AD-753 926

# AUTOMATION OF WASTEWATER TREATMENT SYSTEMS

Joseph L. Pavoni, et al

Environmental Consultants, Incorporated

Prepared for:

Army Construction Engineering Research Laboratory

December 1972

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

*TECHNICAL REPORT E-3*
*December 1972*

C
E
R
L

# *AUTOMATION OF WASTEWATER TREATMENT SYSTEMS*

*by*

**J. L. Pavoni**
**P. R. Spinney**

*CONSTRUCTION ENGINEERING RESEARCH LABORATORY*
**Champaign, Illinois**



*Approved for public release; distribution unlimited.*

TECHNICAL REPORT E-3

# AUTOMATION OF WASTEWATER TREATMENT SYSTEMS

Prepared by

Environmental Consultants, Inc..
Clarksville, Indiana 47130

Joseph L. Pavoni
and
Peter R. Spinney

December 1972

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORY
P.O. Box 4005
Champaign, Illinois 61820

UNCLASSIFIED

Security Classification

**DOCUMENT CONTROL DATA - R & D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Construction Engineering Research Laboratory<br>P.O. Box 4005<br>Champaign, Illinois 61820 | 2a. REPORT SECURITY CLASSIFICATION<br>Unclassified<br>2b. GROUP |

3. REPORT TITLE

Automation of Wastewater Treatment Systems

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*

Joseph L. Pavoni
Peter R. Spinney

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| December 1972 | 255 | 11 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO.<br>DACA 23-71-C-0016<br>b. PROJECT NO.<br>c.<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br><br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) |

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY |
|---|---|
| | Department of the Army |

13. ABSTRACT

The basic objective of this investigation was to review and evaluate the present state-of-the art technology for automating new or expanded wastewater treatment facilities, and for upgrading the performance of existing treatment plants. This study may permit the more efficient and economic operation of treatment facilities subjected to variations in organic and inorganic loading while maintaining effluent quality in conformance with increasingly strigent antipollution standards.

The current expanding national concern with regard to pollution control emphasizes the need for increasing both the number and accuracy of samples taken and analyzed to assure the optimum in treatment plant efficiency. This report presents and evaluates automatic control systems for specific wastewater unit processes as well as the interfacing of these various systems to provide complete control of the wastewater treatment process.

14. KEY WORDS

automation, wastewater treatment plants
instrumentation, wastewater treatment plants
wastewater treatment plants

DD FORM 1473, 1 NOV 65 — REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED

Security Classification

## ABSTRACT

The basic objective of this investigation was to review and evaluate the present state of the art technology for automating new or expanded wastewater treatment facilities, and for upgrading the performance of existing treatment plants. This study may permit the more efficient and economic operation of treatment facilities subjected to variations in organic and inorganic loading while maintaining effluent quality in conformance with increasingly stringent antipollution standards.

The current expanding national concern with regard to pollution control emphasizes the need for increasing both the number and accuracy of samples taken and analyzed to assure the optimum in treatment plant efficiency. This report presents and evaluates automatic control systems for specific wastewater unit processes as well as the interfacing of these various systems to provide complete control of the wastewater treatment process.

# FOREWORD

This investigation was supported by the Department of the Army, Construction Engineering Research Laboratory (CERL) under Contract DACA 23-71-C-0017, "Automation of Wastewater Treatment Systems." The study was funded under Project 4A062112A891, "Pavement Construction Materials and Techniques," Task 04, "Facilities Engineering Methods and Technology," Work Unit 001, "Optimum Automation of Water Sewage and Waste Collection and Treatment. Technical Monitor was Mr. A. P. Norwood.

The Environmental Consultants' personnel directly concerned with this study were Messrs. Joseph L. Pavoni, Ph.D., and Peter R. Spinney, M.S. James A. Munich, M.S., and Richard L. Clevidence of Environmental Consultants served as technical advisors.

# PREFACE

The past three decades have witnessed unparalleled advances in instrumentation applications in most areas of science and industry. Despite practical applications of these tremendous technological improvements by many unrelated fields of endeavor, the wastewater treatment profession has lagged considerably behind others in instrumentation applications to its various unit processes. With increasing emphasis on stringent water quality standards, it seems apparent that optimizing modern instrumental methods of analysis must assume a more important role in the continual monitoring and controlling of wastewater treatment processes.

Instrumentation for continuous or semicontinuous analysis of wastewater samples can serve the purpose of:

1. automatically monitoring the quality or change in quality of natural bodies of water and of flows in wastewater treatment works, distribution systems, or wastewater collection systems.

2. analyzing large numbers of samples in the laboratory.

Automation can be complete or partial and the analytical information presented can be direct or translatable by calibration of the instrumentation system.

The current expanding national concern with regard to pollution control emphasizes the need for increasing both the number and accuracy of samples taken and analyzed to assure the optimum in treatment plant efficiency. Most of the work reported in the literature to date has been limited to instrumental monitoring of specific water quality parameters. Previous studies have developed and evaluated automatic control systems for specific unit processes, such as chemical coagulation; however, very little if any information exists on optimization through instrumental control of a complete wastewater treatment system. The development of criteria is therefore required to determine the optimum degree of automation control for various treatment facilities.

This study represents the initial phase of a research program being developed by Construction Engineering Research Laboratory, to delineate the operational criteria for determining the optimum economic degree of automation desirable in controlling U.S. Army wastewater treatment systems. The basic objective of this study was to review and evaluate present technology for automated control of U.S. Army wastewater treatment systems. Basic unit processes were investigated to determine the efficiency controlling parameters. Subsequently, the feasibility of automatically controlling these vital parameters was determined. Processes investigated included:

I. Primary treatment

1. Bar Screens - course and fine
2. Comminution
3. Grit removal, collection, concentration and disposal
4. Primary sedimentation
5. Flotation

II. Secondary biological treatment

1. Activated sludge

   a. Conventional
   b. Contact stabilization
   c. Step aeration
   d. Completely mixed
   e. Extended aeration

2. Trickling filters

3. Oxidation ponds

4. Miscellaneous biological treatment (high purity oxygen aeration)

III. Sludge handling and disposal

1. Sludge blending
2. Sludge thickening
3. Anaerobic digestion

IV. Chlorine Disinfection

Study results indicated a reasonable availability of control and automation equipment directly applicable to wastewater treatment systems. Installation of such equipment, however, was found to be lacking. In the most highly automated of new wastewater treatment plants instrumentation represents a capital expenditure of approximately 10% of total plant cost; more often instrumentation represents 1% - 5% of total cost. Since sewage treatment is a process operation, it is legitimate to compare costs with other process industries. The petrochemical industry regularly invests 15-20% on instrumentation for new plant construction costs. While it is not fair to compare a profit-motivated investment with a non-revenue-producing public utility, the basic reason for process instrumentation is identical: efficiency.

Increasing process efficiency has a threefold effect:

1. It produces a better quality product. With new and more stringent effluent quality guidelines constantly coming into being, this is a very important aspect of plant operation.

2. Efficiency reduces operating costs by using the proper amount of chemicals and power and by reducing the manual operating responsibilities.

3. Efficiency means getting the most from a particular plant design. If the population contributing to a sewage system is static, a smaller plant can be designed to handle a given load which might otherwise require large overcapacities to make up for inefficient operation.

Also, if the population base is increasing, the addition of instrumentation to existing plants would increase the capacity of those plants as well as lead to a better quality product.

In view of the increasing number of water quality standards being imposed on the environment, automated control of wastewater treatment facilities by means of instrumental analysis seems justified. Automation throughout various areas of system operation will not only reduce manpower requirements, thereby reducing overall expenditure, but also will result in a more precise effluent quality control regardless of pollutional loading. It seems doubtless that the time will come when the various wastewater treatment unit processes will be entirely controlled by computerized instrumentation; and it is the authors' hope that this investigation will stimulate more advances in water quality instrumentation applications.

TABLE OF CONTENTS

LIST OF FIGURES

With a level controller, measurement of the level may be accomplished by a float-cable-drum arrangement: measurement is reported to and evaluated by the controller, which automatically regulates the position of a valve in a line feeding liquid to the tank.

An automatic control system may be outlined as consisting of:

1. The process

2. The method of measuring

3. The method of controlling

Methods of measuring can ususally be divided into:

1. The primary element (thermometer, Venturi tube, float, etc.)

2. The secondary element (bellows, set of mercury wells, etc.)

Methods of control usually consist of:

1. The controller mechanism

2. The final control element

3. The control agent.

Note that an automatic control system consists of the process, the measuring method and the controlling method, all arranged in a closed-loop. It is important to know the difference and be able to distinguish between closed-loop, feedback control and open-loop, calibrated-system pacing. A system which seems to have the three elements listed is not a control system in this sense of the expression if the closed-loop characteristic is missing.

The true control system consists of a continuous circuit from the measurer, through the controller, through the final control element and the control agent, through the process, and finally back to the measurer. Each part of the system must receive and react to a change in every other part, either directly or through the agency of one or more of the other components.

In a true control system the control agent which is regulated by the final control element must affect a modification of the measured variable. The control agent must be introduced at a point in the process where its effect on the measured variable can be sensed by the measurer.

Consider the input of a constant weight feed of dry chemical to a coagulation process. The system includes a belt, a dry chemical depth regulating gate, a gate positioner, a rate setter feeding to the positioner, and a weight sensing means. The rate setter positions so that the weight sensing means shows the desired rate of delivery. In operation, if the bulk density of the chemical varies, the weight delivered, as indicated by the weight sensor, will also vary, since the gate is fixed in the position dictated by the rate setter adjustment. Here chemical weight delivery is being paced from the rate setter and any variation in gate position vs. weight feed from that which existed when the initial adjustment was made will result in incorrect feed. Effectively the initial adjustment of the rate setter constituted a calibration which holds only so long as all conditions affecting chemical feed remain constant. There is no closed loop, therefore no automatic control. This is merely a pacing system.

Now consider that a controller has been added to the above system. Let the rate setter signal go, not directly to the gate positioner, but into the controller; furthermore, let the chemical weight sensor output feed back into the controller. Now, set the rate setter at a value representing the desired rate of chemical weight delivery. The controller will continuously compare the actual value of chemical weight delivery with the desired value. If the values do not coincide, the controller output is adjusted to reposition the gate and eliminate the error. If a bulk density change occurs, the gate position will automatically be changed to maintain the desired chemical weight delivery. This system is under automatic control - the loop is closed.

It might be questioned whether a pacing system in which the secondary material is delivered upstream of the measuring device, will run away with itself. Under certain system sensitivity conditions this may take place. For example, if sensitivity is such that passage through the metering device of one gallon of water causes a feeder delivery of one gallon of chemical, then it is obvious that the additional gallon of feeder delivery will cause yet another additional gallon of feed, etc., until the maximum delivery of the feeder is reached. In other words, such a system has critical sensitivity, and will just run away. If sensitivity is less than critical, that is, if one gallon through the meter causes less than one gallon of feeder delivery, the system will not run away. For all sensitivities greater than critical sensitivity, a run-away effect will occur. Obviously, such a system must be designed to operate far below critical sensitivity.

The truly automatic control system and the pacing system each has its proper application. The pacing system is not to be regarded as inferior in all applications to the true control system. Pacing systems, properly designed and applied, are entirely practical and satisfactory. In many cases, completely automatic control may be impossible.

Increasingly "feed forward" systems are finding application in conjunction with feedback control. It must be remembered that while all feed forward control is a form of pacing, not all pacing is feed forward, that is, when sensors and controllers are lacking in the control scheme. Figure 1-1 shows the relationship between feedforward and feedback control.

## 1.2 SIGNIFICANCE OF MEASUREMENT IN CONTROL SYSTEMS

In an automatically controlled system, a control action cannot occur until a controlled variable change is detected by the measuring system because of a change in the measured variable. A person observing a thermometer and controlling a steam valve would not readjust the valve until he detected a change in temperature. Previously, he would have no basis to make a change in the steam valve position.

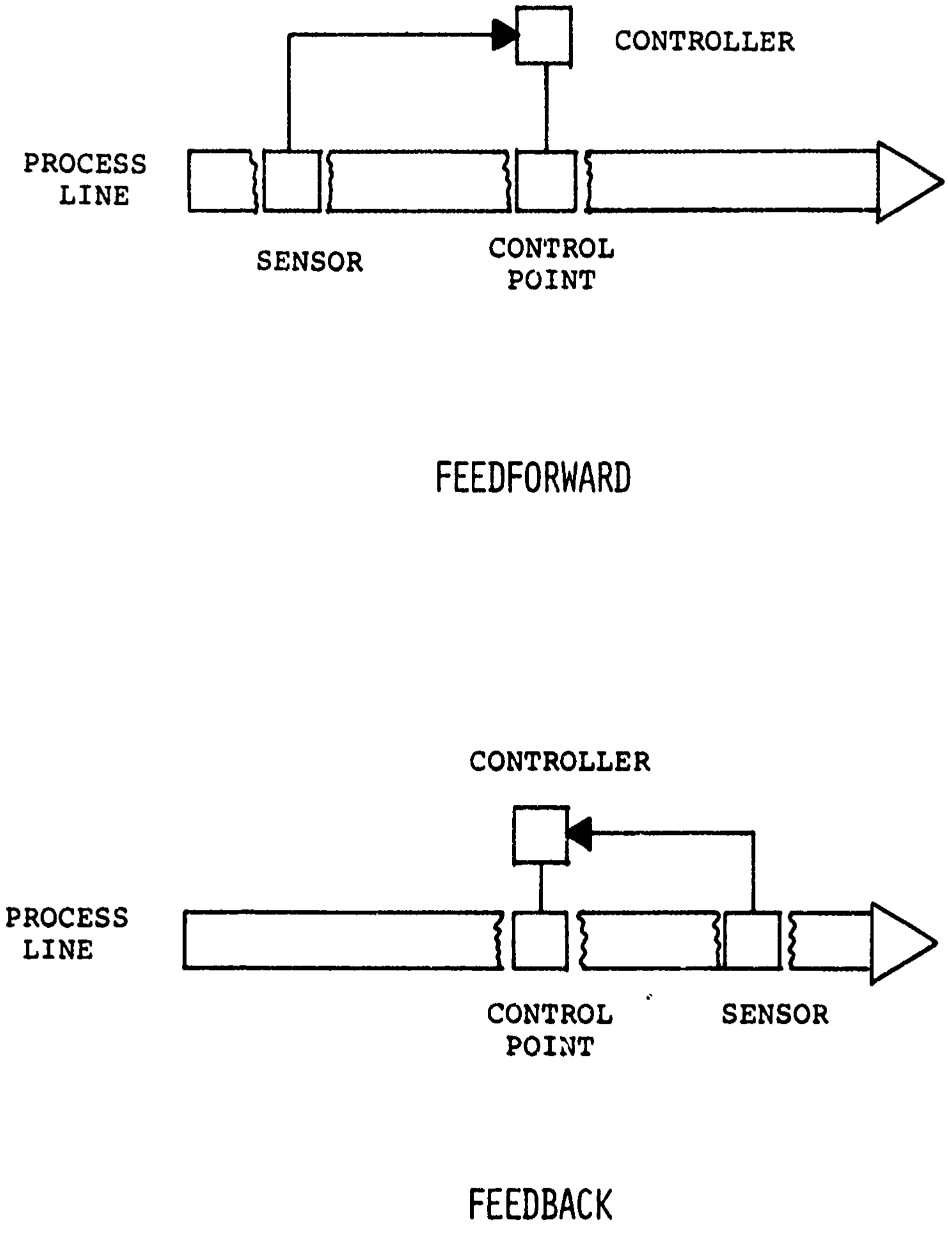



FIGURE 1-1

RELATIVE POSITIONING OF SENSORS AND CONTROLLERS IN FEEDFORWARD AND FEEDBACK CONTROL LOOPS

The measurer must not only be sensitive to variable changes but also be immediately sensitive. Any time lapse involved in reporting a variable change to the controller increases the time before corrective action can be initiated. Such a delay permits a greater variation for a longer time from the desired control point.

The two basic types of measurement errors are static and dynamic. Of these two, dynamic error is generally the far more serious. When considering a temperature control system the static error is usually small when the temperature is not varying. For example, a thermometer is usually off about a degree of so when measuring a steady 200°F. However, if the temperature suddenly changes, the dynamic error may be many degrees.

A cold thermometer suddenly plunged into boiling water will not immediately read 212°F. A certain lag time is required for the mercury to reach the 212°F mark. If the hot water is rapidly diluted with cool water, the thermometer will show a decreasing temperature reading which will be higher than the actual temperature. At any instant the difference between the indicated temperature and the actual temperature will depend upon how fast the temperature is dropping and the characteristics of the thermometer itself. The change in temperature shown by the thermometer lags behind the actual change in temperature. The difference between actual and indicated temperature becomes negligible only after steady state conditions have been reached and maintained for a certain period of time.

It is obvious that an insultated thermometer bulb will have a much larger temperature lag than an uninsulated one. The heat transfer between the water and an insulated bulb will slow down with a concurrent increase in dynamic error, or lag. This heat transfer coefficient is the thermometer characteristic to which reference was made above, and which, in conjunction with the rate of water temperature change, determines the amount of lag or dynamic error.

Thermometer bulb insulation will not affect the static error. For any heat transfer coefficient value greater than zero the thermometer's temperature will eventually reach a constant value provided the water temperature has reached a steady state value. After equilibrium has occurred the static error will be the difference between the actual and indicated temperature after the latter reaches a constant value.

If the controller does not know now what is happening now, the quality of control will suffer. As a matter of fact, the controller at any instant knows only what has happened at some previous time. It does not know what is actually happening at that instant. All that is possible is to reduce the dynamic error to as small a value as possible recognizing that it can never be made absolutely zero.

## 1.3 THE EFFECT OF PROCESS CHARACTERISTICS ON AUTOMATIC CONTROL

The process in a controlled system may be considered a procedure, or series of procedures, to which energy is added or taken away to maintain certain process characteristics at desired values. To heat a tank of water, energy may be supplied in the form of steam in quantities varying according to the demand.

If the process is chemical in nature, and if the reaction rate is to be controlled, some measure of this rate, such as heat generated, alkalinity, pH, or color changes produced, etc., must be found and used as the variable to be measured.

A major change in process control agent is not reflected simultaneously in the measured variable thereby producing a time delay. Such a delay is referred to as dead time or transportation time.

For example, a sudden change in the rate of chemical injection at an upstream point in a pipeline conveying water must be transported by the flowing water to the point of measurement before any change in measurement appears. During dead time no response is observed at the measuring point to a change in control agent flow.

A sudden change in control agent flow acting through a process may appear at the measuring point, not as a corresponding sudden change in value of the measured variable, but as a more gradual change. This characteristic of a process which reduces a sudden change in input to a gradual change in output is referred to as lag. A completely mixed water basin being heated by steam exhibits this property. A sudden change in the ultimate temperature of the basin is not affected by a sudden change in steam flow. Instead the ultimate final temperature is approached slowly over an extended period of time. This characteristic commonly referred to as process lag is similar to dynamic lag mentioned earlier with respect to measuring systems.

The extent of process lag may vary for specific situations. For example, for a given position change in a steam valve of given size the rate-of-change of temperature in a large tank full of water may be very slow as compared to the rate-of-change of temperature in a small tank. Even in the same tank the rate-of-change of temperature will vary depending upon whether the tank is full or nearly empty.

As a general rule, process lag and dead time are undesirable and should be minimized as much as possible. However, high internal process energy capacity may be a desirable characteristic for maintaining close control at a fixed point, although an undesirable characteristic of the control point is to be changed rapidly and often.

## 1.4 MEASUREMENT DEVICES IN WASTEWATER TREATMENT SYSTEMS

An essential element of any control system is the method of measurement. This method is the basis of automatic control operation, consequently errors or lags in the measuring means will result in reduced quality control. Wastewater treatment systems utilize various types of measuring means to meter flow based on function, accuracy, and system compatibility.

Various flow meters commonly encountered in wastewater treatment include:

A. Liquid and gas measurement

1. Differential type
   a. Venturi tube
   b. Orifice plate

2. Area type
   a. Rotameter

B. Liquid measurement only

1. Flumes and weirs
2. Kennison Nozzle
3. Positive displacement
4. Magnetic

C. Solid measurement only

1. Belt scales

The differential type flow measuring device is very widely used. The Venturi section or orifice plate produces a differential which varies as the square of the flow. The differential, so produced, may be measured by a set of manometer-type mercury wells with a float resting on the mercury in one leg; float motion is brought outside through a stuffing box. Bellows, ring-balance, and pressure cell types of differential measuring devices are also extensively used.

The area type flow meter operates on the constant differential variable area principle and is exemplified by the familiar rotameter. In this device flow is directed upward through a vertical tapered glass tube containing a loose fitting "float." For a given rate, the float will move upward in the tube until the differential pressure across the float, acting on the cross-sectional area of the float, balances the weight of the float. Its position in the tube then constitutes measurement of flow rate. For automatic control purposes the float position can be sensed by electrical means.

Other measurement devices used throughout wastewater treatment processes include:

A. Liquid level measurement devices

   1. Float-level-stuffing box

   2. Manometer and float

   3. Pressure type head measurers

   4. Float-cable-drum

B. Colorimetric measurement devices

   1. Fluoride

   2. Hardness

C. Potentiometric measurement devices

   1. Conductivity

   2. pH

   3. Chlorine residual

D. Pressure measurement devices

   1. Bourdon tube

   2. Spiral

   3. Helix

   4. Bellows and spring

   5. Pressure cell

   6. Manometer and float

E. Photoelectric measurement devices: Turbidity

F. Miscellaneous measurement devices

1. Bimetallic thermometer

2. Expansion hydrometer

3. Resistance moisture-content

## 1.5 FUNCTION OF CONTROLLERS AND CONTROL MODES IN AUTOMATIC CONTROL

The primary function of the controller in an automatically controlled system is to receive information as to the state of the measured variable forwarded to it by the measurer. After interpreting this information the controller makes possible counteraction in the process to eliminate deviation of the measured variable from a desired value through manipulation of the final control element and the control agent. The method by which the controller interprets deviation and institutes corrective measures is referred to as the mode of control.

