently being slowed, or even stopped. This seems to indicate that the types of new growth have been changed from the normal spectrum of types of bacteria present in the "matured" biomass to the quick-growing type which are undesirable and cause difficulty in efficient sedimentation in the secondary clarifier.

Conditions Existing in May 1975

The effects of the RAS ATP control coupled with modified F/M ratio decisions for setting RAS flow rates appear to have influenced instability when the biomass was in a "too-young" condition.

Control decisions caused high RAS flow rates which, when combined with the problem of slow-settling floc, resulted in some serious, undesirable loss of biomass from the system due to sludge bulking in the secondary clarifier. The process of replacing the partly-matured biomass lost from the system with new growth tended to perpetuate the problem.

As the settling rate of the floc became poorer, the biomass on the bottom of the secondary clarifier became less dense. This caused both the RAS TOC and the RAS ATP to decrease, thus creating a demand for higher return rates. The problem stemmed from the fact that the RAS ATP values decreased more than the RAS TOC. Using the RAS ATP parameter as a control, higher return rates were demanded compared to using RAS TOC for control. Consequently, it appears that decisions based on RAS TOC might have alleviated the sludge bulking problem.

Other Considerations in Process Control

On April 17, 1975, alum was added to the aeration basin for control of filamentous organisms. Following this addition, on April 23rd, wasting of sludge was much higher than desirable. During this period plant operation deviated from the wasting program for several days. It is believed that the alum addition interfered with the wasting program by giving the erroneous indication that there was more biomass present in the system than actually measured by RAS-TOC tests. This resulted in excessive wasting of "matured" biomass from the system and increased the 5-minute corrected settlometer readings. During the first part of June 1975, heavy organic loading occurred after the "young" sludge was already present. This caused another upward trend in the 5-minute corrected settlometer further perpetuating the problem.

SUMMARY

The foregoing was presented to illustrate how the results of this study were applied to plant operation and also how plant problems might be diagnosed by the case of process information.

GLOSSARY

AE - Aerator Effluent. This term is distinguished from ML (mixed liquor) by the point of collection which is in the aeration tank immediately prior to passing to the secondary clarifier. ML samples may be collected at various defined points in the aerator after PE and RAS combine.

ATP - Adenosine Triphosphate. As determined by a JRB-ATP Photometer. ATP is a substance found in all living cells and therefore provides a means of measuring the portion of the activated sludge that is viable. See Section 7 for the procedure used in this study.

Aerator Mode. A term expressing numerically the number of quadrants the RAS and ML are receiving aeration. The first digit defines the number of quadrants in which RAS is reaerated or stabilized before mixing with PE to form ML. The second digit is the number of quadrants ML receives aeration after PE and RAS mix to form ML.

CSV_5. Corrected settling volume after 5 minutes settling in a 2000 ml settlometer and adjusted to a concentration of 2 g/l following the procedure outlined in Section 7.

ML - Mixed Liquor. Refers to any point in the aerator after PE and RAS are combined.

Modified F/M. The relationship of food to microorganisms at the juncture point of the PE and RAS. Values were defined either by PE-TOC for "F" and RAS-TOC for "M" or RAS-ATP for "M".

PE - Primary Effluent. Sample collected at the distribution box prior to entry into the aerator. The TOC of the PE sample is used as a measure of "F" in the modified F/M determination.

PEF - Primary Effluent Flow. Measured in mgd and capable of being fed to any or all of the aerator quadrants.

RAS - Return Activated Sludge. The context of the text delineates usage with respect to flow, concentration, etc.

Reaeration (Stabilization). The condition whereby return sludge is aerated in a quadrant or quadrants prior to mixing with primary effluent.

RR - Repiration Rate. Also, oxygen uptake rate as determined by a YSI DO meter according to the method described in Section 7. Most frequently used for finding the rate in the aerator effluent (AE).

RSF - Return Sludge Flow. Measured in gpm in the modified F/M ratio or expressed as mgd when relating to ratio of RSF/PEF.

SCT - Solids Conditioning Time. A term expressing the relative time solids remain in the aerator during one cycle from entry to exit.

SV_5. Settling Volume reading after 5 minutes settling on an undiluted sample of mixed liquor or AE. May either be determined in a 2 liter Mallory settlometer or 1000 ml graduated cylinder.

TOC - Total Organic Carbon. As measured by a Dohrmann Envirotech Model 50 TOC Analyzer by the method defined in Section 7 of this report.

REFERENCES

1. Biospherics, Incorporated, "Biomass Determination - A New Technique for Activated Sludge Control," Water Pollution Control Research Series, 17050, EOY, January 1972.

2. JRB Incorporated, San Diego California, "JRB ATP-Photometer Instruction Manual," August 1972.

3. JRB Incorporated, San Diego, California, "Methods for Data Analysis Using the JRB ATP-Photometer," January 1973.

4. Petersack, J.R. and Richard G. Smith, "Advanced Automatic Control Strategies for the Activated Sludge Treatment Process," Environmental Protection Technology Series, EPA-670/2-75-039, May 1975.

5. Rickert, David A. and Joseph V. Hunter, "Effects of Aeration Time on Soluble Organics During Activated Sludge Treatment," Journal of Water Pollution Control Federation 43, 1 134.

6. Emery, Richard, Eugene Welch and Russell Christman, "The Total Organic Carson Analyzer and Its Application to Water Research," Journal of Water Pollution Control Federation 42, 9 1834.

7. Joyce, R.J., C. Ortman and C. Zickefoose, "How to Optimize An Activated Sludge Plant," Water and Sewage Works, October 1974, pg. 96.