Controllers may consist of several different types, including:

1. Electric

2. Pneumatic

3. Hydraulic

4. Mechanical

5. Electronic

Many possible modes of control may exist. The major types include:

1. Two-position

2. Multi-position

3. Position-proportional

4. Single-speed floating

5. Multispeed floating

6. Proportional-speed floating

7. Proportional-plus-reset

8. Proportional-plus-rate

9. Proportional-plus-reset-plus-rate

Depending on the control problem and the demand for accuracy, various sophistication levels of controllers or control modes may be used. However, it is undesirable to apply a highly complex controller to a relatively simple process which requires only a simple controller. Providing that a controller can perform the control job required, the simpler the controller the better.

A discussion of the three major modes of control would be valuable. The two position, or on-off, controller regulates the final control element such that it assumes either one of two states (on or off) depending upon whether the controlled variable is above or below the control point. A basic example of an on-off controller is the simple household on-off thermostat heating controls represented in Figure 1-2. Assume that the actual value of the measured variable (temperature) is anywhere below the control point (represented by a measured variable value of 72°F). The controlled heating unit is then at one extreme of its possible position range - on. When the measured variable (temperature) is anywhere above the control point (72°F) the control device (heater) is at its other extreme position - off.

Note that stops may be provided in the control element (a valve or similar device) so that it need not be wide open or fully closed. For instance a valve opening may range between 25% and 75%. However,

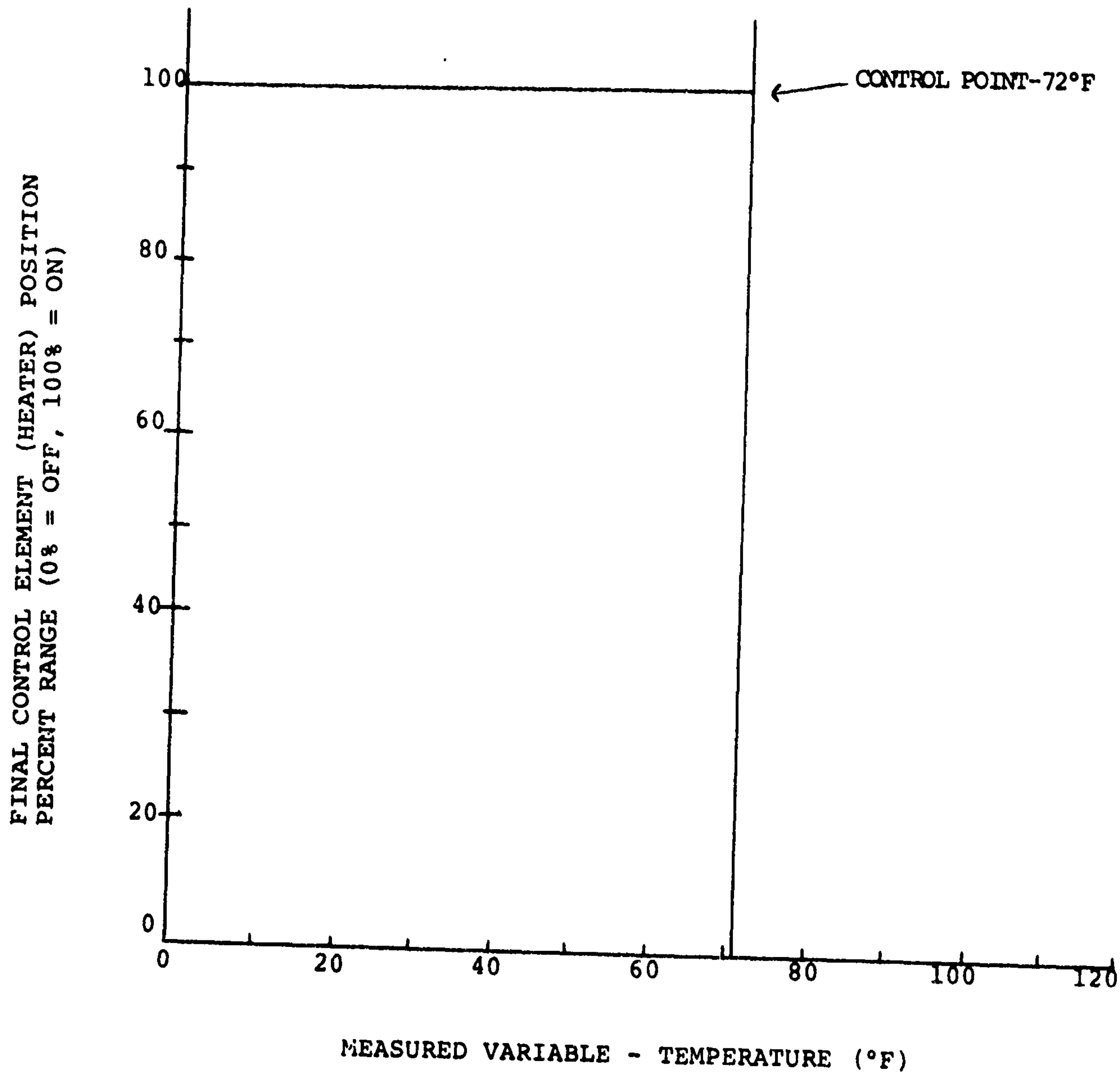



FIGURE 1-2

ON-OFF THERMOSTAT CONTROL
GRAPHIC REPRESENTATION

it must be remembered that a very narrow valve position range may not be able to satisfy process demand.

The two-position differential mode is a variation of the on-off controller which is used extensively in water storage tank level control. Assume a tank system in which it is desired to maintain the water level at 70 ft. Two switches exist in such a system, one which starts a pump delivering water to the tank and the other which stops the pump. The start switch may be activated at level 67 ft. and the stop switch at level 73 ft., allowing a 6 ft. differential. Such a differential allows a reduction in motor, control, and power operation.

An elaboration of the two-position controller is the multipurpose controller in which the positioning of the final control element may assume a number of possible positions depending on the relationship between the actual and desired values of the measured variable. For example, in a five-position controller, control valve openings could be completely shut for measured variable values of 0 to 20 percent, 1/4 open from 20 to 40 percent, 1/2 open from 40 to 60 percent, 3/4 open from 60 to 80 percent, and completely open for 80 to 100 percent. Figure 1-3 depicts such a five-position controller. The multipurpose controller is applicable to more difficult processes than the two-position controller because of its added "intelligence" that recognizes to a limited extent whether the actual measured variable is near the control point or far away.

The proportional controller is yet more elaborate than the multiposition controller. Consider the five position controller previously discussed. Now assume that the possible number of positions or steps of the controller is increased to infinity. Such a controller can achieve true proportionality of valve position with changes in measured variable, that is, a definite corresponding position of the final control element is provided for each value of

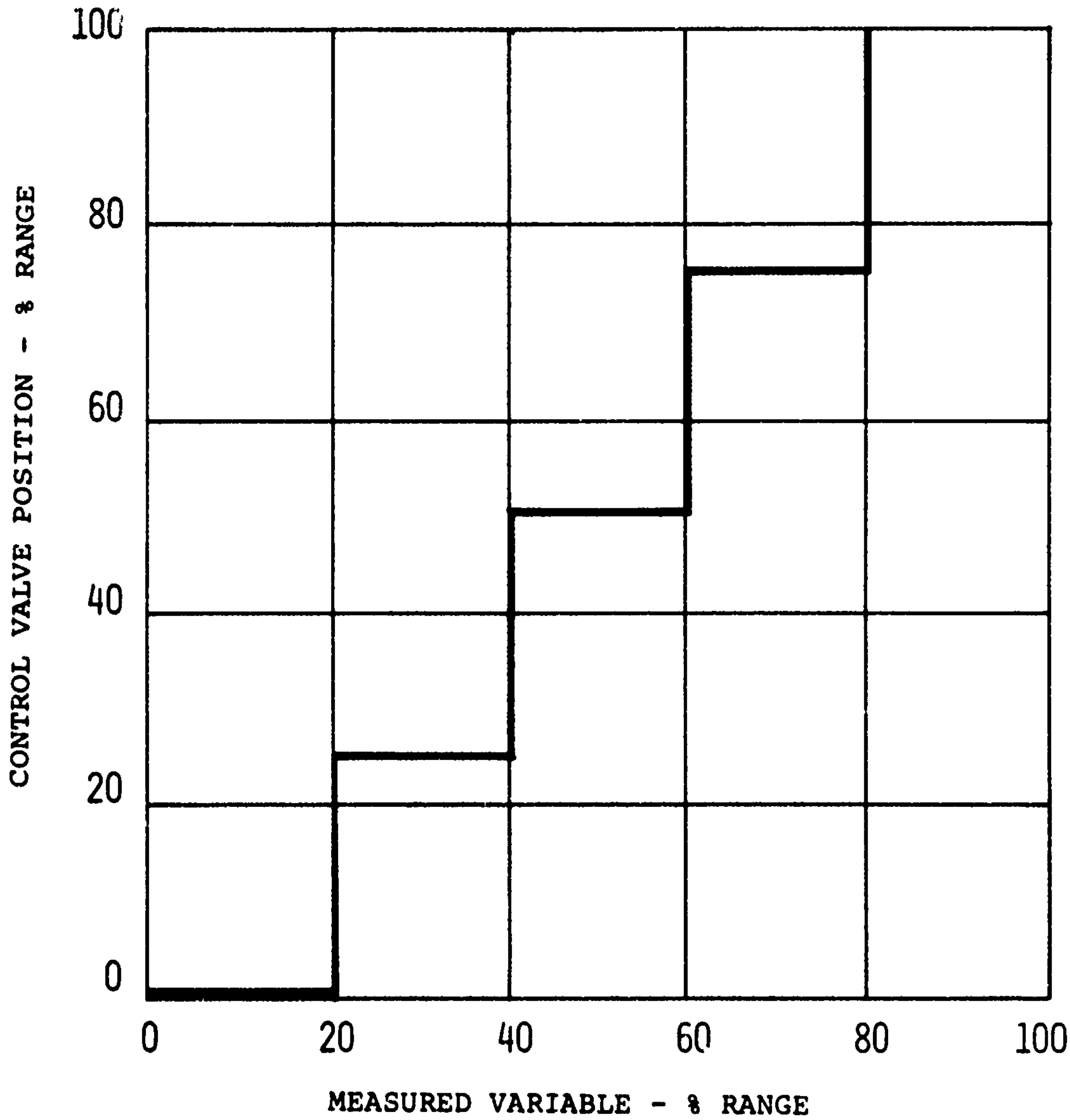



FIGURE 1-3

CONTROL OF A VARIABLE USING
A FIVE-POSITION CONTROLLER

the measured variable. The proportional controller maintains the valve in step with the measured variable as if the valve were geared together with the measured variable. The proportional controller therefore is able to "recognize" that the measured variable is deviating from the control point together with the direction of error, the amount of error, and the rate of change of the error. This proportional controller then produces output changes based on the above considerations.

This preliminary section was primarily intended to introduce the reader to the three basic aspects of automatic control systems as they specifically apply to wastewater treatment systems. Automatic control must be defined and exemplified before embarking upon a meaningful state-of-the-art investigation of the subject. This brief section has defined the following parameters that will be discussed continuously throughout this report:

1. Automatic control systems
2. Pacing systems
3. Measuring methods
4. Controller functioning

## 1.6 INSTRUMENTATION AND PROCESS CONTROL COMPANIES

### 1.6.A Instrumentation Systems - Design and Manufacture

There are three major companies that have developed extensive experience in the instrumentation and automation of wastewater treatment plants: BIF, Fischer & Porter, and Autocon. In addition, Fisher Controls has recently entered this field. The major advantage to the design engineer and operating agency is the fact that these companies have developed a policy of systems responsibility, that is, regardless of who manufactures a particular detector or control instrument, they will guarantee the operation of all aspects of any system that they design and assemble.

For instance, a designer does not have to specify the entire offering of a particular manufacturers product line in order to have them do design work for the control system. Therefore, if an operator has problems with a flow transmitter marketed by XYZ Co., he can go to the company who designed the entire flow controlling system, even if it is XYZ's competitor, ABC, and get service from a single source.

Foxboro, who manufactures a variety of hardware for water and wastewater plants, has recently made the corporate decision not to actively seek business in the municipal wastewater treatment field.

1.6.B Computer Control

Three of the previously named companies, Autocon, Fischer & Porter, and Fisher Controls, are presently developing and employing computer systems designed to monitor and/or control wastewater treatment plants. Autocon, a subsidiary of Control Data Corporation, is utilizing the computer capabilities of their parent company. Fischer & Porter starts with a Varian 620i mainframe and expands and programs for the specific job application.

Computer use in the wastewater field is becoming the most economical way of managing and operating a wastewater treatment system. The lowest level of computer application is for data logging, that is, the computer takes the place of strip chart recorders and level alarms. The point at which a data logger becomes economically feasible is 10-15 instrumentation readouts. The cost of a data logger is in the neighborhood of $110,000.

Beyond the data logging ability of specialized computers, direct-digital-control (DDC) is becoming the way in which plant operation can be made most efficient. DDC represents the ultimate in present process control technology although it still acknowledges the necessity of having analog back-up. Analog control is the basis of the control theory discussed previously, and in fact, it is generally analog-type equipment which furnishes the signals for DDC. The big advantage of DDC is the ability of a programmer to build discriminatory logic into the computer. For instance, the computer is capable of discriminating between an acceptable and unacceptable measurement to detect transmitter failure.

While DDC would probably not be advantageous for treatment plants of the 1-10 MGD capacity, the logging type function would be of definite value in helping an operator up-date and improve his operational reports. These loggers can be programmed to present daily or weekly reports in a format specified by the operator. This kind of capability would also greatly aid engineers and enforcement agencies in determining the operational efficiency of a particular plant. Of course, the computer is only as good as the information it receives, and its contemplated use must be weighed in the light of the amount and quality of the detectors and transmitters used in the instrumentation of the plant.

With the above considerations in perspective, the remainder of the report will be devoted to specific instruments, processes, and control loops designed to increase an operators control of his plant's discharge.

CHAPTER 2

PRELIMINARY SEWAGE TREATMENT -
FLOW MEASUREMENT, HARMFUL SOLIDS REDUCTION, AND ODOR CONTROL

## 2.1 FLOW MEASUREMENT

The single most important operational parameter in wastewater treatment is accurate measurement of the raw sewage flow. It is upon this measurement that a great many subsequent process steps may depend, such as: supplying correct air flow in activated sludge systems, proportioning return activated sludge, proportioning recirculated sewage in trickling filter systems, pacing chlorinators for odor control, controlling primary sludge withdrawal, dividing flow to primary settling basins, controlling sampling proportional to flow, and accurate record keeping for determining plant capacity.

### 2.1.A Open Channel Flow Measurement

Two methods are usually used for measuring raw sewage flow: open channels with Parshall flumes or closed conduit with a velocity meter. In the case of open channel measurement, flumes are the preferred method of measurement since there is no problem of solids accumulation as is generally the case with weirs. Since the basic parameter is head height in the horizontal portion of the flume, several methods have been devised to measure, transmit, records, and/or totalize the flow. Initially, Parshall flumes were designed with stilling wells and floats to measure the head height, but there is the constant maintenance problem of clogging orifices which connect the well and flume.

Two of the more recent innovations that have supplanted the stilling well are the float actuated instream flow meter, and the pneumatic bubbler system.

Figure 2-1 shows the basic open loop for the indicating, recording, and totalizing of raw sewage flow. The level of the float actuated arm is converted to water depth. Depending upon the remoteness of the receiver from the transmitter, the signal output from the transmitter may be either electric time-pulsed for telemetering, or an electric milliamp signal. The totalizer then integrates the flow signal to give total sewage flow. The cost for this system is approximately $1450.

Figure 2-2 shows the second method of determining head height. In this pneumatic system the depth of the water is measured by forcing air into a submerged tube. The pressure that is necessary to overcome the water head is measured by a pneumatic-to-electronic converter which transmits a depth measurement to a receiver in a manner similar to the float device. While much experience has been gained in the installation of the float actuated in-stream flow meter, the bubbler system has been used only in the past few years for this purpose, but with apparently satisfying results. The price of this system is about $1000.

Either of the above systems could be easily placed in existing plants having Parshall flumes, since only mounting brackets are needed for installation.

Fischer & Porter and Leupold & Stevens market the float-type in-stream flow meters; and BIF and Fischer & Porter produce the bubbler systems for depth measurement.

2.1.B Flow Meters

The second major method of measuring raw sewage flow is by the use of in-line velocity meters. Two schools of thought and usage have developed as to the most accurate and practical methods for determining closed-line flow. Basically the philosophical and manufacturing rivalry revolve around magnetic flow meters versus venturi type flow tubes. There is hardly a limit to the size of these flow meters since the "magmeters" are made up to 96" and the venturi tubes can be 120" in diameter. All aspects of the

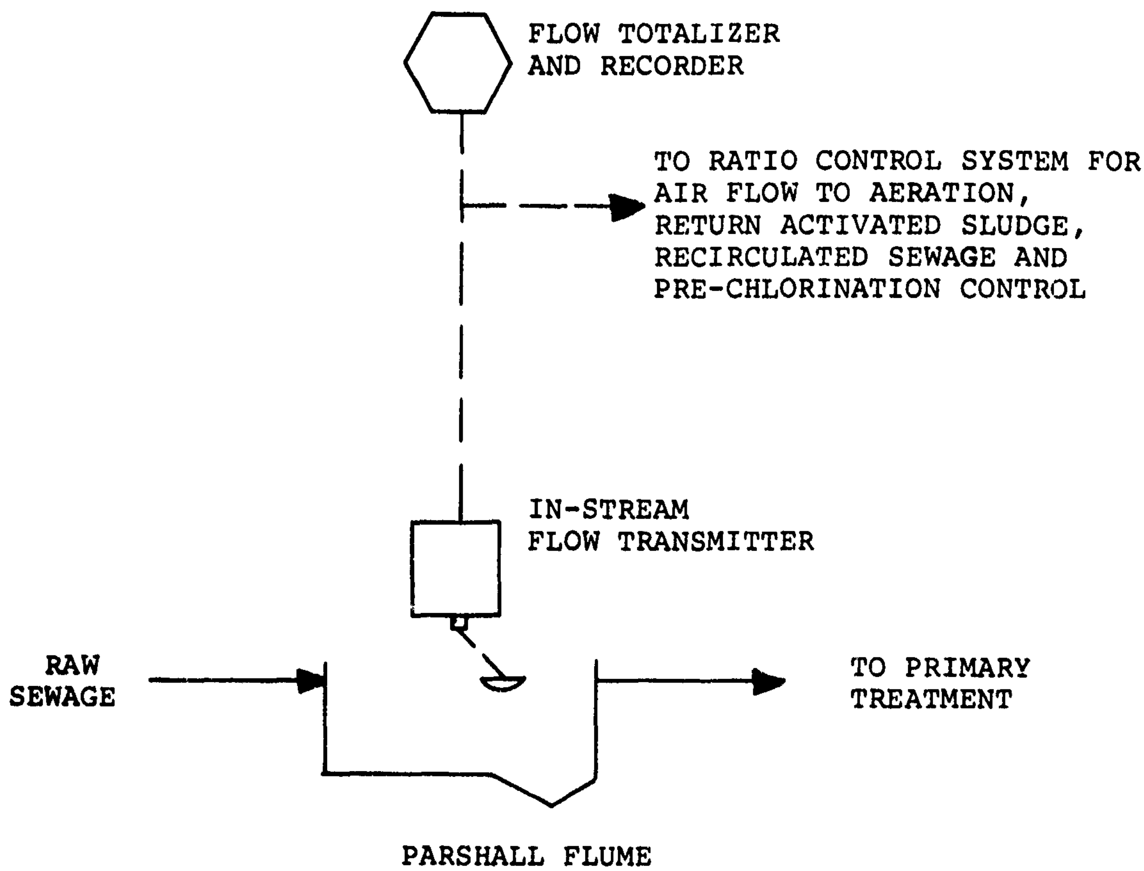



FIGURE 2-1

MEASUREMENT OF RAW SEWAGE FLOW IN PARSHALL FLUME WITH IN-STREAM FLOAT

COURTESY OF FISCHER & PORTER CO.

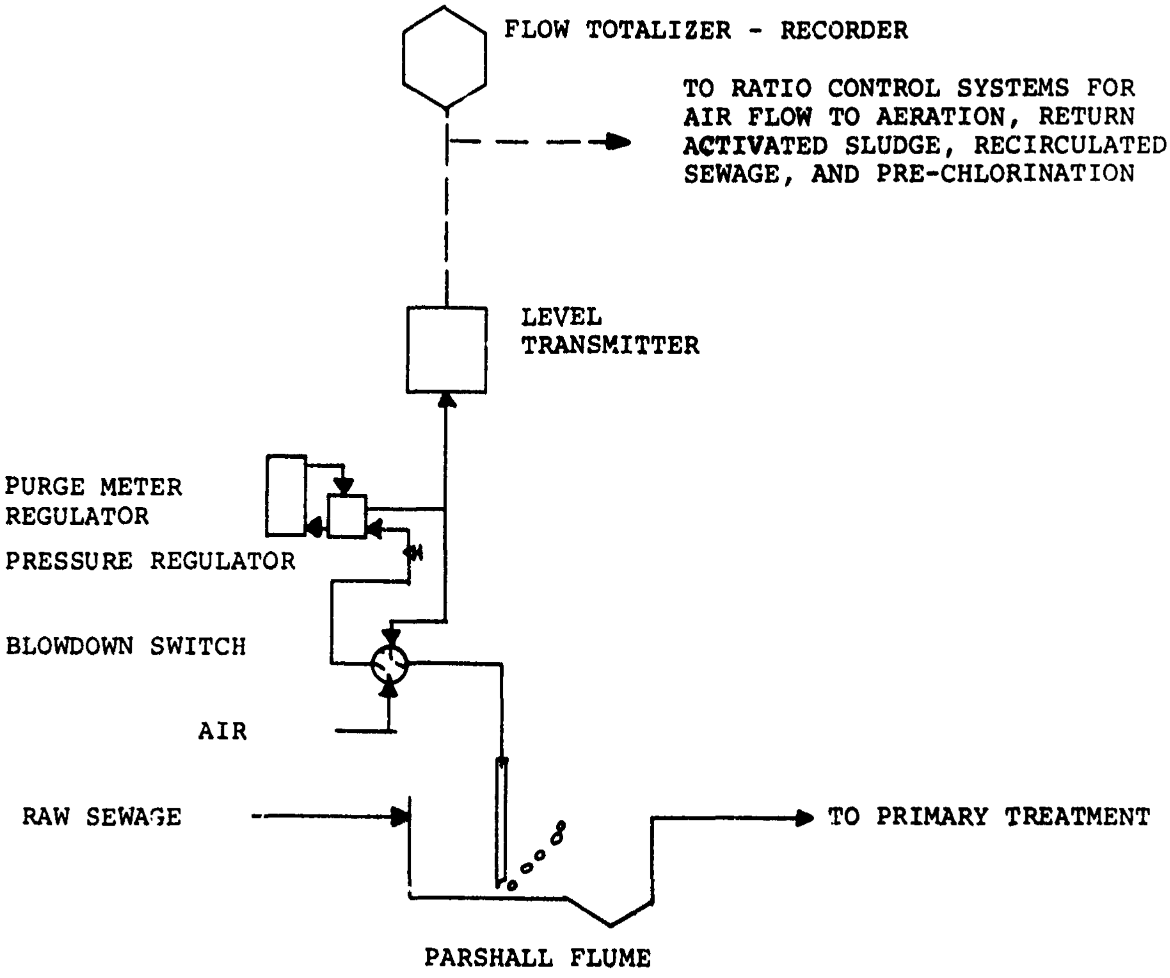



FIGURE 2-2

MEASUREMENT OF RAW SEWAGE FLOW USING BUBBLER SYSTEM FOR DEPTH MEASUREMENT following discussion may be applied to primary flow devices regardless of where they may be used in a system. Historically, venturi type flow tubes have been considered the primary device by which all other flow devices have been compared. Basically, the venturi tube employs the Bernoulli principle whereby pressure differential produced by a constriction is a function of the fluid velocity. Figure 2-3 shows a typical venturi tube as applied to wastewater systems. One of the continuing problems faced by users of these devices is the plugging of the pressure sensing orifices by solids in the wastewater. Several methods have been devised to deal with this problem, one is illustrated here. A flushing line is attached to each opening, the high pressure and low pressure ports. The flushing water flows constantly, and at equal rates (as determined by in-line rotameters) to prevent solids accumulation. It is necessary to have the flow rate constant in the flushing lines, otherwise incorrect pressure differentials will be generated leading to a false flow reading from the tube. In addition to the flushing, a pair of hand operated plungers are periodically used to clean the parts. Plant operators generally find it necessary to manually clean only once a month even on return activated sludge lines. Presently, BIF Corporation is developing a port-less venturi meter which senses pressure differential through membranes instead of relying upon actual fluid contact with mercury wells used for detecting pressures. This should eliminate some of the more common problems associated with venturi flow tubes. One of the advantages of the venturi tube is its capability to be calibrated in the field.

There are several manufacturers of venturi-type flow tubes, the major producer being BIF Corporation. Other suppliers are Fischer & Porter and Foxboro. Since differential pressure flow devices come in a variety of sizes and types (depending upon accuracy desired and the physical limitations of piping), no attempt will be made here to list all the price options. As an example, a 10" cast iron flow tube with a stainless steel throat, capable of handling 2.5 MGD, would cost about $2000 including the mercury well rate-of-flow transmitter.

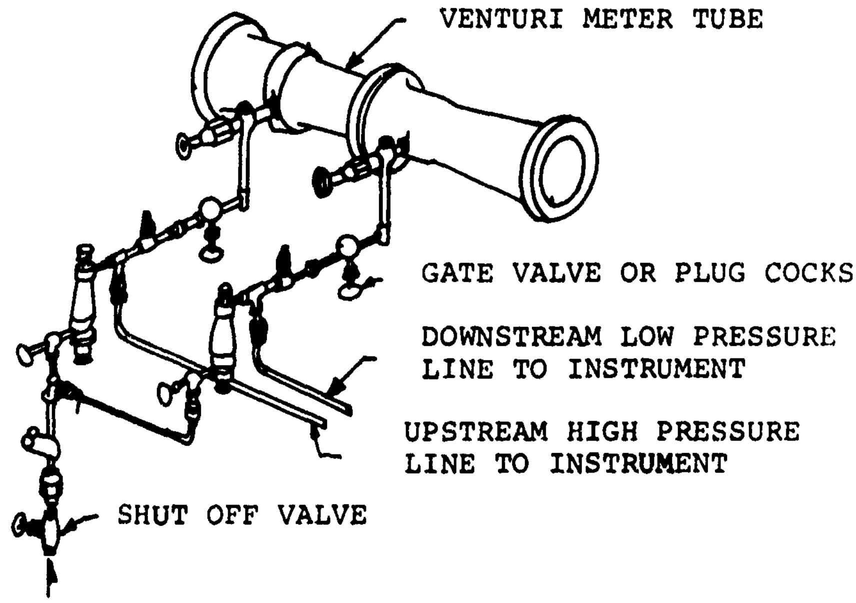



FIGURE 2-3

VENTURI TUBE WITH VENT FLUSHING

COURTESY OF BIF CORP.

The latest development in fluid measurement, and fast becoming widely accepted, is the magnetic flow meter, or "Magmeter." One type of magnetic flow meter is shown in Figure 2-4. The magmeter uses the Faraday principle of electromagnetic induction which states a conductor moving at right angles to a magnetic field generates a voltage directly proportional to the velocity of the conductor. A magnetic field is impressed upon the flowing sewage by induction from an electromagnet. Two small electrodes mounted in a plane at right angles to the magnetic field contact the fluid and act like brushes in a generator. They provide a means by which the voltage induced in the moving fluid is brought out for external measurement. The magnetic flow meter's greatest asset is its smooth flow-through design which makes it extremely practical for uses in fluids with high solids content. Electrodes are the most vulnerable features of the magmeter. As these electrodes become coated with the grease omnipresent in sewage, their sensitivity, and therefore strength of signal output, falls off. To counteract this, Fischer & Porter has developed a method of cleaning the meters in-place by the ultrasonic vibration of the electrodes to remove the grease and oils.

Three installation design criteria have been established to ensure the satisfactory operation of magnetic flow meters. Contrary to early hopes, the magmeters should be installed in fairly straight pipe runs to reduce in-line turbulence. Secondly, they should be installed in a vertical position to ensure complete filling of the pipe section comprising the meter body. And lastly, if the meter is not provided with automatic cleaning devices for the electrodes, the meter section should be sized smaller than the rest of the pipe. This causes a venturi effect, i.e. a speeding up of the liquid flow, thus giving a scouring action to the fluid as it passes through.

Magnetic flow meters have already evolved into a second generation, one of which is illustrated in Figure 2-4. In the first generation instruments, the field coils were placed around the outside section of pipe used for the meter body. This necessitated

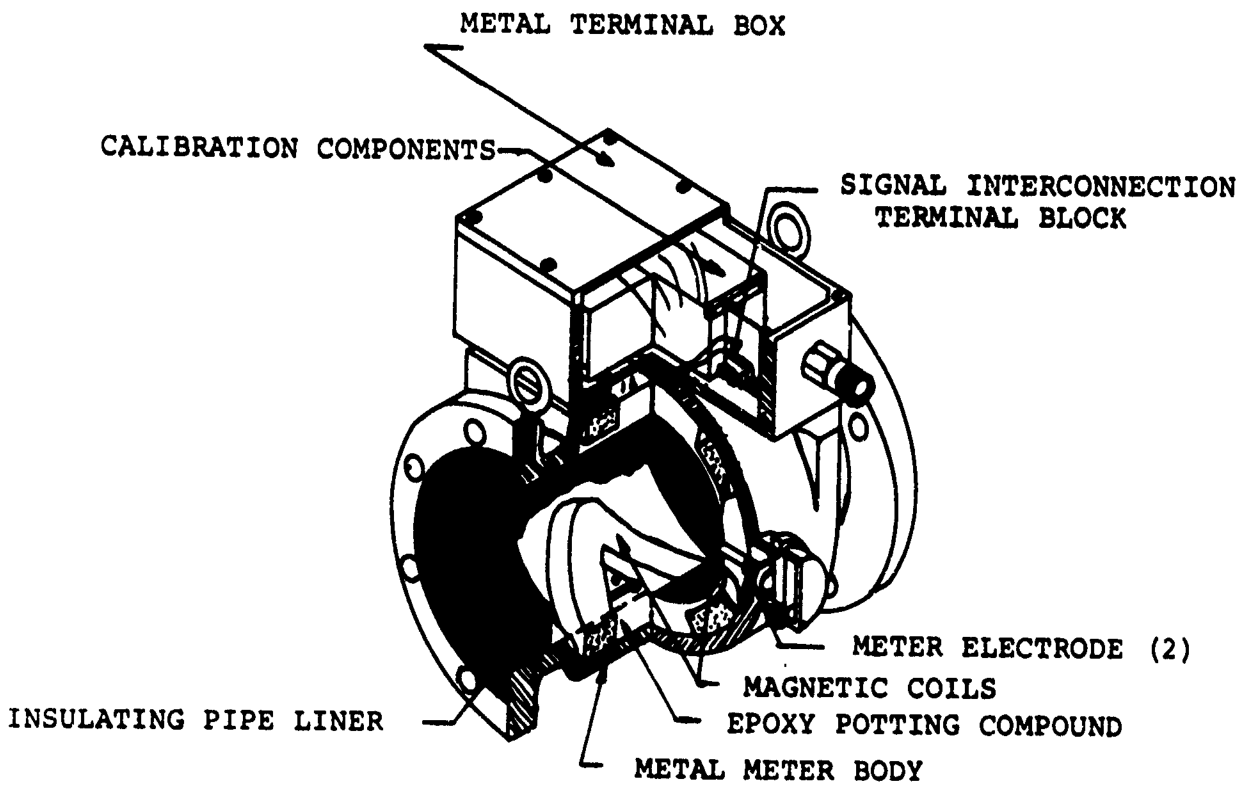



FIGURE 2-4

MAGNETIC FLOW METER UTILIZING INTERNAL FIELD COILS

COURTESY OF FISCHER & PORTER CO.

the use of extremely large, bulky coils to generate a field strong enough to penetrate the pipe walls. Now, except for the smallest of magmeters, the field coils are embedded in various chemically resistant plastic compounds lining the meter body. This design change has greatly reduced the overall size of the meter by reducing the requirement for extremely large electromagnetic field coils.

There are several producers of the magnetic flow meter, the major producer being Fischer & Porter, Inc. Other manufacturers are Brooks and Foxboro. Again, the multiplicity in size and compositon of magmeters prevent listing of all the price options. As an example of price, a 6" magnetic flow meter capable of handling 1 MGD is $2500-$2800, including the transmitter.

Figure 2-5 illustrates the manner in which the flow measurement from a magmeter could be transmitted, recorded and totalized, and used for additional control purposes. It is in this area of signal generation that the proponents of magmeters and venturi flow tubes enter into heated debate. In both instances the initial readout is non-linear due to the nature of velocity measurement. BIF linearizes the signal produced by the venturi tube by using a cam that is cut to follow the flow equation for a particular tube. The cam is attached to the mercury float wells, and as the well levels change due to the differential pressure, the cam rotates. The rotation of the cam is followed by an arm that generates an impulse directly and linearly proportional to the flow rate. The amount of deviation claimed for this system is less than 1% of actual flow at all flow rates.

The voltage signal that is produced by the magnetic flow meter is non-linear and has an increasing error over the range of the meter, with a one percent error at maximum flow. Fischer & Porter has compensated for this by building into the transmitter an electronic circuit which corrects for this deviation, so that the transmitted signal is linearly proportional to actual flow rate.

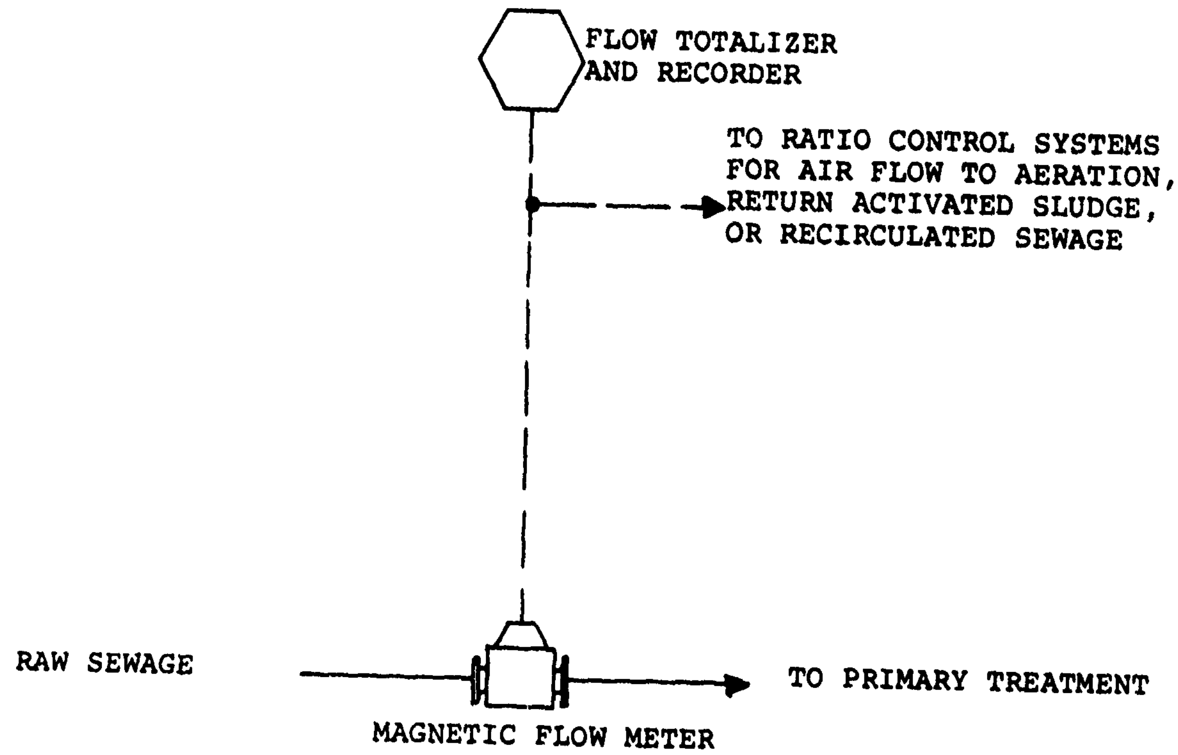



FIGURE 2-5

MEASUREMENT OF RAW SEWAGE FLOW WITH
A MAGNETIC FLOW METER

COURTESY OF FISCHER & PORTER COMPANY

Neither the Venturi tubes with flushing nor magnetic meters with cleaning have yet proved entirely successful for use in sewage and sludge service.

Whether magmeters or venturi flow tubes are used for in-line flow devices, field engineers have found it helpful to arrange those devices so that a rough check can be made from time to time on the meter. For instance, a magnetic flow meter on a line from a pump with a submerged point of discharge cannot be checked. However, if the discharge is exposed, or it flows into a channel where a weir can be placed, a rough check on the magnetic flow meter can be made.

## 2.2 HARMFUL SOLIDS REDUCTION

The initial stage in any wastewater plant consists of removing non-biodegradable solids and reducing the size of large pieces of material which may later be biologically oxidized. The purpose of these preliminary treatment processes is to (1) protect appliances and equipment in the following process steps and (2) render the coarse solids so that they can pass through pumps and be incorporated with the other sewage solids for removal by sedimentation. In addition, by making coarse pieces of sewage smaller, the surface areas increase and thereby they may be more readily biologically or chemically oxidized.

Screenings are materials in the raw wastewater that are caught on screens having openings usually 1/2 inch to 2 inches. The screens, placed at the head of the treatment plant, remove materials such as rags, sticks, and garbage.

Grit can be described as small, mainly inorganic solids that are removed from the wastewater after screening. Examples of grit are sand, silt, gravel, ashes, and coffee grounds. Skimmings consist of all types of floatable material which rises in sedimentation tanks.

### 2.2.A Screenings

#### I. Process Description

The quantity of screenings captured in a treatment plant is 0.5 to 6.0 cu. ft. per million gallons of sewage for screen openings of 1/2 to 2 inches and 3.0 to 5.0 cu. ft. for openings of 3/32 to 3/4 inches. Screenings have a moisture content of about 85 to 95 percent and an organic content of 50 to 80 percent. A sanitary means of disposal is required due to the high organic content. Therefore, these materials are usually buried. Sometimes they are incinerated or ground by hammermill-type shredders into small particles and added to sewage for later removal in sedimentation basins. Returning ground screenings to the treatment process may make them more amenable to biological treatment.

One method by which screenings may be handled in a wastewater stream is to direct the incoming sewage through a barscreen. Barscreens are designed to remove floating matter and lighter suspended solids. These screens come in three sizes (coarse, medium, and fine) and can either be stationary or moveable. The coarse racks are nothing more than a rack of parallel bars of steel or iron spaced two inches or more apart. These racks retard only large objects such as pieces of wood, dead animals, etc., from entry into the treatment plant. The medium racks have an opening of 1/2" to 1-1/2" and remove floating materials that will form a heavy and troublesome scum in sedimentation basins. The medium rack is almost universally used.

The screens can be cleaned manually or mechanically by a system of rakes by which the collector materials are scraped off the screens and onto a conveyer for disposal.

## II. Methods of Automatic Control for Barscreen Cleaning

There are two alternatives available for automatically actuating the cleaning of barscreens. The first is a time basis by which screen cleaning devices are actuated periodically, as predetermined by the operator, during those periods when the heaviest accumulation of coarse solids is greatest. The second alternative for automatic actuation is by loss of head.

The cleaning mechanisms on barscreens can be automatically actuated so that cleaning takes place whenever the hydraulic loss across the screen exceeds the preset value. Such an arrangement also takes care of frequent cleaning when sudden increases in refuse occur.

The most common method for measuring head loss is the bubbler type of system. Basically this is a doubling of the head detection system discussed earlier under flow measurement. Figure 2-6 illustrates the measuring and control sections of a complete control loop. The motor controls and motors would close the loop. In this system the differential level measurement upstream and downstream of the barscreen is made by immersing tubes in the flowing sewage, bubbling air through them, and measuring the back pressure created by these levels in a differential pressure transmitter. The transmitter converts the pneumatic signal to the electrical impulse which is then fed to a differential pressure controller. A parallel signal may be fed to a differential pressure trip alarm which can be set to act as a high alarm on an annunciator. The differential controller is equipped with adjustable high and low control points. When the high control point is reached, the cleaning cycle is started. Maintaining contacts in the motor controls assures a complete cleaning cycle once the action is initiated, even though the low control point has been reached. This prevents the cleaning mechanism from stopping in the middle of a cycle and leaving the refuse accumulation on the barscreen. If the accumulation of refuse is so great that it cannot be removed, the differential will continue to increase, and alarms will sound when the high alarm point is reached. Since the controller is actuated by the differential across the barscreen, changes in overall liquid level do not affect it.