APPENDIX
METRIC EQUIVALENTS

METRIC CONVERSION TABLES

Recommended Units

Description	Unit	Symbol	Comments	English Equivalents
Length	meter	m	*Basic SI unit*	39.37 in. = 3.28 ft = 1.09 yd
	kilometer	km		0.62 mi
	millimeter	mm		0.03937 in.
	centimeter	cm		0.3937 in.
	micrometer	μm		$3.937 \times 10^{-3} = 10^3 A$
Area	square meter	m^2		10.744 sq ft = 1.196 sq yd
	square kilometer	km^2		6.384 sq mi = 247 acres
	square centimeter	cm^2		0.155 sq in.
	square millimeter	mm^2		0.00155 sq in.
	hectare	ha	The hectare (10,000 m^2) is a recognized multiple unit and will remain in international use.	2.471 acres
Volume	cubic meter	m^3		35.314 cu ft = 1.3079 cu yd
	cubic centimeter	cm^3		0.061 cu in.
	liter	l	The liter is now recognized as the special name for the cubic decimeter	1.057 qt = 0.264 gal = 0.81×10^{-4} acre ft
Mass	kilogram	kg	*Basic SI unit*	2.205 lb
	gram	g		0.035 oz = 15.43 gr
	milligram	mg		0.01543 gr
	tonne	t	1 tonne = 1,000 kg	0.984 ton (long) = 1.1023 ton (short)
Time	second	s	*Basic SI unit*	
	day	day	Neither the day nor the year is an SI unit but both are important.	
	year	yr or a		
Force	newton	N	The newton is that force that produces an acceleration of 1 m/s^2 in a mass of 1 kg.	0.22481 lb (weight) = 7.5 poundals

Recommended Units

Description	Unit	Symbol	Comments	English Equivalents
Velocity linear	meter per second	m/s		3.28 fps
	millimeter per second	mm/s		0.00328 fps
	kilometers per second	km/s		2 230 mph
angular	radians per second	rad/s		
Flow (volumetric)	cubic meter per second	m^3/s	Commonly called the cumec	15,850 gpm = 2 120 cfm
	liter per second	l/s		15.85 gpm
Viscosity	poise	poise		0.0672/lb·sec ft
Pressure	newton per square meter	N/m^2	The newton is not yet well-known as the unit of force and kgf cm^2 will clearly be used for some time. In this field the hydraulic head expressed in meters is an acceptable alternative.	0.00014 psi
	kilonewton per square meter	kN/m^2		0.145 psi
	kilogram (force) per square centimeter	kgf/cm^2		14 223 psi
Temperature	degree Kelvin	K	*Basic SI unit* The Kelvin and Celsius degrees are identical. The use of the Celsius scale is recommended as it is the former centigrade scale.	$\frac{5F}{9} - 17.77$
	degree Celsius	C		
Work, energy, quantity of heat	joule	J	1 joule = 1 N-m	2.778×10^{-7} kw hr = 3.725×10^{-7} hp-hr = 0.73756 ft-lb = 9.48×10^{-4} Btu
	kilojoule	kJ		2.778 kw-hr
Power	watt	W	1 watt = 1 J/s	
	kilowatt	kW		
	joule per second	J/s		

Application of Units

Description	Unit	Symbol	Comments	English Equivalents
Precipitation, run-off, evaporation	millimeter	mm	For meteorological purposes it may be convenient to measure precipitation in terms of mass/unit area (kg/m^3). 1 mm of rain = 1 kg/sq m	
River flow	cubic meter per second	m^3/s	Commonly called the cumec	35.314 cfs
Flow in pipes, conduits, channels, over weirs, pumping	cubic meter per second	m^3/s		
	liter per second	l/s		15.85 gpm
Discharges or abstractions, yields	cubic meter per day	m^3/day	1 l/s = 86.4 m^3/day	1.83×10^{-3} gpm
	cubic meter per year	m^3/yr		
Usage of water	liter per person per day	l/person day		0.264 gcpd
Density	kilogram per cubic meter	kg/m^3	The density of water under standard conditions is 1,000 kg/m^3 or 1,000 g/l	0.0624 lb/cu ft

Application of Units

Description	Unit	Symbol	Comments	English Equivalents
Concentration	milligram per liter	mg/l		1 ppm
BOD loading	kilogram per cubic meter per day	kg/m^3 day		0.0624 lb/cu-ft day
Hydraulic load per unit area; e.g. filtration rates	cubic meter per square meter per day	m^3/m^2 day	If this is converted to a velocity, it should be expressed in mm/s (1 mm/s = 86.4 m^3/m^2 day).	3.28 cu ft/sq ft
Hydraulic load per unit volume; e.g. biological filters, lagoons	cubic meter per cubic meter per day	m^3/m^3 day		
Air supply	cubic meter or liter of free air per second	m^3/s l/s		
Pipes diameter	millimeter	mm		0.03937 in.
length	meter	m		39.37 in. = 3.28 ft
Optical units	lumen per square meter	$lumen/m^2$		0.092 ft candle/sq ft

TECHNICAL REPORT DATA

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15. SUPPLEMENTARY NOTES

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16. ABSTRACT

This research was conducted to determine the feasibility of using TOC, ATP and respiration rates as tools for controlling a complete mix activated sludge plant handling a significant amount of industrial waste. Control methodology was centered on using F/M ratio which was determined by the TOC of the influent to the aerator and the TOC (or ATP) of the return sludge. Process control was affected manually and based on 5 to 7 determinations per day. Respiration rates were used to indicate the need for increased or decreased sludge aeration time. Process control decision making was aided by the use of a programmable calculator. Process control information was set up so that operators could input plant data and receive printed instructions for process settings. Functional programs included return rates, mode changes, wasting rates, respiration rate and corrected settlometer volume.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Waste treatment Activated sludge process Microorganism control (sewage) Sewage treatment Control Process control Control theory	Respiration rate TOC ATP	13B

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