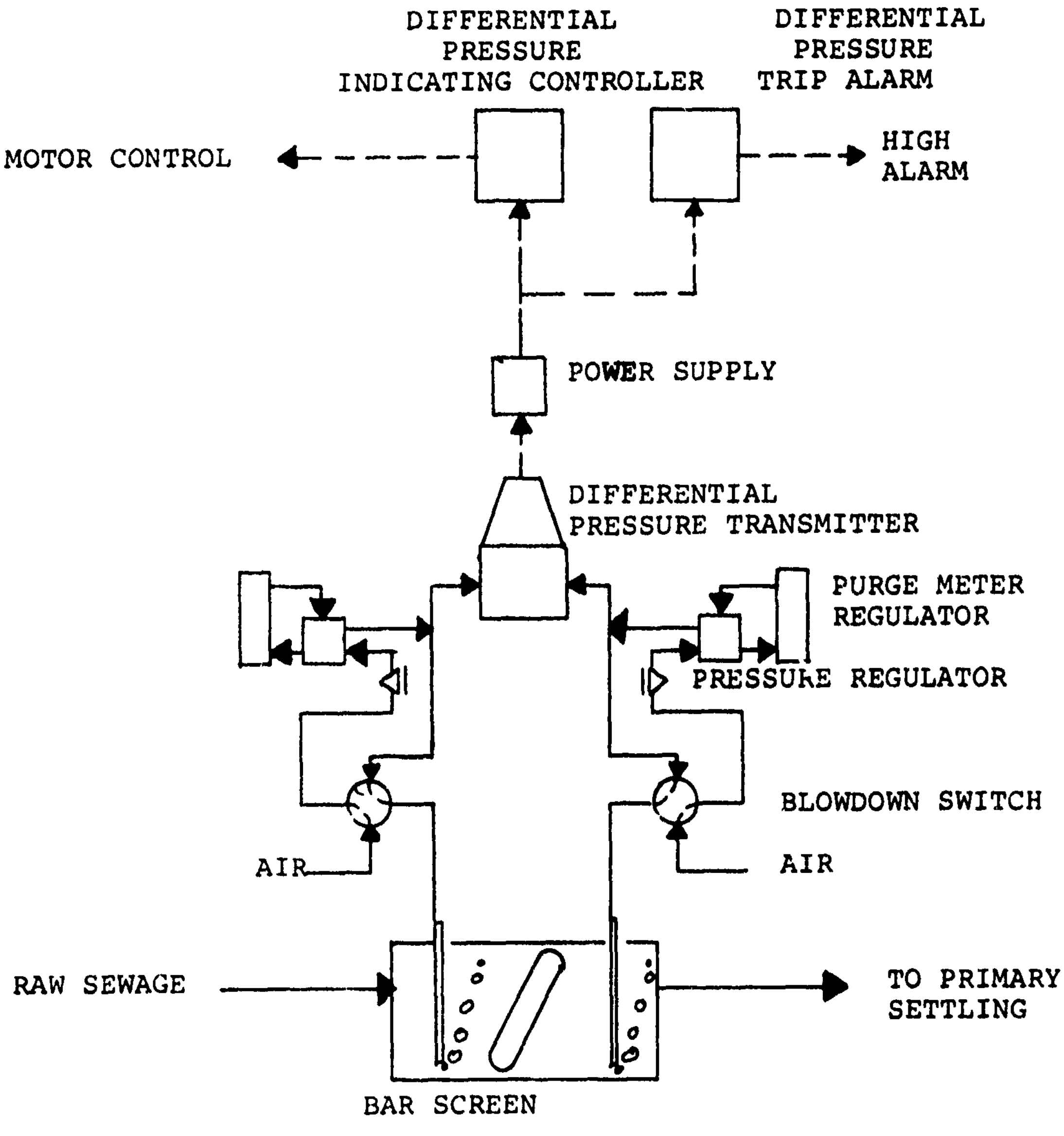



FIGURE 2-6

ACTUATION OF BAR SCREEN BY MEASURING
HEAD DIFFERENTIAL WITH A BUBBLER SYSTEM

COURTESY OF FISCHER & PORTER CO.

In addition to making barscreen control automatic, the controller causes the barscreen cleaning mechanism to operate the minimum period of time required to maintain the limiting differential across the screen. This saves wear on the cleaning mechanism and reduces power consumption.

The suppliers of differential pressure actuators for barscreens are: Fischer & Porter, BIF, Foxboro, Chicago Pump and Autocon, and the approximate price is $1400.

## 2.2.B Grit

### I. Process Description

Grit is removed at almost all sewage treatment plants even though the wastewater collection system may be separated. The problem becomes acute where treatment plants must deal with combined flow systems, i.e., sanitary and storm discharges.

After screening, influent flow may then pass through a grit chamber. Grit gets into the sewage flow at manholes, from garage floors or washing racks, through pipe joints by infiltration, and by street washings in combined systems.

Heavy inert particles of grit are selectively deposited in units installed at the head of treatment plants by velocity control in simple gravity settling structures or by air flotation classification of the inerts and lighter organics in aeration tanks.

Generally, grit collection units are designed to remove particles having a specific gravity of 2.65 and diameters down to 0.2 mm. The quantity of grit collected normally varies from 1 to 12 cu. ft. per million gallons with an average of 4 cu. ft. Specific quantities removed depend on many parameters including topography in the wastewater collection area, the surface cover, size of sewers and whether they are separate or combined, the intensity of rain storms, and the design of the grit removal system. The moisture content of grit varies from 14 to 34 percent. Grit is often washed after collection to reduce the organic concentration which may be as much as 50 percent of the total solids.

Grit considerably affects the heat value of sludges which are to be incinerated by decreasing the volatile content per pound of sludge. Therefore, it can be seen that the eventual fate of screenings and grit have a great influence upon the design of the grit removal apparatus. If grit is to be disposed of separately by landfill methods, it would be most desirable to remove as much organic matter as possible. If the facility is to contain equipment for sludge incineration and the grit is to be burned, it may be well to retain as much organic matter as possible to prevent lowering of the heat value in the incinerator feed.

Grit chambers vary in design from long rectangular channels to square and round collectors. Several methods are used to obtain nearly constant velocity through grit chambers. Chambers are now constructed with a control weir or other section at the outlet end to keep the velocity approximately constant at the varying flow rates. The area of the grit chamber must be sufficient to allow settlement of the smallest grit particle it is designed to remove. Several design innovations have appeared which offer variations on the traditional rectangular grit chamber. For instance, the vortex grit remover, (Figure 2-7) has an impeller to set up a vertical circulation which is aided by the spiral flow set up by a tangential inlet pipe. This vortex action moves the grit to a central hopper.

Grit chambers which use air for classification are little affected by fluctuations in flow and are considered as the best solution to the problem of removing grit from organic matter. It is claimed that flow velocities are established by the air that remove grit particles 0.2 millimeters and over with

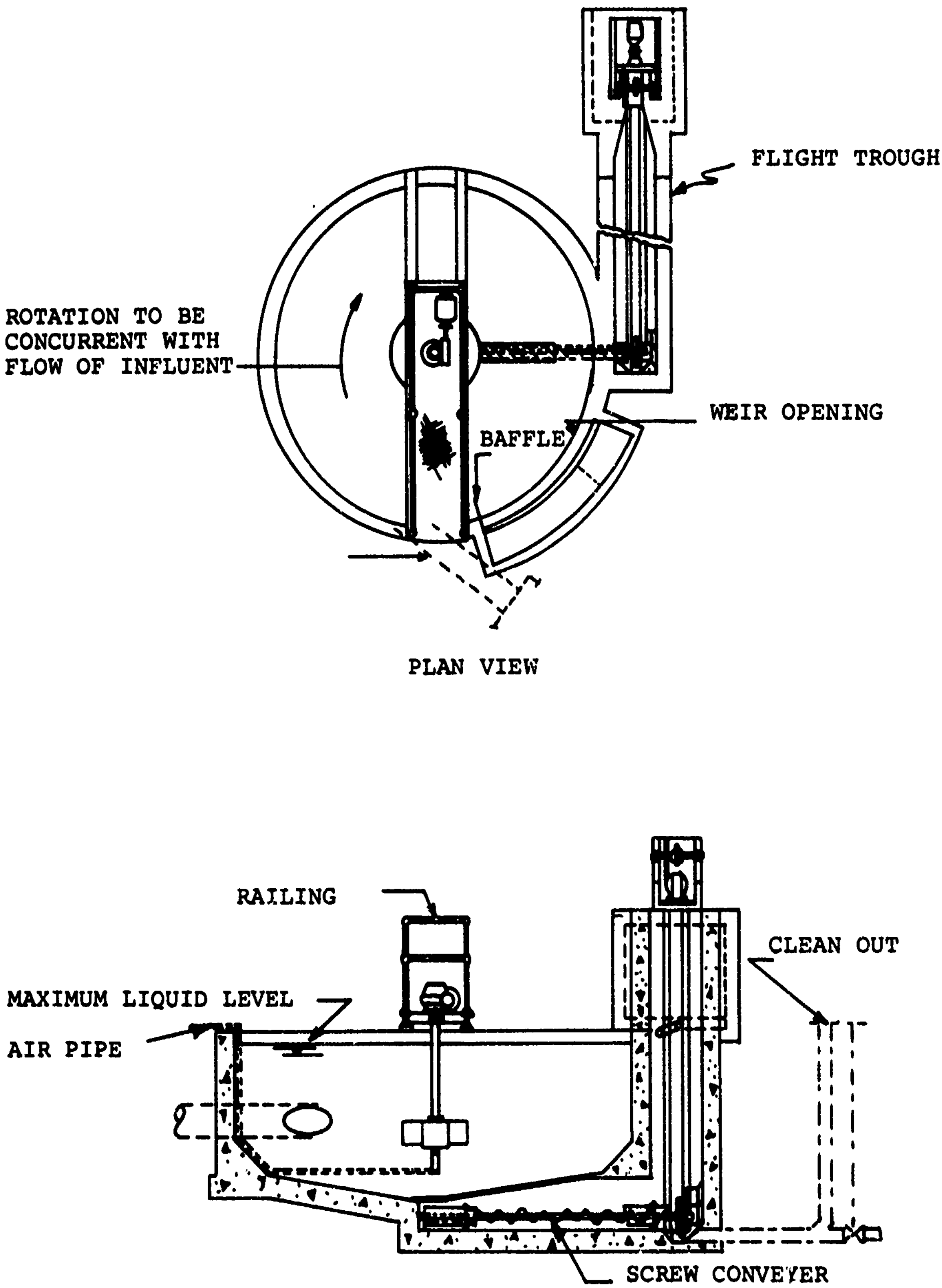



FIGURE 2-7

AERATED VORTEX GRIT CHAMBER

COURTESY OF INFILCO PRODUCTS CO.

little organic matter. Detention periods are one to two minutes and air is supplied at three cubic feet per minute per foot of tank length when aerated chambers are rectangular. It has been established that preaeration of sewage insures a fresher influent to the primary clarifier, assists in flocculating organic solids, and releases oil and grease from the liquid. In order to achieve these results, Infilco recommends a detention period of fifteen minutes in their aerated vortex grit chamber. Plant studies released by the U.S. Public Health Service (Project 332-8) show that preaeration results in an average improvement of 7.5% in removal in the primary clarifier.

There are some potential problems occuring from the use of aerated grit chambers. They may be a source of odors if the influent wastewater is septic. In this case, the grit removal unit should be completely covered to capture gases and thereby reduce odors, or odor control by prechlorination may be desired.

Grit that settles in chambers can be removed either manually or mechanically. In manual removal there should be two chambers built in parallel so when one is being cleaned the other is in operation. These chambers usually are cleaned every two weeks. If grit sedimentation is not accompanied by aeration, the next step is to remove and wash the grit. Washing the grit is necessary in order to remove the organic matter which may cause odor problems in dewatered grit.

Grit chambers which use rotating arms and circular tanks are known as Detritors (trademark, Dorr-Oliver Corp.). In this tank, rotating arms move the grit to a pocket on one side. From the pocket, rakes, screws, or other means of conveyance move it upward and discharge it into a container or hopper.

One of the newer methods for dewatering collected grit is by pumping grit laden water from either the bottom of an aerated grit chamber, or from a Detritor, through a hydrocyclone, (Figure 2-8). In this piece of apparatus, feed water from the chamber is introduced into a rubber lined metallic cone. This action developes a cyclonic vortex pattern. Centrifugal forces throw the grit contained in the slurry to the walls of the cone. As the solids collect along the walls of the cone they move toward the apex, and eventually discharge out the unit through the apex opening or valve. The lighter grit free sewage and sludge together with the major portion of liquid, move to the inner portion of the vortex where they are displaced into a vortex finder or overflow opening.

Final grit washing and dewatering takes place in a classifier. Grit and other particles from the cyclone are collected in the pool section of the classifier. Coarser, heavier particles settle in the bottom while organic materials remain in suspension for discharge over a weir into an overflow launder. The settled grit then travels up either a double flight spiral conveyer or an oscillating ladder where it is washed by a spray, and then discharged into a storage hopper.

II. Method of Automatic Control of Grit Removal

At present there is only one good parameter which can be used for the periodic actuation of degritting operations; that parameter is time. After an initial period of operation, the plant operator should be able to determine the periods when grit accumulations are greatest and set timing devices accordingly. The timing device may then actuate pumps, bucket elevators, screw conveyors, etc., which remove the grit and transport it to storage hoppers to await eventual disposal.

## 2.2.C Screenings

### I. Process Description

Comminutors are devices which combines screening and cutting, and are submerged in the sewage conduit

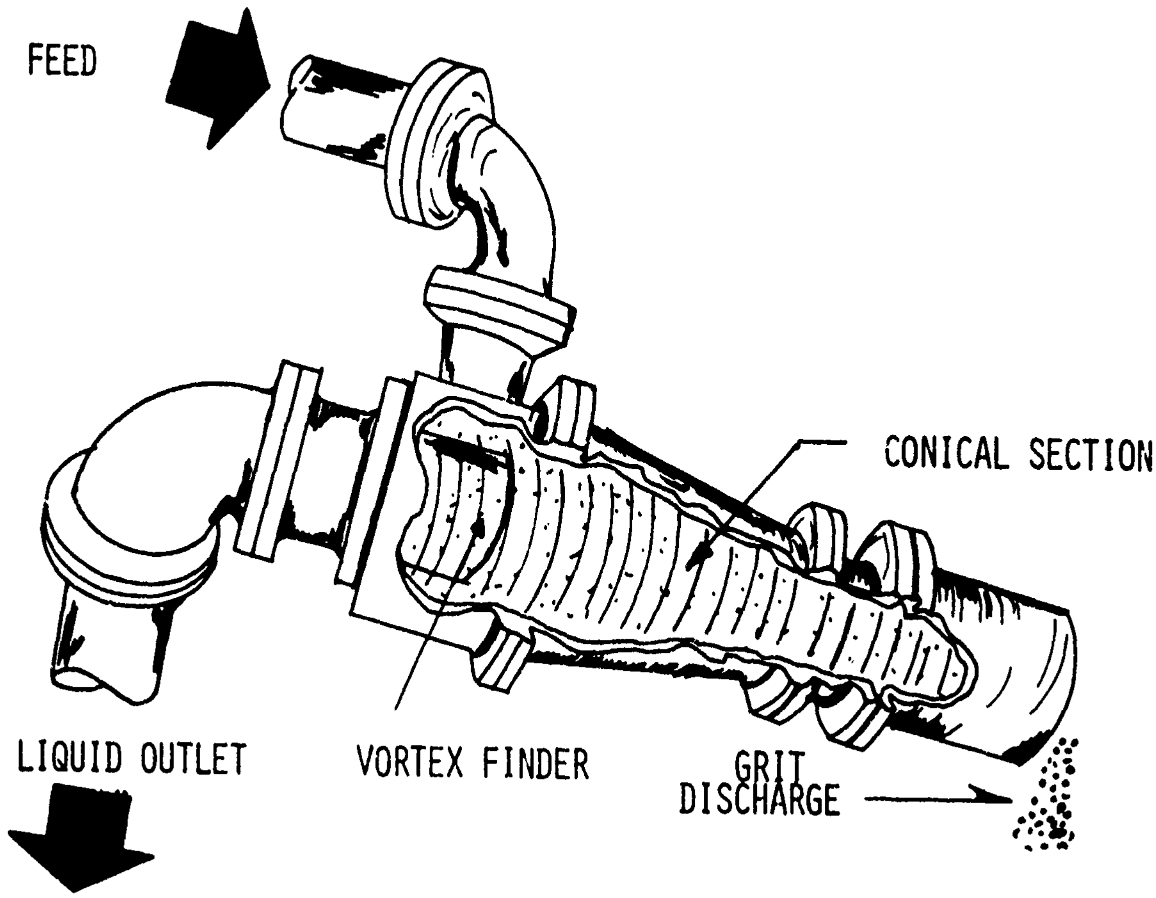



FIGURE 2-8

GRIT REMOVAL WITH A HYDROCYCLONE

(see Figure 2-9). Generally, comminutors should be located downstream from the grit chamber so that those items which would interfere with operation, such as large stones, metal objects, toys, etc., can be removed prior to grinding, and thus extend the life of the cutting blades. Comminutors are of two basic designs in their operation. The first employs a continuously rotating disc of cutting bars or a slotted cylindrical drum. In the former instance the sewage passes through horizontally as it would through a barscreen. In the latter instance, the sewage flow completely surrounds the cylinder, passing inward through the slotted drum and downward through a U-shaped pipe which then discharges into an adjacent open channel.

There is a second major classification of comminutor which employes a fixed semicircular screen grid. Its cutters also operate within this semicircular grid and oscillate back and forth in this pattern. This type is illustrated in Figure 2-9.

For those applications where comminuting is desired only on a demand basis there is a hybrid device called the Barminutor (Barminutor is a registered trademark of Chicago Pump.) Basically, the "Barminutor" consists of a barscreen, over the face of which a comminuting device travels vertically up and down the rack; the cutters pass through the fixed slots of the screen while rotating continuously. With the cutting unit in the up position and out of the channel flow, the full hydraulic capacity of the screen is utilized at all times.

## II. Methods for Automatic Control of Comminutors

As with barscreen cleaning, the best way for detecting and actuating "Barminutors" is head loss across the device (See Figure 2-6). As solids are accumulated by the screen and a predetermined liquid level differential is reached upstream from the Barminutor, the cutting unit is actuated only if required to eliminate solids accumulation. Comminutors per se are generally designed for continuous operation. But head loss actuating systems have also been employed to control their operation. For those

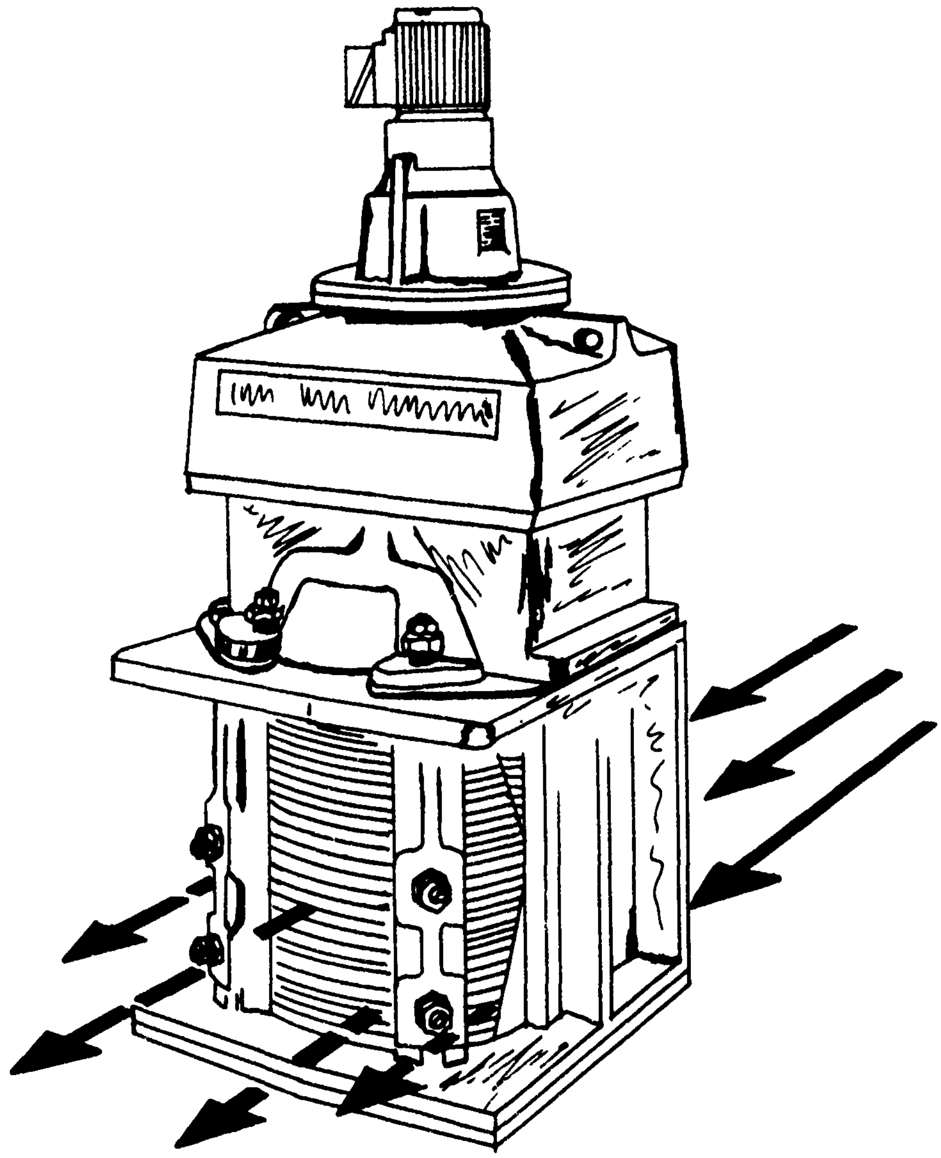
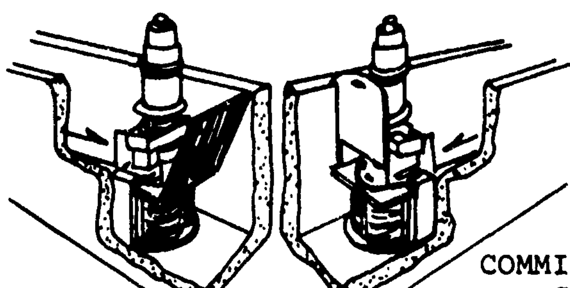


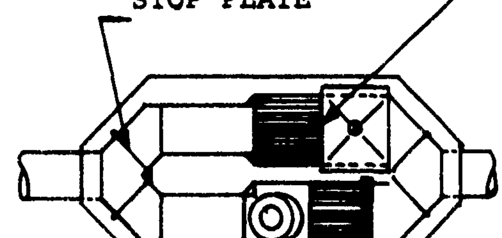
FIGURE 2-9

COMMINUTORS

COURTESY OF WORTHINGTON, INC.



VARIOUS CHANNEL
INSTALLATIONS FOR COMMINUTORS




COMMINUTOR POSITION IN A BY-PASS
CHANNEL CONFIGURATION

continuously operating comminutors it is quite possible to instrument the operating condition of a comminutor by monitoring one of the motor functions. If the comminutor becomes stuck due to lodgement of rags or other items of high shear strength, the sudden heating of the motor bearing, or reduction in the rate of rotation could be displayed on a control panel to warn the operator of developing trouble. RPM is easily monitored by the installation of an electronic tachometer and transmitter at the motor site. This signal then could be transmitted to a high-low alarm and annunciator to indicate motor problems.

## 2.3 ODOR CONTROL

### 2.3.A Process Description

In many wastewater treatment facilities the sewage that comes to the plant is extremely septic in nature due to the length of the collection system, or low flow rates within the sewers. If the treatment plant is located near a residential area this odor problem can become very obnoxious. These odors are due to the formation of such foul smelling substances as hydrogen sulfide, indole, skatole, mercaptans, and cadaverine. Hydrogen sulfide usually is regarded as the forerunner of the other foul-odor substances. Accordingly, odor control measures are quite likely to result in control of unpleasant odors from all the substances listed. Chlorine, when applied, changes hydrogen sulfide to hydrogen chloride and sulfur. In addition, the application of chlorine results in a slowing of biological activity, thereby reducing the rate at which oxygen is removed from the sewage.

Since chlorine reacts indiscriminately with other materials present, some workers prefer to add ferrous chloride for a more selective removal of S, thus: $H_2S + FeCl_2 \rightarrow FeS + 2HCl$. Chlorinated benzols (one isomer being the active agent in mothballs) also have been applied in sewer systems for odor control.

Chlorine treatment is highly regarded for odor control. In the concentrations used (usually 4-5 mg/l, and sometimes over as wide a range as 3-30 mg/l), a residual chlorine should not be produced, and treatment processes should not be impaired. Breakpoint chlorination is the most effective form of chlorination for odor control, although chemical oxidation for odor control does not always produce nonodorous by-products.

2.3.B Automatic Control of Chlorination

Figure 2-10 depicts the most common method of automatically regulating the rate of chlorination for odor control. The chlorinator is paced by the raw sewage flow signal to give an approximate rate of chlorine dosage. Fine adjustment is provided by a second signal derived from an oxidation-reduction potential (ORP) monitoring loop.

ORP is a measure of the relative state of oxidation or reduction of sewage. It is a parameter of the bacteriological environment, some bacteria thriving at one level of ORP while other bacteria thrive at a different level of potential. Specifically aerobic bacteria will thrive at positive levels of ORP while anaerobic bacteria function best at negative values. If the operator can control the environment to one suitable for the life processes of the aerobes he can overcome septic conditions in the raw sewage and the problems resulting from this condition.

Chlorine, in subresidual levels can be used as a chemical oxidizing agent to maintain ORP of the raw sewage at a desirable value. Since the environment is being controlled, the amount of chlorine fed will be at a minimum. The amount of chlorine required to control odor and its corresponding ORP signal is an empirical relationship determined by experimentation with any particular plant. The set-point of the indicating controller would be the experimental point because by changing it, the amount of chlorine needed to produce a given ORP would be directly governed. Oxidation-reduction potential measuring cells express the relative concentrations of the oxidized and reduced forms of a substance present in the sample. This determination is accomplished by measuring the potential difference between the two half cells of an ORP cell. Equipment for ORP measurement compares closely to that for pH measurement. The reference electrodes can be identical (usually silver-silver chloride) but a noble-metal electrode replaces the glass pH electrode. Ideally the inert metal electrode in a well mixed oxidation-reduction system serves only to acquire the electro-chemical potential of electrons, depending on the prevailing redox equilibrium in solution. The metal donates and accepts electrons. The particular metal used is relatively unimportant as long as it is sufficiently non-reactive. Platinum and gold are the most common ORP electrodes. The actual potential measured is the difference between that of the noble-metal electrode and the reference electrode.

Some of the manufacturers of ORP cells are Beckman, Fischer & Porter, Foxboro, Universal Interloc, and Kerotest, and their prices are about $1200, including the associated controller for interfacing with a chlorinator.

2.3.C Operation of Chlorinators

A chlorine gas feeder is a fairly simple apparatus. It operates on the principle of regulating flow by controlling conditions existing upstream and downstream of an orifice in a flow line. This orifice may be constant or variable. Various additional refinements are incorporated in the modern chlorine gas feeder, but these refinements do not alter the basic principle. The rate of fluid flow through a pipeline may be determined by introducing into the line an orifice of known size in order to create a differential pressure condition. As flow takes place, a pressure drop or differential represents a particular flow. Therefore, if means are provided whereby given differentials may be set up, known flows may be established through a line and chlorine gas feed varied according to manual or automatic control. Conversely, flows may be governed by maintaining a constant orifice and changing the pressure differential. The most popular method for manually accomplishing gas feed control is to maintain the differential

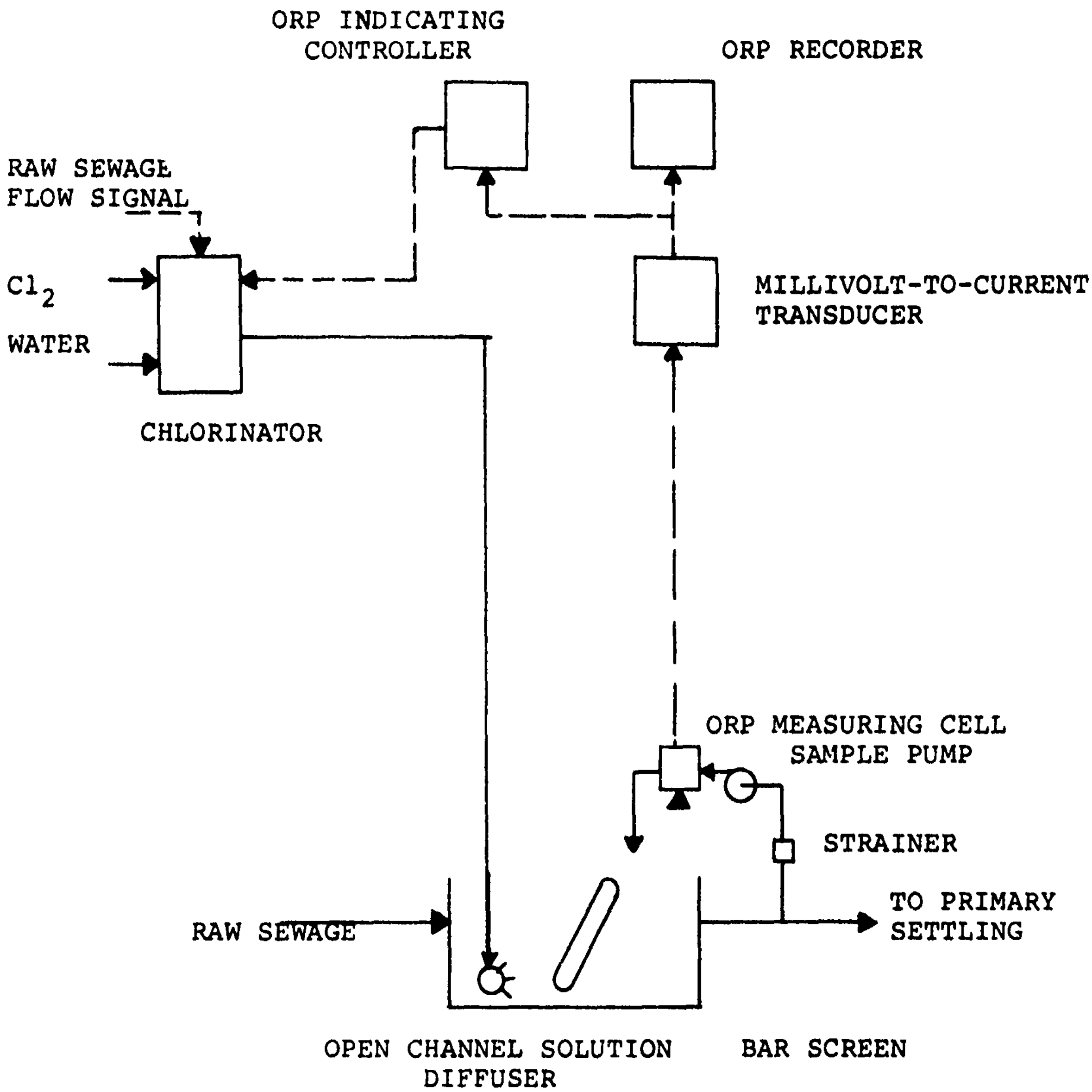



FIGURE 2-10

PRE-CHLORINATION FOR ODOR CONTROL BY PACING WITH RAW SEWAGE FLOW, AND TRIMMING CONTROL PROVIDED BY ORP.

COURTESY OF FISHER & PORTER CO.

across the orifice at a constant value, and change the rate of flow by changing the size of the orifice.

In the automatic control of chlorine dosing, two variables at a time may be controlled within the chlorinator. If a single controlling impulse is received, it actuates a servomotor which in turn positions a valve changing the orifice size. If two signals are used to govern the rate of dosage two alternatives may be followed. The first is to send a flow proportioning signal to the differential regulator and a dosage or trimming signal from manual control or remote sensing devices (such as ORP cells and chlorine analyzers) to the motorized valve. Alternatively, the flow proportioning signal may be transmitted to the motorized valve, and dosage trimming signal from an automatic analyzer applied to the differential regulator.

Some of the producers of automatic chlorination equipment include Wallace & Tierman, BIF, and Fischer & Porter. The prices for chlorinators with motorized valves are approximately $1800.

The control loops associated with the chlorination of treatment plant effluent will be presented in Chapter 7.

## CHAPTER 3

## PRIMARY CLARIFICATION

### 3.1 PROCESS DESCRIPTION

The first step in removing suspended organic matter in the sewage flow occurs in the primary sedimentation tank. The sedimentation tank can be oblong or circular in shape and is usually designed for a retention time of two hours. It has been shown that the efficiency of settling basins depends upon surface area rather than flow velocity and detention time. Therefore, the removal of discrete particles is independent of tank depth and is a function only of the overflow rate of the tank effluent. The area of the primary sedimentation tank is arrived at by assuming an average surface hydraulic loading of 900 GPD per sq. ft. in tanks ten feet deep above the sludge zone. This design generally results in BOD removals of 33 - 37% and suspended solids removal of 55 - 60% at initial concentrations of 100 - 300 mg/l for each parameter. While in the tank the larger suspended organic materials settle out producing raw sludge.

Since the actual residence period is generally less than the theoretical detention period of a tank, the actual detention time is referred to as the "flowing-through period." How close this will approximate the detention period will depend upon the design of the tank. The ideal settling basin is one in which the variation of flow is horizontal and the velocity is uniform in all parts of the settling zone for a time equal to the detention period. The concentration of suspended particles of each size should be the same at all points of the vertical cross section at the inlet end. A particle will settle when the impelling force of gravity exceeds the inertia and viscous forces. Therefore, the particle is effectively removed when it reaches the bottom of the settling zone.

Sedimentation as a process can be considered in three basic classifications depending upon the nature of the solids present in the suspension: discrete, flocculant, and zone settling. In discrete settling the particle maintains its individuality and does not change size, shape, or density during the settling process. Flocculant settling occurs when the particles agglomerate during the settling period, with a resulting change in size and settling rate. Zone settling involves a flocculated suspension which forms a lattice structure and settles as a mass exhibiting a distinct interface during this settling process.

Sewage must be in the tank long enough for the particles to settle. This is accomplished by installing baffles to deflect and distribute the incoming flow downward along the bottom of the tank. For the discrete particle the efficiency of removal is related only to the overflow rate, but when flocculation occurs, both overflow rate and detention time become significant. The foregoing is based on the performance of an ideal settling tank under quiescent conditions. In practice, however, short circuiting, turbulence, and bottom scour will effect the degree of solids removal. Scour occurs when the flow-through velocity is sufficient to resuspend previously settled particles. Scour is usually not a problem in large settling tanks but can occur in grit chambers and narrow channels.

## 3.2 AVAILABLE EQUIPMENT AND TECHNOLOGY

### 3.2.A Tank Design

Tanks are rectangular, square, and circular. For rectangular tanks a ratio between the length and width of 2 to [illegible] is favored by some engineers. Long, relatively narrow tanks are less affected by inlet and outlet disturbances in cross currents caused by breezes. Tanks that would require large surface area are therefore sometimes divided into several units by walls placed longitudinally.

Circular clarifiers may employ either a center feed well or a peripheral inlet. The tanks can be designed for center sludge withdrawal or for vacuum withdrawal over the entire tank bottom. The flow of sludge to the center well is for the most part hydraulically motivated by the collection mechanism, which serves to overcome inertia and avoid sludge adherence to the tank bottom.

An inlet device is designed to distribute the flow across the width and depth of the settling tank. The outlet device is likewise designed to remove the effluent uniformly at the outlet end of the tank. Inlets and outlets of good design will reduce the short circuiting characteristics of the tank. The ideal inlet reduces entering velocity to prevent pronounced currents toward the outlet and distributes the water as uniformly as practicable over the cross section of the tank. Influent water should mix with the water already in the tank to prevent the entering water, which is usually denser than the water in the tank, from sinking to the bottom and moving along the bottom toward the outlet.

The tank outlet is usually a free-falling submerged weir discharging into a conduit extending across the end of the tank. A long weir has a smaller depth of sewage over it and more nearly skims off the surface liquid. Such an arrangement will produce a better effluent. Weir loading should not exceed 15,000 gallons per day per linear foot and preferably should be 5,000 to 10,000 gallons per linear foot. Weirs that are notched on one foot centers give more constant flows since they are not affected by local differences in surface tension. Extending the effluent channels back into the basin and providing multiple effluent channels will give increased weir length. In circular basins, inboard or radial weirs will insure low takeoff velocities. Relocation of weirs is sometimes necessary to minimize solids carry over induced by density currents that result in upwelling swells of sludge at the end of the settling tank.

The hydraulic characteristics of the settling tank can be defined by a dispersion test in which dye or other tracer compound is injected into the influent as a slug and its concentration in the effluent is measured as a function of time. It is frequently possible to improve the performance of an existing settling basin by making modifications based on the results of a dispersion test.

Peripheral feed clarifiers have been used quite successfully in upgrading the performance of existing center feed circular clarifiers. According to Eckenfelder, dispersion studies on hydraulically overloaded centerfeed settling tanks indicate that their conversion to peripheral feed tanks will increase their effective detention time by as much as a factor of three or four.

3.2.B Sludge Removal Mechanisms

Sludge collection mechanisms are one of three major types. For rectangular tanks the collectors consist of two endless chains operating on sprocket wheels and supporting wood cross bars or flights. The flights push the sludge to a hopper at the end as they move slowly along the bottom. For primary sedimentation the flight should move back at the surface to push the scum toward a trough at the opposite end. Since the heaviest sludge accumulation is near the inlet of the tank the sludge hopper should preferably be at the influent end. The second type of rectangular clarifier employs a traveler spanning the tank which pulls a single scraper slowly along the bottom of the tank to the hopper and on the return trip the scraper rises in order to push the scum to a trough near the outlet.

For square and circular tanks sludge collectors consist of two or four rotating arms supported by a central shaft or similar support. The arms have blades or plows which push the sludge toward a hopper and the sludge discharge pipe at the center. The sewage enters the settling tank at the center through ports in a casting and is diffused by a perforated circular baffle. The effluent leaves over a continuous weir around the periphery of the tank. A modification of the rotary arm type collector uses two continuous spiral steel blades to push the sludge to the center instead of arms with small blades.

Since tank clarifiers are also utilized for secondary settling of activated sludge or trickling filter effluent, it should be mentioned here that there is a modification of the rotary sweep sludge collector which has hollow arms. In this hydraulic vacuum system, the hydrostatic head is utilized to force the sludge through orifices in the hollow arm. This type of mechanism is adapted to light, flocculant sludges that may be disturbed as they are pushed toward the tank center by other types of sludge collecting mechanisms.

Sludge removal pipes convey the sludge from the bottom of the hopper to separate digesting tanks, lagoons or other processing units. If sufficient hydrostatic head is available, sludge may be withdrawn by gravity; otherwise pumping will be necessary. In most cases when treating raw sewage the collectors are not operating continuously but only with sufficient frequency (daily or more often) to keep sludge from accumulating in excessive amounts in the tank.

## 3.3 AUTOMATIC CONTROL OF SLUDGE WITHDRAWAL

It is desirable to maintain sludge at its highest possible concentration to aid in further sludge handling processes such as dewatering, digestion and incineration. Therefore, by monitoring the density of the sludge it is possible to minimize the excess water that might be removed when pumping sludges from primary and/or secondary clarifiers. Several instruments exist that aid in determining sludge concentration in situ.

### 3.3.A Sludge Withdrawal-Density Control

Three different concepts have been employed to measure the densities of solutions and slurries flowing in pipe lines. One method is based upon measuring the effect of the media weight upon a vibrating "tuning fork." The slurry to be measured flows through a U-tube section which is connected to the tuning fork arrangement (see Figure 3-1). A drive coil is electrically excited by a pulsating current which drives the U-tube into mechanical vibration. The vibration becomes a

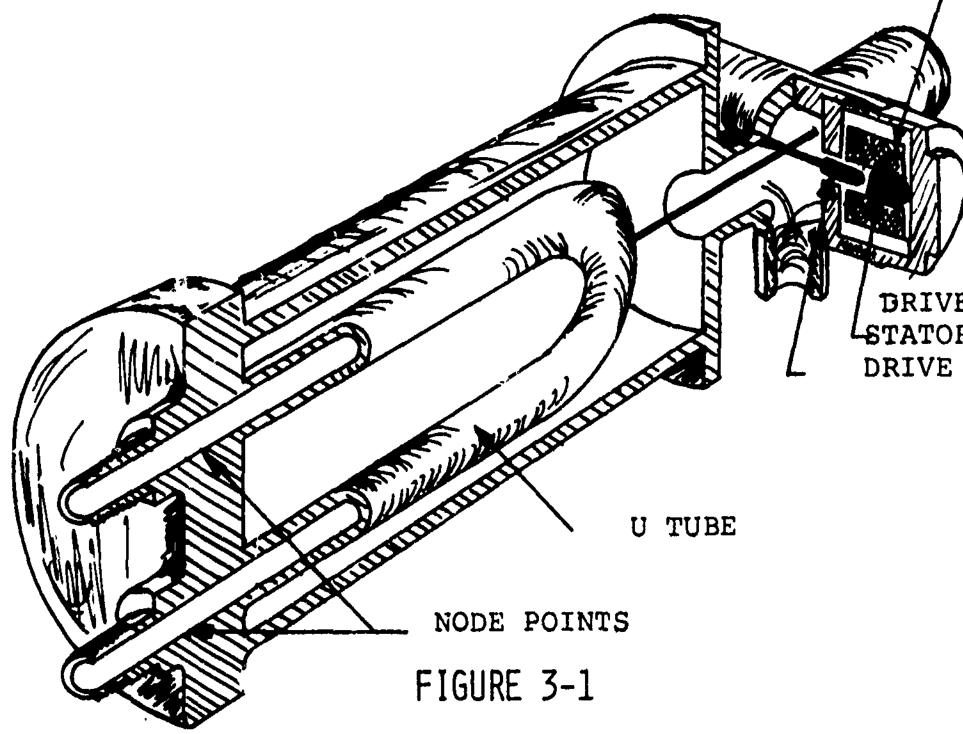



FIGURE 3-1

DENSITY/SPECIFIC GRAVITY DETECTOR

COURTESY OF AUTOMATION PRODUCTS, INC.

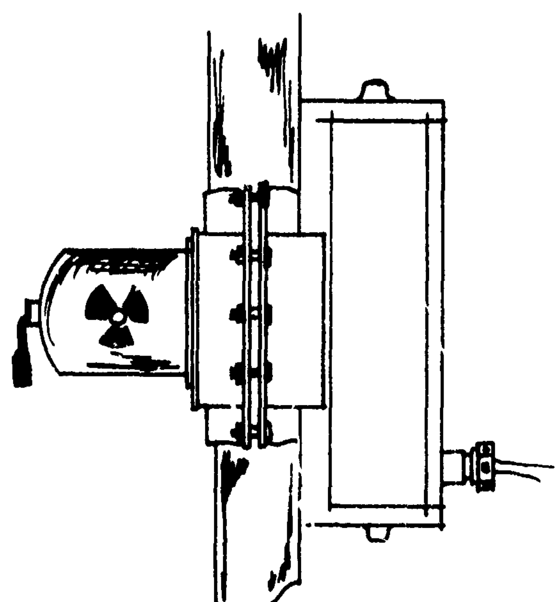


FIGURE 3-2

NUCLEAR DENSITY DETECTOR-TRANSMITTER

COURTESY OF ROBERTSHAW CONTROLS, INC.

function of the mass of the media contained in the U-tube. This vibration is sensed in the pick-up end. The pick-up end consists of an armature and coil arrangement which is similar to the drive end. The vibration of the pick-up armature induces an A.C. voltage in the pick-up coils. This output voltage is then interpreted by a converter-recorder as the relative density of the media. When the density of the slurry decreases this is interpreted as an increase in water content and the sludge pumping may be automatically stopped. This device is generally installed across a sludge pump. Since the tube size in the density meter is 1/2 inch, its use is recommended for controlling sludge flows from secondary clarifiers and from digesters. This device is made by Automation Products, Inc., and costs $2000 - $2500 depending on the service requirements.

Another approach to the measurement of sewage sludge density is the ultrasonic density meter. This device impinges sonic vibration upon the flowing fluid. An electronic control unit generates an electrical signal which is converted to an ultrasonic signal. This signal is directed across the pipe section through the sludge where it is received and reconverted to an electrical signal. The attenuation of sonic energy is a direct exponential function of the solids entrained in the fluid. When a percent of solids is the predominant variable, the system determines whether the sludge is above or below a preselected percentage. This device is used in place of a pipe section much as the magnetic flow meter. The acoustic density meter is made by National Sonics Company.

The third concept applied to remote measuring of sludge densities is the use of nuclear radiation. In this technique the density of a slurry is inversely proportional to the amount of gamma radiation that passes through a pipe. Gamma rays, i.e., electromagnetic pulses, are generated by radioactive isotopes of cesium or cobalt. As the radiation passes through a slurry, individual particles will absorb some portion of the energy.

The greater the media density the greater the absorption, and the less radiation that is detected (see Figure 3-2). The detector is placed on the opposite side of the pipe from the radiation source and is composed of an ionization chamber which generates a DC current in direct proportion to the radiation received. This current is then amplified and a converter interprets the signal as density. The big advantage to this is the ease with which it may be applied externally to any pipe. There is no need for the measuring device to be in intimate contact with the pipe contents. Problems caused by direct contact with the product and vessel fittings are eliminated. Mechanical costs are also minimized since pipe mounting brackets are normally supplied with the instruments.

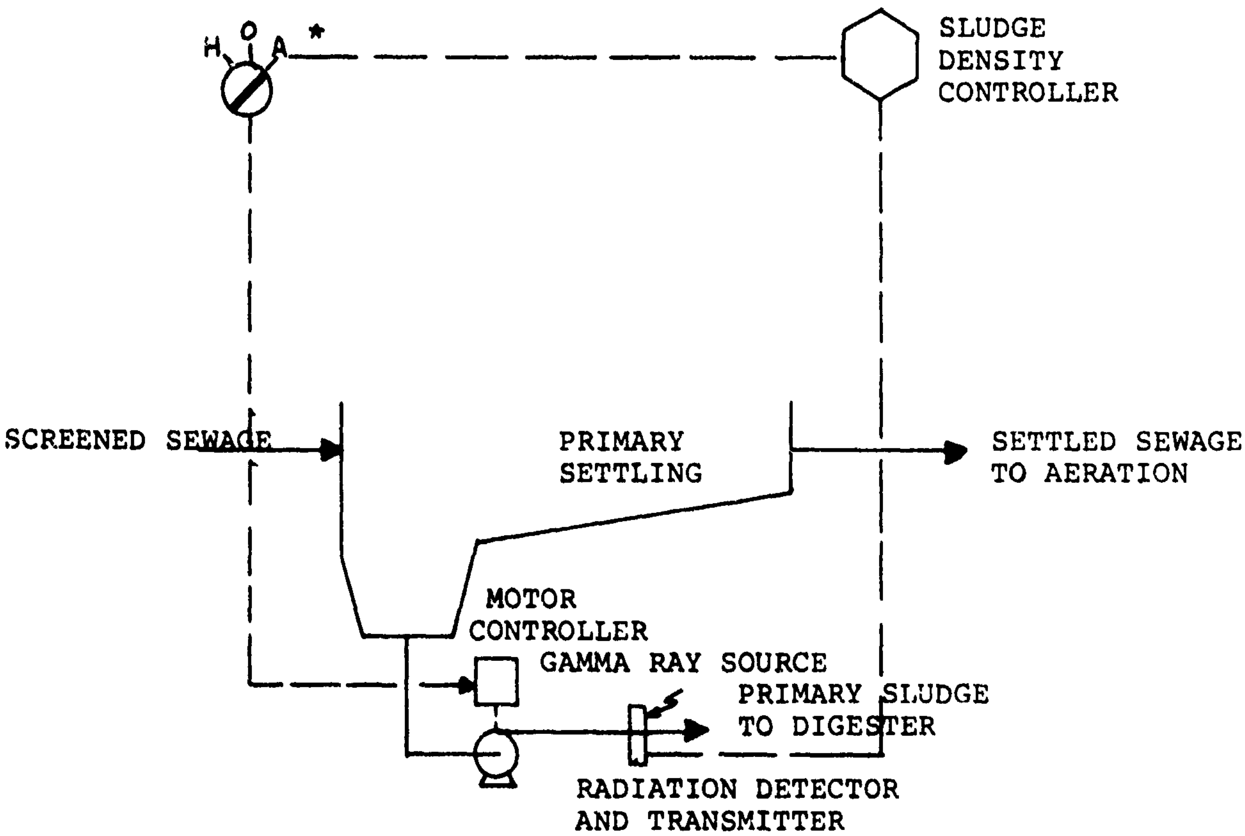
There are two basic differences between nuclear radiation instruments and other instrumentation, these being legal and economic. While adequate shielding is provided with this type of system, all radioactive sources must be licensed by the Atomic Energy Commission. The second difference involves the cost of this equipment. In a number of instances nuclear instruments cost more than the more conventional types, however, the added cost may be justified because radiation devices may work where other types may not, since it is noncontacting and will operate under varied conditions.

There are two major design and operational difficulties encountered with the nuclear density devices, one of which is the possible need for increased pipe cross-sectional area in vicinity of the gamma ray source. Doing this increases the path that the rays must travel and any material in between the source and the detector will attenuate the signal to a greater degree. The effect here is the same as that used in an analytical laboratory employing the colorimetric test: The greater the path length that the light must travel (i.e. the more intense the color for a given concentration) the greater will be the accuracy of the test. In addition, this allows for lower limits of detectability. Using this design criteria, the next problem is partially resolved. In sewage sludge, especially raw primary sludge, there are large amounts of grease. This grease coats and accumulates on the insides of pipes . Therefore, as this buildup occurs, the gamma radiation from the source is partially absorbed giving a false high reading on the sludge density. This could result in watery sludge. Therefore, by increasing the cross-sectional area, any attenuation due to grease buildup has a proportionately smaller effect. Provisions must be made to 1) periodically clean the pipe in the area of the detector, and/or 2) recalibrate the system by rezeroing with clean water.

Figure 3-3 shows how such a density meter could be incorporated into a control loop to control the pumping of primary sludge. As with most automatic systems, this one is provided with an alternate manual control mode (illustrated by the hand-off-automatic selector).

The principal suppliers of nuclear density detectors for sewage treatment plants are Ohmart, Robertshaw and Kay-Ray.

The main function of a sludge density device is to determine for the operator, or controller, the length of time during which sludge should be withdrawn. Still to be included in the control loop (either open or closed) is the method by which the withdrawal process will be initiated . The simplest way is to insert an interval timer in the loop so that at expected periods of high sludge accumulation the pumping process will automatically commence and continue until there is a signal from the sludge density controller that terminates the process. Of course a time delay circuit has to be incorporated into this system so that the newly pumped sludge has time to reach the density meter. Otherwise, the low density material from the previous pumping will cause the density controller to cease pumping almost immediately.




* HAND-OFF-AUTOMATIC

FIGURE 3-3

PRIMARY SLUDGE WITHDRAWAL
DENSITY CONTROLLED
(NUCLEAR RADIATION)

3.3.B Sludge Withdrawal - Time Control

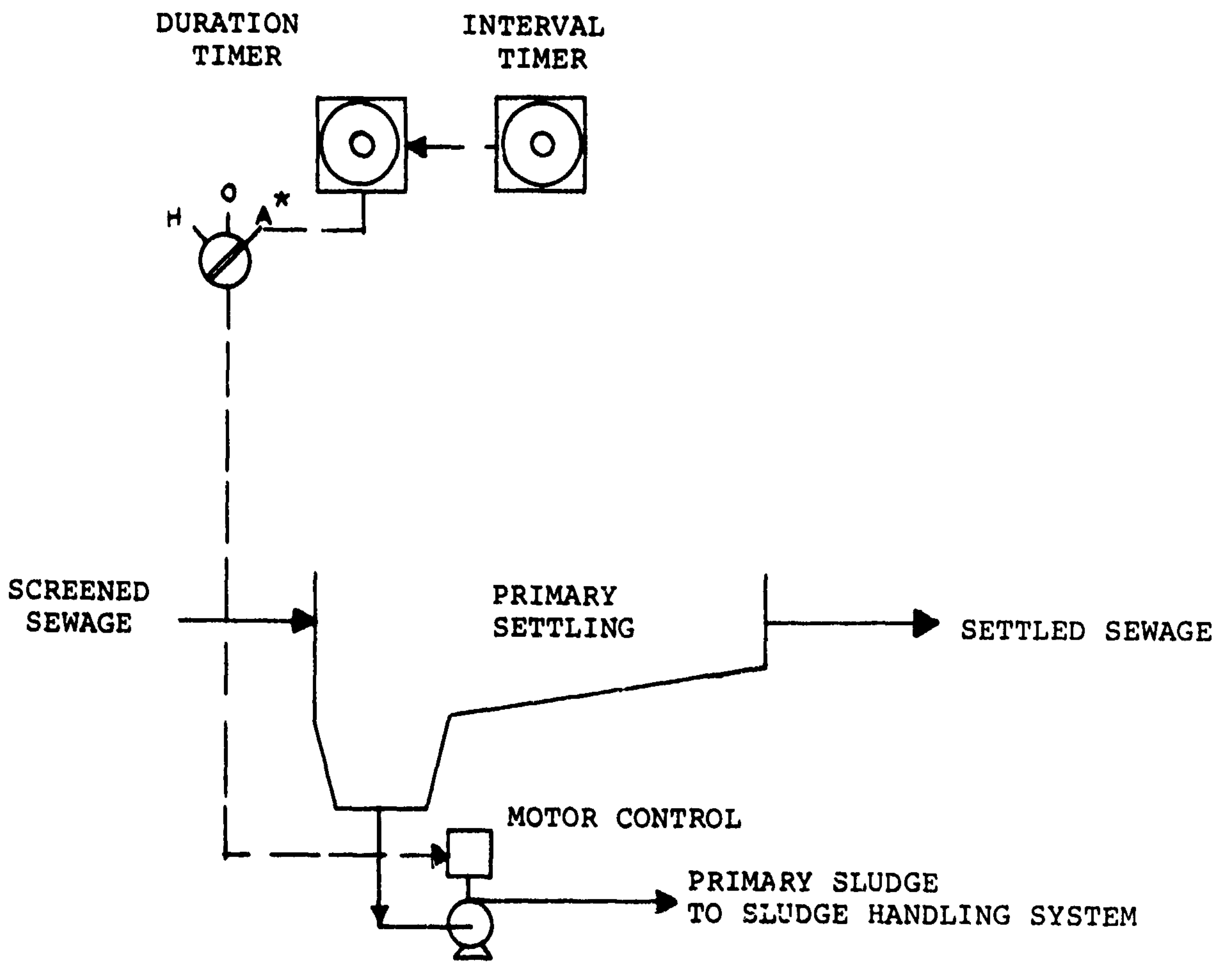
Since the two major control parameters for sludge withdrawal (initiation and duration) have been satisfied with one combination of instruments, two less sophisticated but equally effective alternatives will be presented. Figure 3-4 illustrates an open-loop method for controlling sludge withdrawal. In this system an interval timer initiates the process, as discussed previously. The signal from the interval timer then actuates a duration timer. The duration timer governs the length of time that pumping occurs. This timer functions according to the operators experience with his plant, i.e. he sets the timing cam. This system has been found to be as reliable as pumping sludge by flow control (see Section 3.3.C).

3.3.C Sludge Withdrawal - Flow Control

Figure 3-5 represents a compromise in automatic sophistication between density control and interval pumping. Since most plants have a means for measuring the raw sewage flow, it is possible to integrate and totalize that flow signal. A signal from the totalizer-integrater is continuously fed to a batch totalizer or predetermining counter. Again, according to operator experience, a predetermined volume of sewage is set into the batch totalizer, and every time this volume is reached the pumping process is started. Here, as with the previous example, the length of pumping is controlled by a duration timer. The ultimate in sludge withdrawal automation would be process initiation by batch totalizing, and pumping duration by sludge density.

3.3.D Sludge Withdrawal - Operator and Magmeter

One additional method will be mentioned here which is purely a result of operator experience, and not of engineering design. In those plants which monitor sludge volume by magnetic flow meters (Figure 3-6), operators have observed the velocity with which sludge flows through lines. As long as the flow rate remains low, pumping is continued. But as soon as the flow rate starts to increase due to the drop in viscosity, pumping is stopped. While this is not an automatic procedure, it represents full utilization of instrumentation for proper plant operation.




*HAND-OFF-AUTOMATIC

FIGURE 3-4

PRIMARY SLUDGE WITHDRAWAL, A
(INTERVAL-DURATION TIMED)

COURTESY OF FISCHER & PORTER CO.

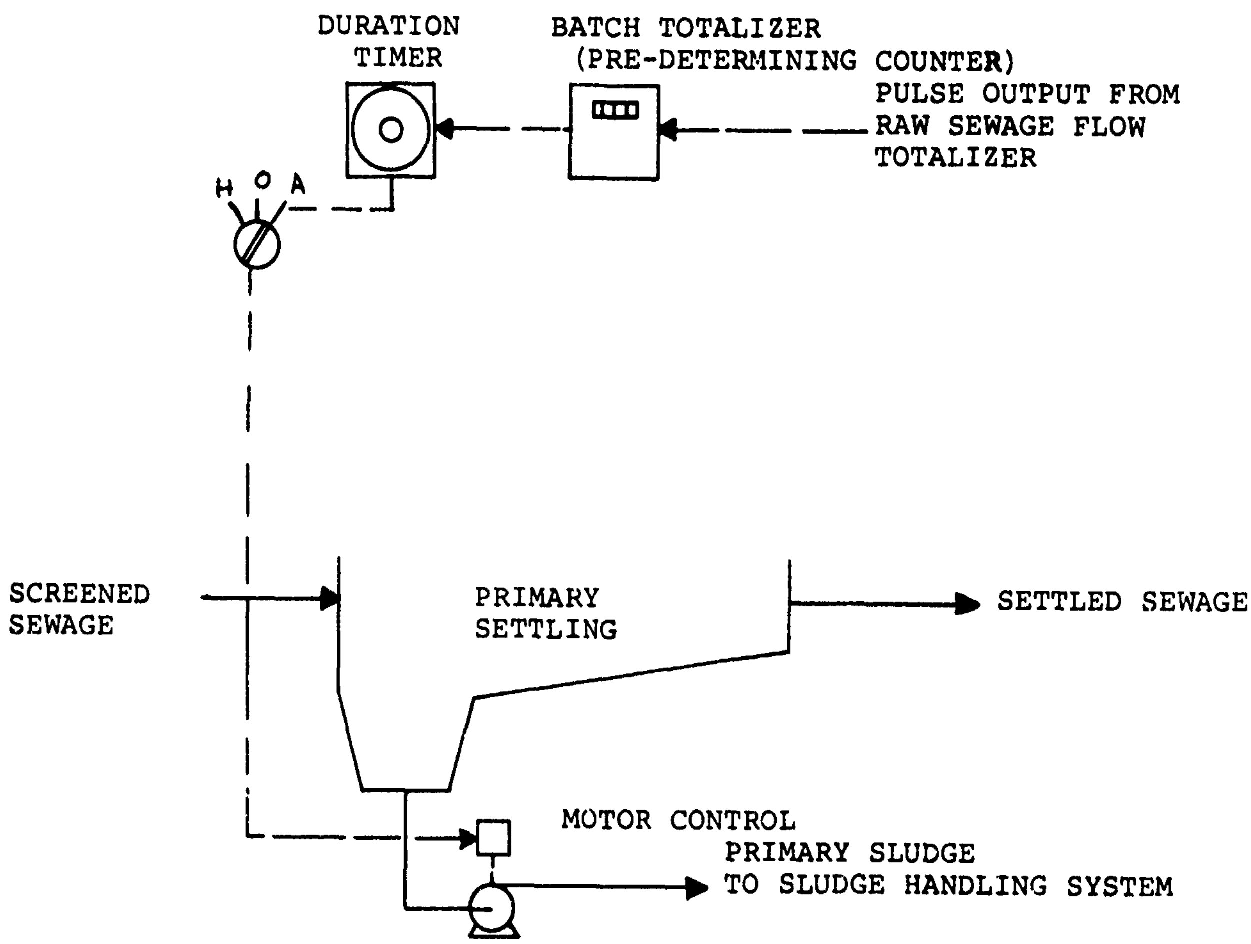



FIGURE 3-5

PRIMARY SLUDGE WITHDRAWAL, B
(TOTALIZED INITIATION)

COURTESY OF FISCHER & PORTER CO.

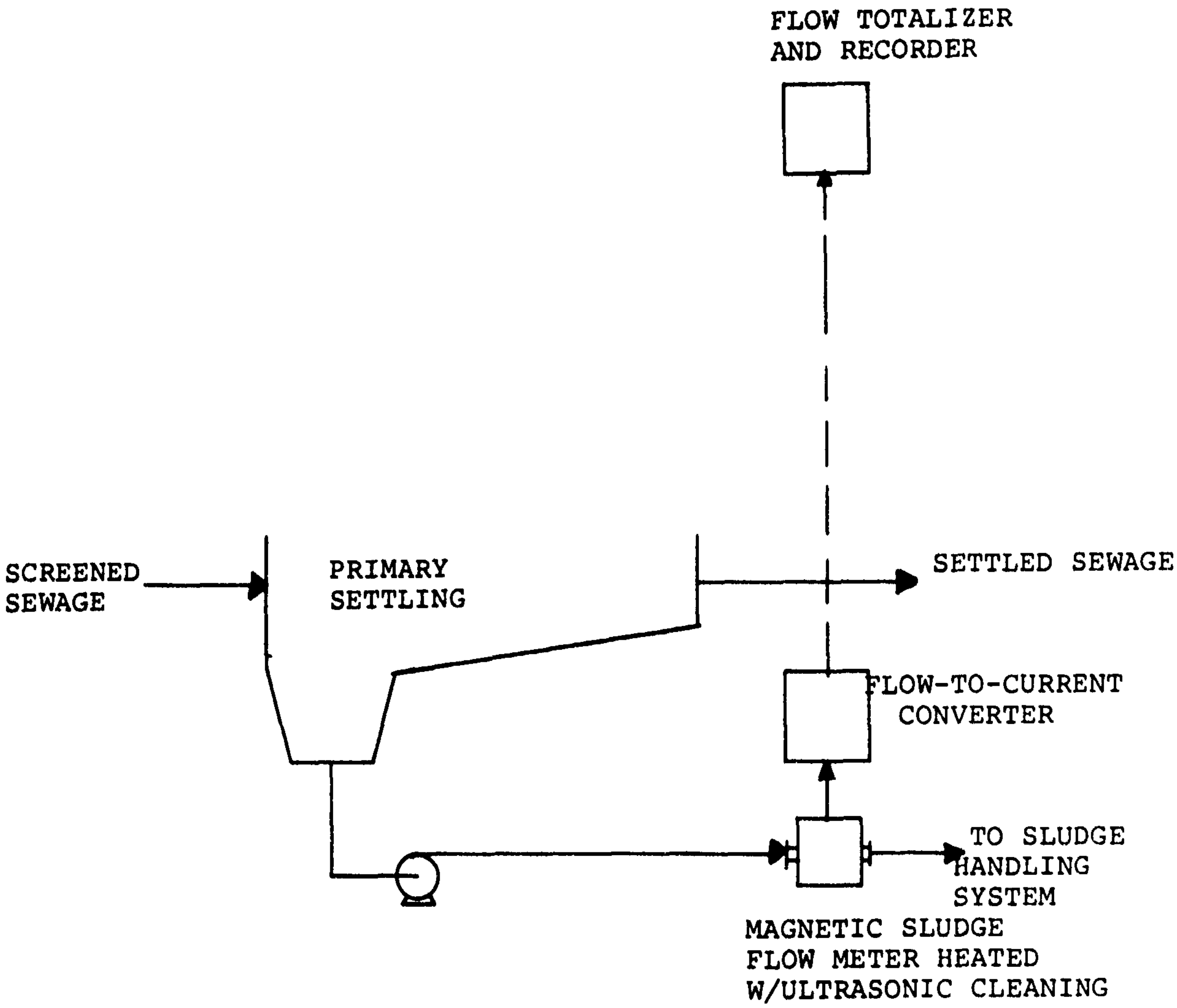



FIGURE 3-6

PRIMARY SLUDGE FLOW
(MAGNETIC FLOW METER)

COURTESY OF FISCHER & PORTER CO.

The manufacturers of devices to be included in these control loops are Fischer & Porter, BIF, Foxboro, and Autocon.

## 3.4 IMPROVEMENTS AND INNOVATIONS IN CLARIFIER DESIGN

Recent improvements in design have yielded higher efficiencies of solids removal. The separation of suspended solids from the liquid by means of gravity is primarily a matter of settling area. The addition of parallel plates inclined at 45° to the horizontal has improved removal efficiency. These plates serve as collecting surfaces. This particular design is known as lamella separation. This technique works with liquid lamellas between oblique plates which give a large settling area in a small volume. The Lamella Separator (trademark of the Parkson Corporation) is a variation of the tube settling process (see Figure 3-7). The Lamella Separator is suitable for separation of suspended matter from low concentration suspensions, particularly where the density difference between liquid and solids is low. The suspension passes in laminar flow downwards through a system of parallel plates. The suspended matter settles on the plates and runs under the action of gravity and shear force from the liquid phase down to the sludge collector. The clarified liquid is discharged via separate outlet channels.

The Lamella apparatus has no moving parts. Its design is very compact giving a reduction in volume up to 90% when compared with conventional settlers of comparable capacity. For instance, a Lamella Separator composed of 3900 square feet of settling area has a capacity of processing 1000 gallons per minute (1.4 MGD) of primary sewage when lime is added to an adjacent flocculation basin (see Figure 3-8). The entire volume of the flocculation basin and the separator having this capacity is 7560 cubic feet.

A.J. Shuckrow, E. W. Steel, and W.W. Eckenfelder all attest to the promise of the tube settling process. Concommittant reservations must also be made concerning this process. In all cases this type of separation process is more suitable for plants which use chemical aids, such as lime and alum, for the preliminary sedimentation of raw sewage.

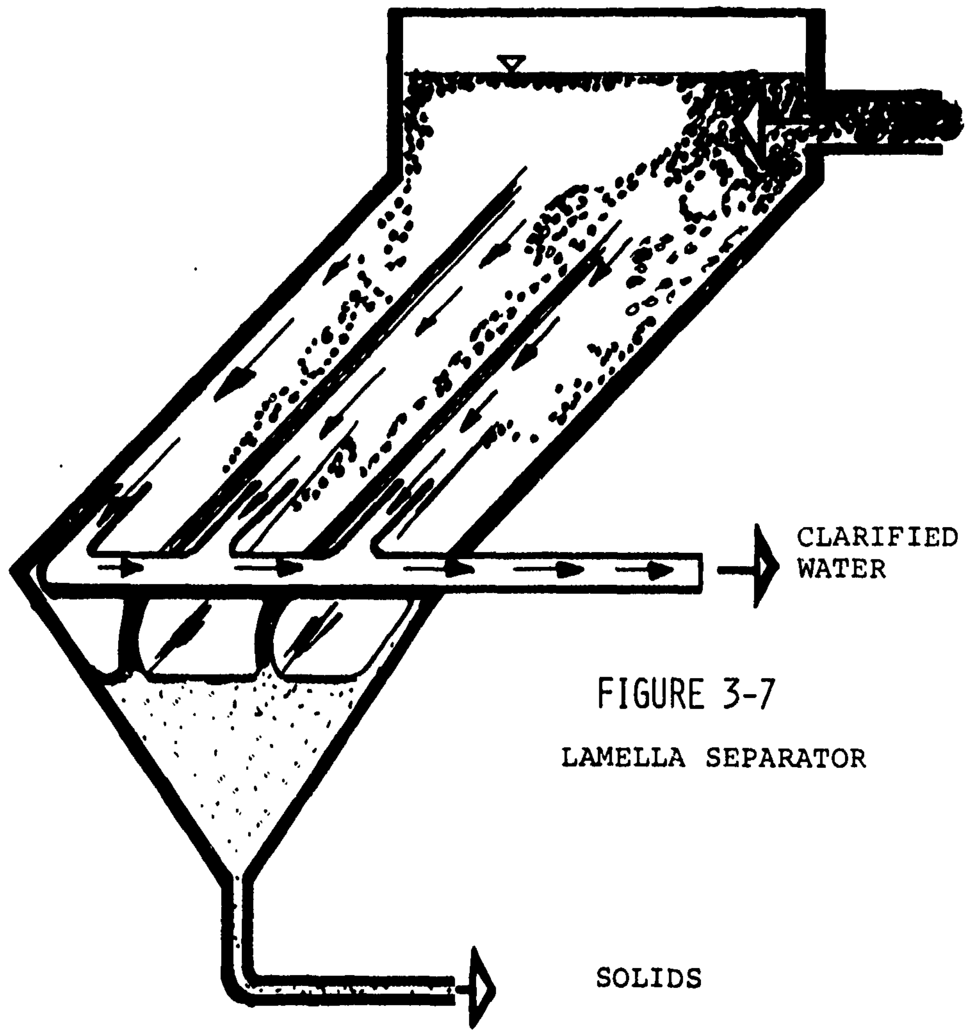



FIGURE 3-7

LAMELLA SEPARATOR

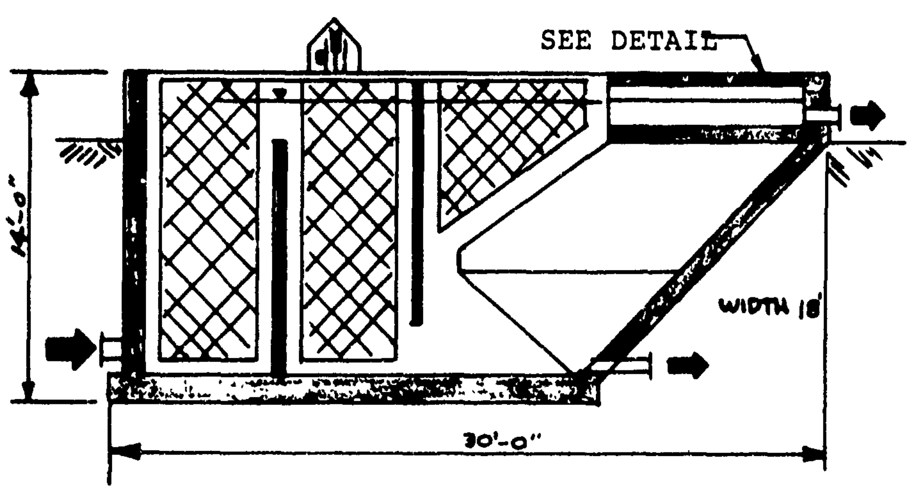



FIGURE 3-8

LAMELLA SEPARATOR WITH A CHEMICALLY AIDED FLOCCULATION BASIN

COURTESY OF PARKSON CO.

One of the recent innovations in preliminary treatment of raw sewage is the use of rotary-gravity type screen machines. Their use in treating domestic sewage is an adaptation of these type machines from industrial water screening applications. The design and operating principle of rotary-gravity screening machines is based on the principle of screening from inside a cylinder to outside, a wire mesh covering the revolving cylinder (see Figure 3-9). Within the trough there is a screw conveyor which removes the solids from the interior of the drum. Solids deposited in this trough are thus dewatered to a great extent by the action of the screw conveyor which expells the solids out the rear of the machine. A reduced volume of primary sludge that must be disposed of is one advantage to credit any preliminary dewatering process.

A rotating gravity screen utilized for preliminary sewage clarification would utilize filtering fabric down to as fine as 60 x 60 mesh wire cloth, or a 246 micron removal range. In screening raw incoming sewage and supplanting primary settling tanks, one unit can handle as high as 2500 gallons per minute (3.51 MGD). Solids are removed immediately as they enter the facility and thus are kept from turning septic. These units can be used in the primary treatment phase to remove all incoming solids after going through a barscreen and as a substitute for primary settling tanks. Wire cloth fabrics from 10 x 10 down to 20 x 20 mesh have been utilized for this purpose. The screens may or may not be used in conjunction with comminution. Solids are pumped immediately to the digester. The cost of these machines vary from $5,000 to $25,000, depending upon the length of the drum and the type of construction materials. Cochrane-Crane and Green Bay Foundry and Machine Works manufacture rotary screens.

One of the major advantages of this type of sediment removing system is its high capacity for the relatively small area involved. There is no need for large excavations to build fairly deep settling tanks, because only a 12" hydraulic head is necessary for the adequate operation of this machine. In addition, for those facilities where winter temperatures are an important operating consideration, equivalent

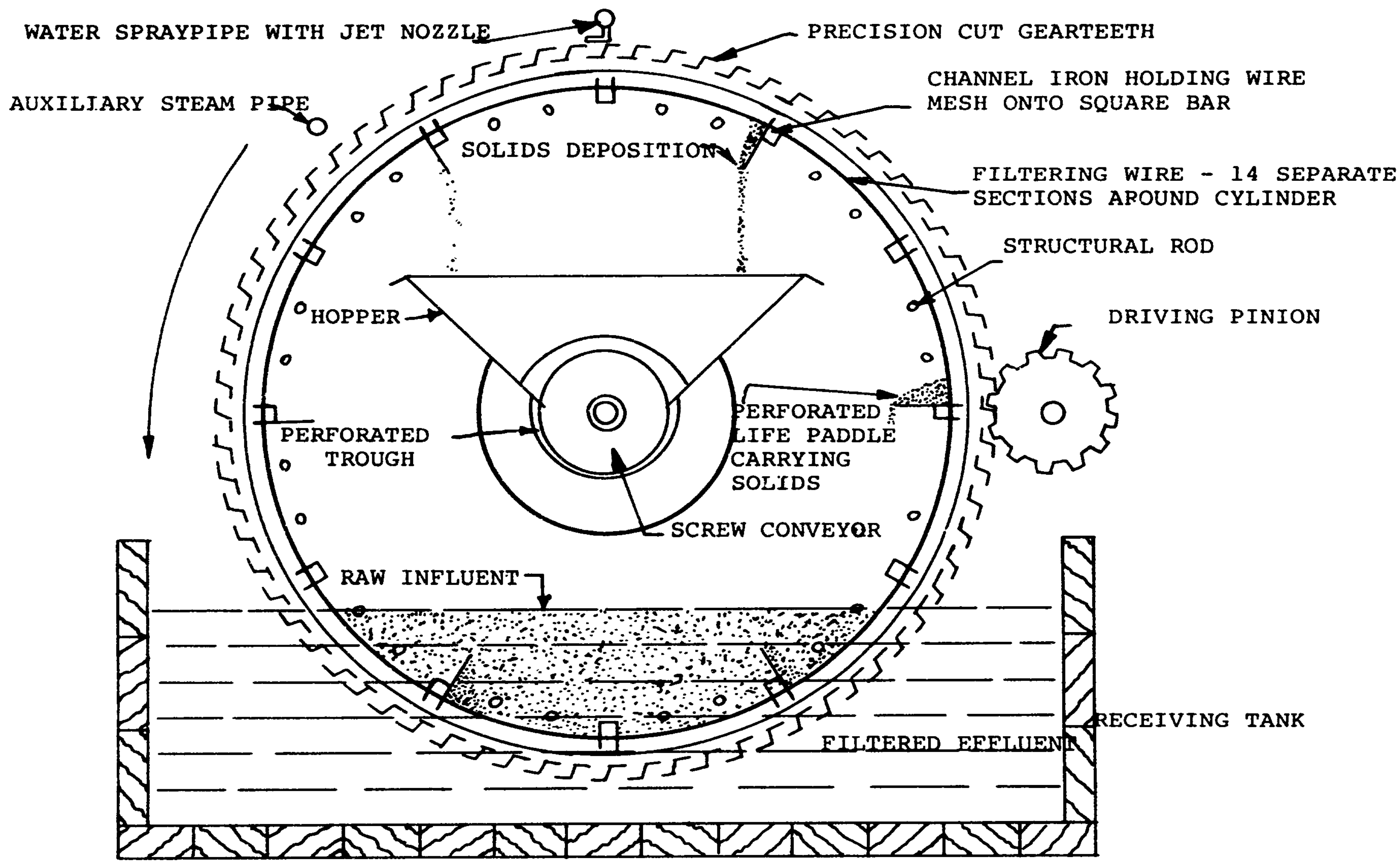



FIGURE 3-9
CROSS SECTION OF ROTARY-GRAVITY SEWAGE SCREEN SHOWING CONSTRUCTION

COURTESY OF GREEN BAY FOUNDRY AND MACHINE WORKS sediment removing capacity can easily be enclosed in a weatherproof building.

A major disadvantage to the rotary screen system is its inability to be adapted to physical-chemical processes whereby flocculating chemicals are added to the influent sewage which aid in organic and nutrient removal. Due to the nature of the screening activity, floc is not retained by the screen.

In order to cut construction costs, dual purpose settling basins have been designed which perform the function of both primary clarifier and activated sludge thickener. In this system waste activated sludge is cycled to a ClariThickener (trademark of Eimco, Inc.) which has an additional depression in the center of the tank (see Figure 3-10). Solids are collected here for specified periods, and are subject to gentle, continuous agitation to allow release of bound water. Between the influent solids and activated sludge solids, dry weight content of 8 - 9% is claimed as the thickening capacity of this system.

Air flotation has been used infrequently in the primary separation of sewages. It has been used with some success in sewage streams that carry large amounts of industrial wastes containing oils and greases. One application of dissolved air flotation for non-industrial waste sources has been the separation of combined sewer overflow. Engineering-Science, Inc. designed a dissolved air flotation system for treating combined sewer overflow in San Francisco. This unique system has the responsibility of providing the sole treatment step during excessively rainy weather and therefore was designed to operate only intermittantly. Air flotation will be treated in more detail under the discussion concerning sludge handling and disposal.

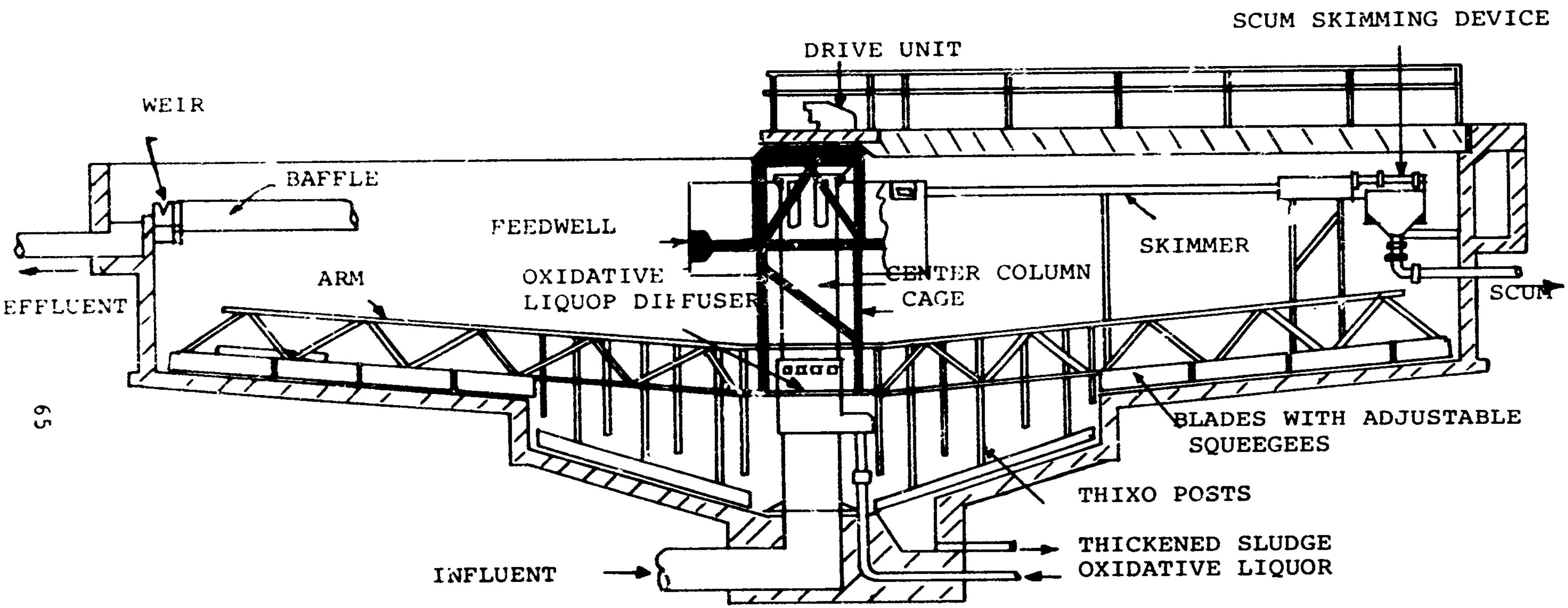



FIGURE 3-10

CLARITHICKENER COMBINATION CLARIFIER AND GRAVITY THICKENER

COURTESY OF EIMCO, DIVISION OF ENVIROTECH

CHAPTER 4

# AUTOMATED CONTROL OF BIOLOGICAL WASTEWATER TREATMENT SYSTEMS

## 4.1 BIOLOGICAL WASTEWATER TREATMENT

Wastewater treatment is only one of the many useful applications of biological metabolism. Biological processes are widely used for commercial production of such commodities as alcohol, acetone, organic acids, antibiotics, and glycerine. There exists, however, a basic difference in the fundamental objectives of wastewater treatment processes and the commercial ones; in the latter case, specific metabolic end products are desired in the greatest possible yield. In wastewater treatment, the metabolic end products are unimportant, and the efficiency of the process is measured solely by measuring the concentration of biologically degradable organic matter remaining in its effluent.

The major purpose of any wastewater treatment system is to provide an effluent water of such organic quality that its discharge into a receiving water body will have no adverse effects. In some environments only a slight degree of purification may be required, but in most inland areas where the dilution afforded to the waste flow may be minimal or negligible, an effluent of high quality is frequently desired. Insufficient wastewater treatment may produce harmful environmental effects including the creation of nuisances and menaces to health and the impairment of the receiving water's domestic, recreational, and industrial uses.

Biological treatment systems are broadly classified as either aerobic or anaerobic depending on whether the process is carried out in the presence or absence of free oxygen. In either situation the organic carbon waste material is assimilated by a mixed population of microorganisms and converted to cellular constituents of the organisms and to other metabolic products. These end products are excreted into the surrounding liquid media where they are either reassimilated by other organisms or escape into the surrounding air and water environment. The major reactant required for aerobic processes is molecular oxygen, and the only carbon-containing substance produced in large quantities, aside from cell materials, is carbon dioxide. Aerobic processes are in general quite efficient with nearly complete assimilation of organic material, provided the contact time between organisms and influent waste is sufficiently extended. Anaerobic processes, however, are not as capable of producing such highly purified effluents, and there are many organic compounds which are not affected by anaerobic treatment.

The microorganisms involved in aerobic biological treatment processes belong to a wide range of biological types. Numerous species of bacteria form the majority of the microbial population, and in most aerobic wastewater treatment systems are responsible for the majority of organic carbon removal. Algae may also exist symbiotically with bacteria in some systems. All aerobic treatment ecosystems also include some fungi, protozoa, rotifers, and various small worms.

The wastewater being treated must ultimately serve as the microbial food source (substrate) for all species of organisms in the system. However, the various types of organisms exist in varying relationships with the organic carbon substrate material and these are in turn devoured by other predatory organisms. Also existing in every system are symbiotic relationships in which two different organisms promote each other's growth. The predominance of microbial species composition is determined by natural selection. In general, the principal growth-limiting factor for microbes which directly attack the substrate is scarcity of food. If a given organism is to flourish in an aerobic wastewater treatment system, it must not only possess a high food gathering efficiency but also be able to proliferate very rapidly in the process environment and avoid removal in the process effluent. Also, the predominant microbial species must not be severly inhibited by substances in the raw wastewater or by the prevailing process environmental conditions including temperature, nutrients, pH, oxidation-reduction potential, and trace element concentrations.

The final result of the extremely varied and complex activities of the individual microorganisms in a wastewater treatment system will ultimately be the disappearance of influent organic carbon material and the production of more microorganisms. Aerobic process waste products appearing in appreciable quantities will be carbon dioxide, water, and inorganic forms of nitrogen. Most other microbial end products serve as substrates for various organisms. Any non-biodegradable organic material in the influent wastewater, especially certain synthetic organics, will appear unchanged in the effluent.

It is of utmost importance to realize that all aerobic biological treatment systems operate on the same general biochemical principles and that the differences between the various systems lie in the environment imposed by the mechanical aspects of the system. In general, microorganisms can continuously remove organic matter from liquid wastes by only one method, synthesis into new protoplasm. Initially microorganisms adsorb large quantities of organic matter onto their cell surfaces but unless this adsorbed organic matter is assimilated into protoplasm the rate of adsorption will eventually approach zero. Since a definite quantity of organic carbon material is required to form the building blocks for the microorganism cell mass and a definite quantity of organic matter must be oxidized to form the energy necessary for synthesis, a correlation can be developed relating the removal of organic matter and the cells synthesized, together with the oxygen consumed. Although simple organic molecules may be immediately adsorbed by the bacterial cells, complex molecules must be broken into smaller molecules before further degradation will proceed. Solid particles in the colloidal size range will be attacked at the surface only and an extensive period of time may be required to completely reduce them. Such particles may become enmeshed within a flocculant assemblage of microorganisms in such a way as to be removed from the liquid phase of the waste for all practical purposes. Large molecular breakdown is catalyzed by enzymes which may be excreted by bacteria into the medium or may be attached to the bacterial cell surface. The major groups of organic matter in wastewater can be divided into proteins, carbohydrates, and fats which will be enzymatically converted respectively to amino acids, simple sugars, and fatty acids. Once the larger organic molecules are broken down they are readily absorbed within the microbial cells and subsequently converted to various cell materials. The major portion of the substrate consumed is oxidized to produce end products of carbon dioxide and water. The energy produced from oxidation-reduction reactions is thereafter used by the microbes in energy-absorbing synthesis reactions and in other natural functions.

Aerobic biological systems commonly used in wastewater treatment include various modifications of activated sludge, trickling filters, and oxidation ponds. In all these processes microorganism populations contained in basins, filters, or ponds, and surrounded by an aqueous medium, perform organic carbon removal. As organic wastes are fed into these systems they are converted by process organisms to cellular constituents and stable end products. Dissolved oxygen comparable to the 5-day biochemical oxygen demand (BOD) of the organic material processed is simultaneously taken up by the organisms from their medium and must be supplied either from the atmosphere or by mechanical methods. Following liquid-solid separation the purified effluent flows out of the system while the organisms are generally retained so that their population in the process remains great enough for effective treatment of the wastewater. The major differences between the various aerobic wastewater treatment processes exist only in the mechanically imposed microbial environment.

## 4.2 ACTIVATED SLUDGE

Most organic wastes encountered by the environmental engineer are converted to inorganic forms by the application of various aerobic biological treatment processes. Of these various processes activated sludge arises as the most popular and versatile. The activated sludge process has been defined as "a biological sewage treatment process in which a mixture of sewage and activated sludge is agitated and aerated." The process was developed in 1913-14 by Arden and Lockett. Sewage had been aerated previously to accomplish purification, however, extremely long periods of aeration were necessary to accomplish an appreciable organic carbon removal. Arden and Lockett subsequently discovered that a relatively short aeration period provided a high degree of treatment if the flocculent sludge formed during sewage aeration was retained, recycled, and aerated with the succeeding sewage flow. In the initial states of process development, plants were occassionally operated on a fill-and-draw basis, the wastewater being aerated with the activated sludge for a specified time then settled and decanted, all in one tank. Obviously the practicality of this procedure was limited, therefore virtually all activated sludge plants constructed in the last forty years have been designed for continuous flow.

4.2.A CONVENTIONAL ACTIVATED SLUDGE

Basically, the process consists of subjecting a liquid waste to a group of microorganisms (activated sludge) in an aerated system. These microorganisms aerobically stabilize that portion of the waste that is amenable to biological degradation, so that finally this fraction of the waste is converted to inorganics and additional activated sludge.

Operationally the conventional activated sludge process can be represented by Figure 4-1. Primary settled sewage enters the aeration basin immediately after it has been mixed with return sludge. This waste sludge system is aerated for approximately 4 to 8 hours by diffused aerators which are placed along the sides of the basin. The organic waste is stabilized during this aeration period and then flows to a secondary sedimentation basin. The activated sludge then flocculates to a settleable mass thereby allowing the discharge of a clear low organic content effluent. A fraction of the settled sludge (approximately 20%) is returned to the head end of the aeration tank with the excess sludge being wasted to the digester.

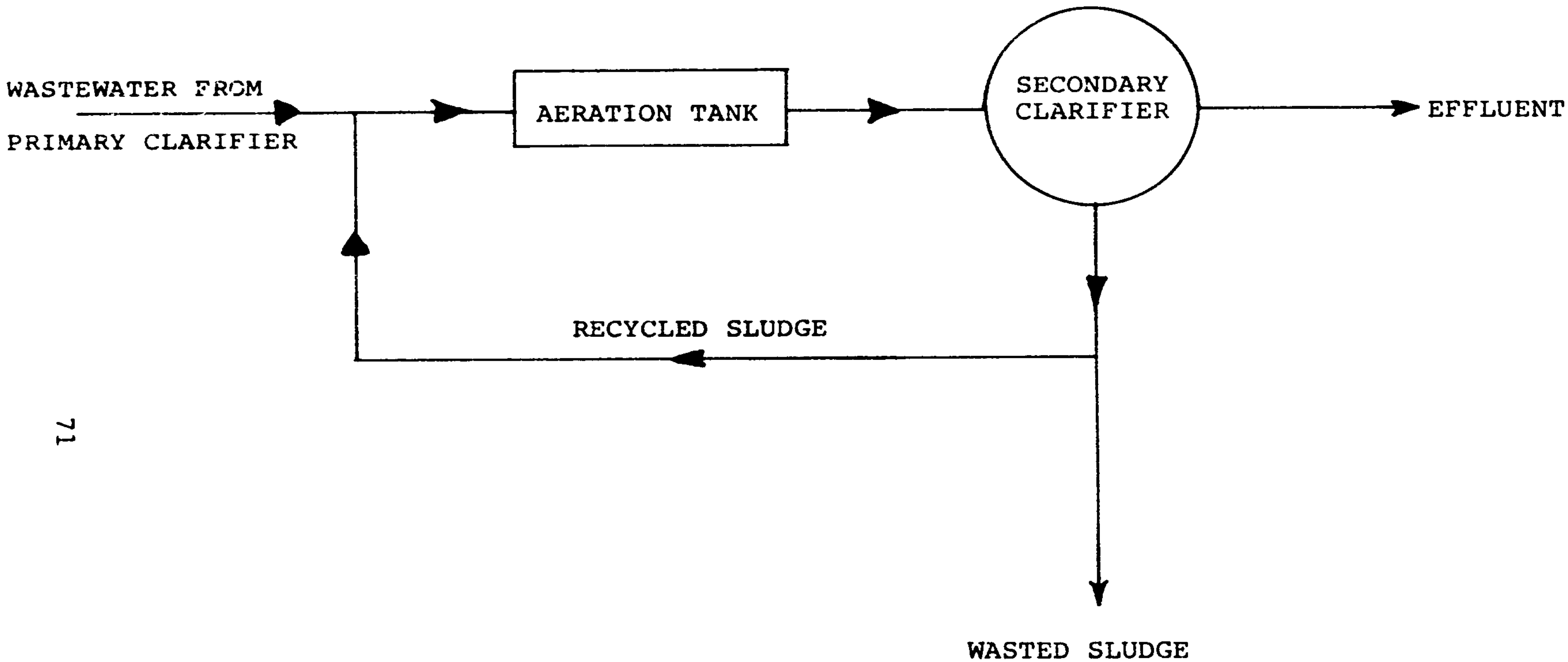



FIGURE 4-1

FLOW DIAGRAM OF CONVENTIONAL
ACTIVATED SLUDGE PROCESS

The conventional activated sludge process operates basically on a continual feed-starve cycle. As the microorganisms enter the head end of the aeration tank they are primarily in endogenous respiration, or a starved state. As the sludge encounters the raw waste, a certain F/M ratio (organic loading to microorganism mass ratio) is set up. If this ratio is high there will be an overabundance of food present and the microorganisms will start out in the log growth phase of the typical growth curve. The retention time of the aeration basin will determine how far along the growth curve the reaction will go. A typical food-microorganism aeration basin curve is shown in Figure 4-2. As can be seen, there will be a high F/M ratio present in the head end of the tank. This condition will induce the log growth process and subsequently rapid organic removal. As the sludge moves down the aeration basin, the F/M ratio will decrease, bringing about the endogenous respiration phase in which the bacteria begin to die off more and more. The micro-organisms are then unable to obtain a sufficient amount of substrate in the liquid around them to fulfill their metabolic activities, and consequently begin to utilize the food reserves inside their cells which were built up while they were occupying the head end of the aeration tank. As the endogenous phase continues, the energy level of the entire system decreases with a sharp increase in the rate of floc formation. Therefore, the further into endogenous growth the microorganisms are allowed to go, the better is the flocculation of the system and the clearer the effluent. It can be seen then, that most of the food is consumed in the head end of the tank with the resultant log growth phase followed by the gradual death and destruction of the microorganisms in the tail end of the tank where a high degree of flocculation occurs.

In the conventional activated sludge process, as with any other biological system, it is possible to express the resultant solids content as a function of the solids synthesized, the solids destroyed, and the solids lost in the effluent as below:

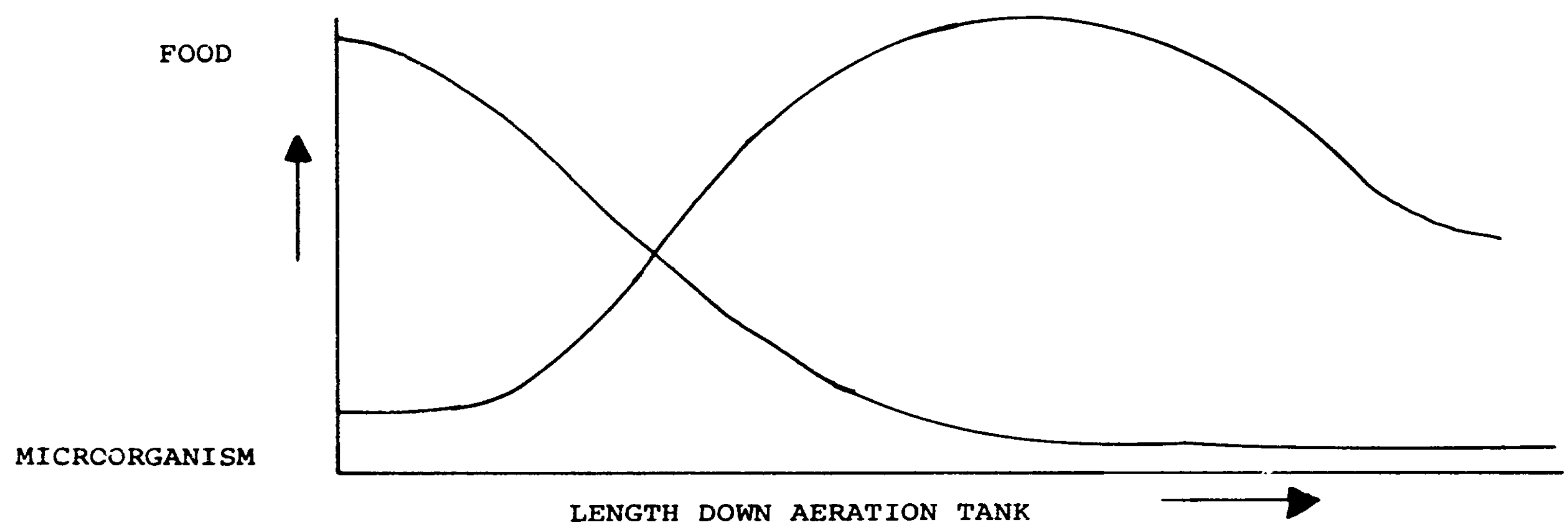



FIGURE 4-2

TYPICAL FOOD-MICROORGANISM AERATION BASIN CURVE

RESULTANT SOLIDS = SOLIDS SYNTHESIZED - SOLIDS DESTROYED - SOLIDS LOST IN EFFLUENT

The resultant bio-mass (or solids) may be shown graphically by considering a typical growth curve as in Figure 4-3. These resultant solids A are of great concern to the environmental engineer since this bio-mass must be ultimately disposed of by other methods.

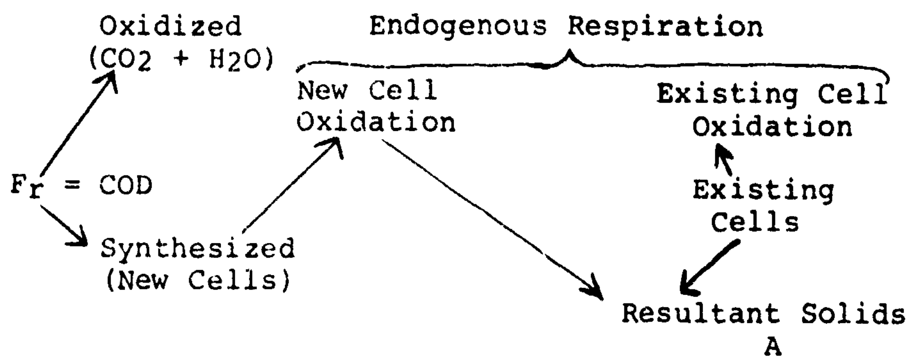
The resultant bio-mass may be expressed in terms of a batch system in which there is no effluent discharge. Consequently, the resultant solids will merely equal the solids synthesized minus the solids destroyed in endogenous respiration. The solids balance of such a batch system may be represented as in Figure 4-4 with the following equation, A = B - C where B and C are the solids synthesized and the solids destroyed respectively.

Another expression for the solids balance may be arrived at by a consideration of the amount of COD removed by the system. If the influent organic concentration to the aeration tank is represented by $S_r$ and the effluent organic content by S, then the amount of COD removed in the aeration basin can be represented as below:

$S_r$ ⟶ [Aeration Tank] ⟶ S

$$COD = S_r - S = F_r$$

Therefore the microorganisms in the activated sludge process remove an amount of substrate or food equal to $F_r$. This food removed from the system can be broken down as follows:



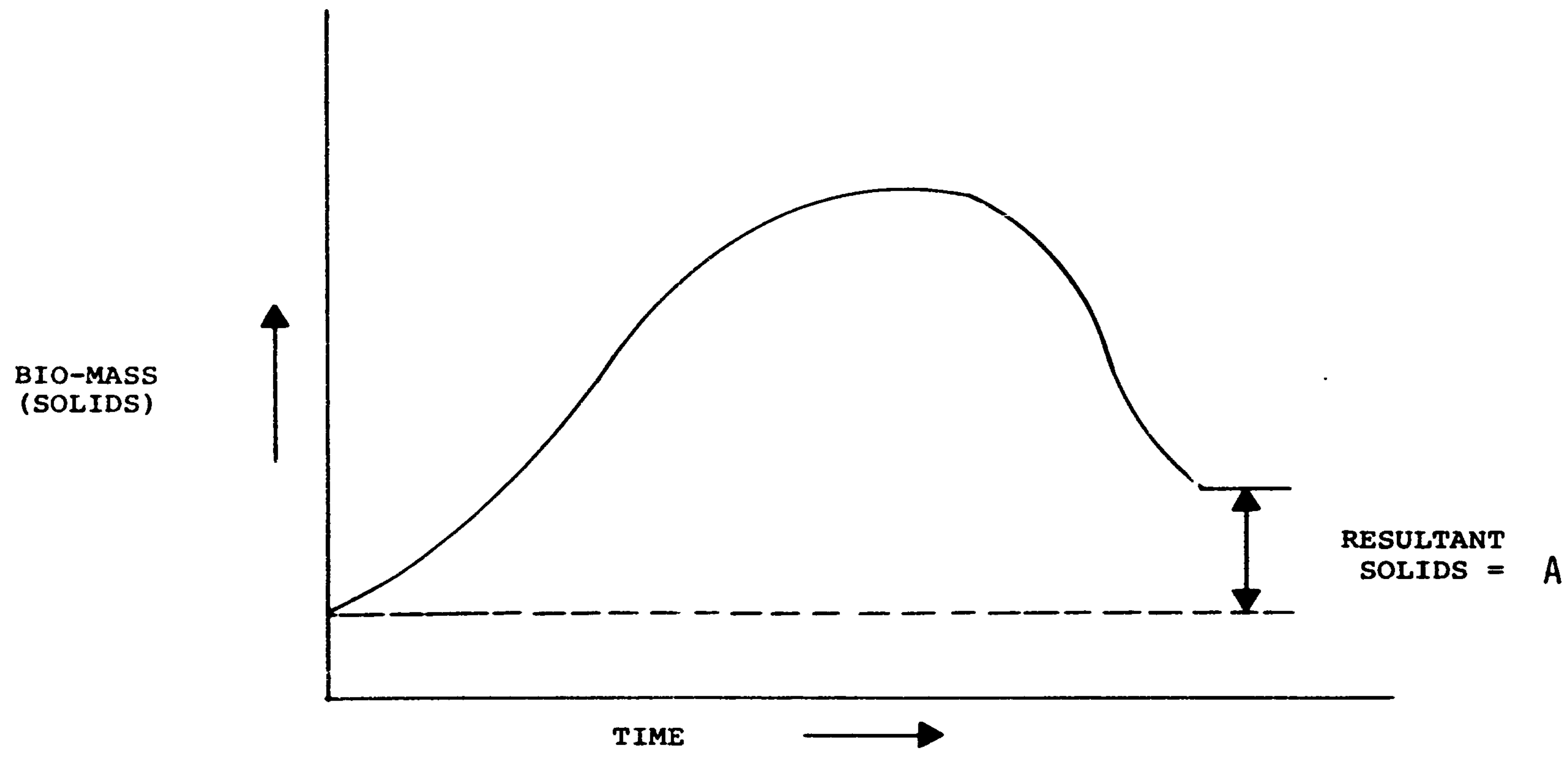



FIGURE 4-3

SOLIDS PRODUCTION DURING BACTERIAL GROWTH

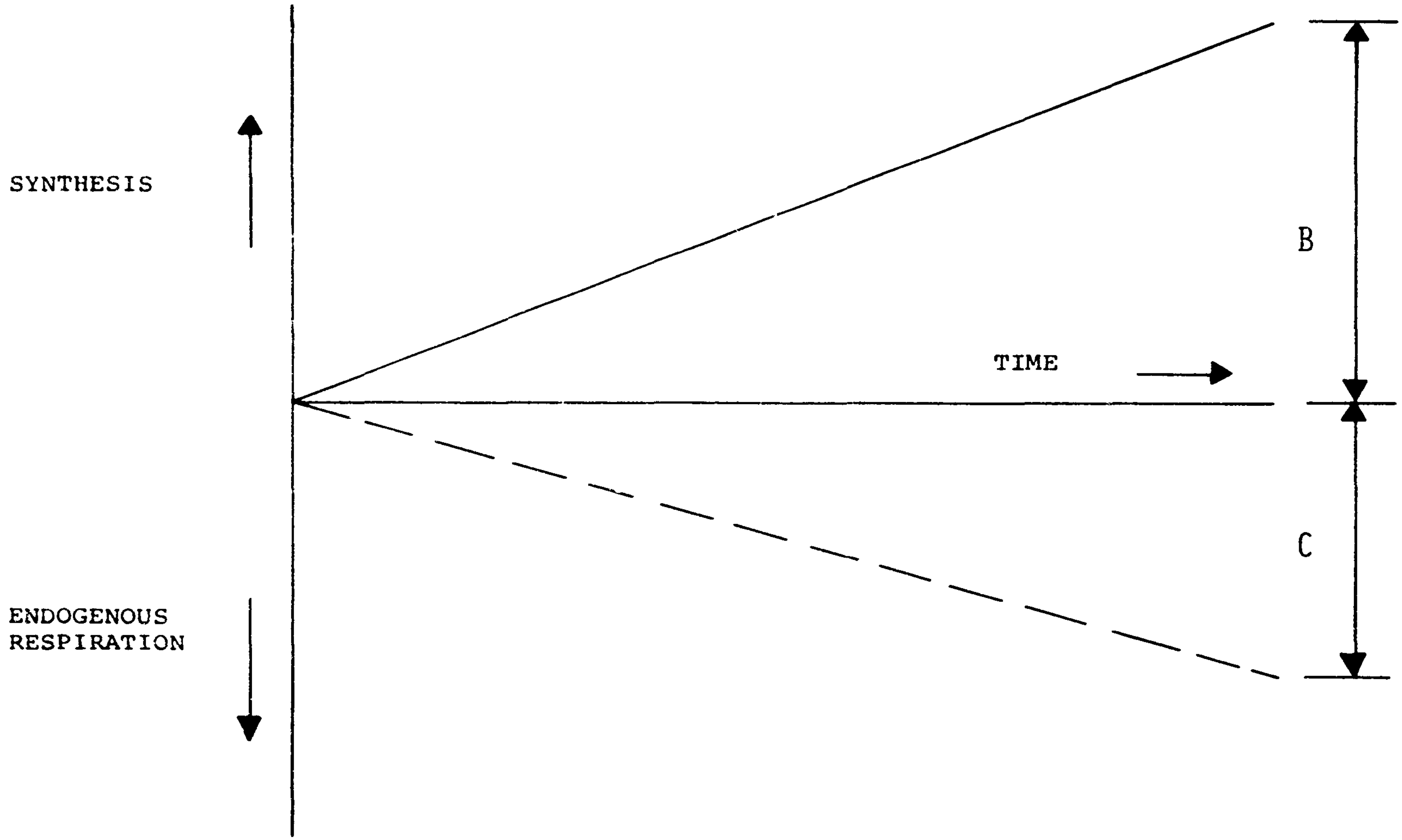



FIGURE 4-4

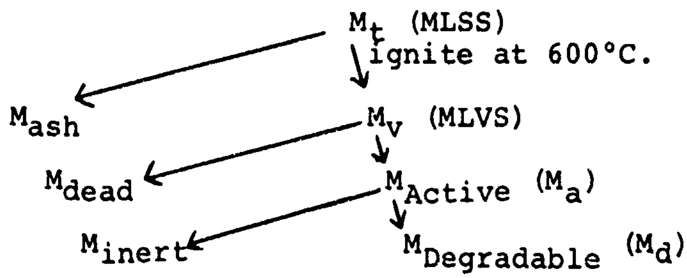
SOLIDS BALANCE IN A BATCH SYSTEM

The relative amounts of each quantity in the above solids balance diagram can be shown to be directly dependent on the F/M ratio at the head end of the aeration tank as shown in Figure 4-5. As previously mentioned, high F/M ratios will result in log growth, a large fraction synthesized, and therefore a large buildup of bio-mass. A general expression for solids balancing may now be expressed in a new form.

RESULTANT SOLIDS = SOLIDS SYNTHESIZED - SOLIDS DESTROYED - SOLIDS LOST

or $A = aF_r - bM_d - fM_a$

where f = flow constant of aeration tank, and $M_a$ and $M_d$ are defined as follows:
Considering the total mass ($M_t$) or MLSS, $M_a$ and $M_d$ may be defined as follows:




Values of "a" have been found to vary between 0.1 and 0.5 whereas values of "b" vary from 0.1 to 0.2. $M_a$ and $M_d$ may be approximated as follows:

MLVS = 0.9 x MLSS
$M_{Active}$ ($M_a$) = 0.8 x MLVS
$M_{Degradable}$ ($M_d$) = 0.96 x $M_a$

Therefore $M_a$ is approximately 72% of MLSS and $M_d$ is about 69% of MLSS.

### 4.2.B Contact-Stabilization (Biosorption)

Contact-stabilization is a modification of the activated sludge process developed simultaneously by

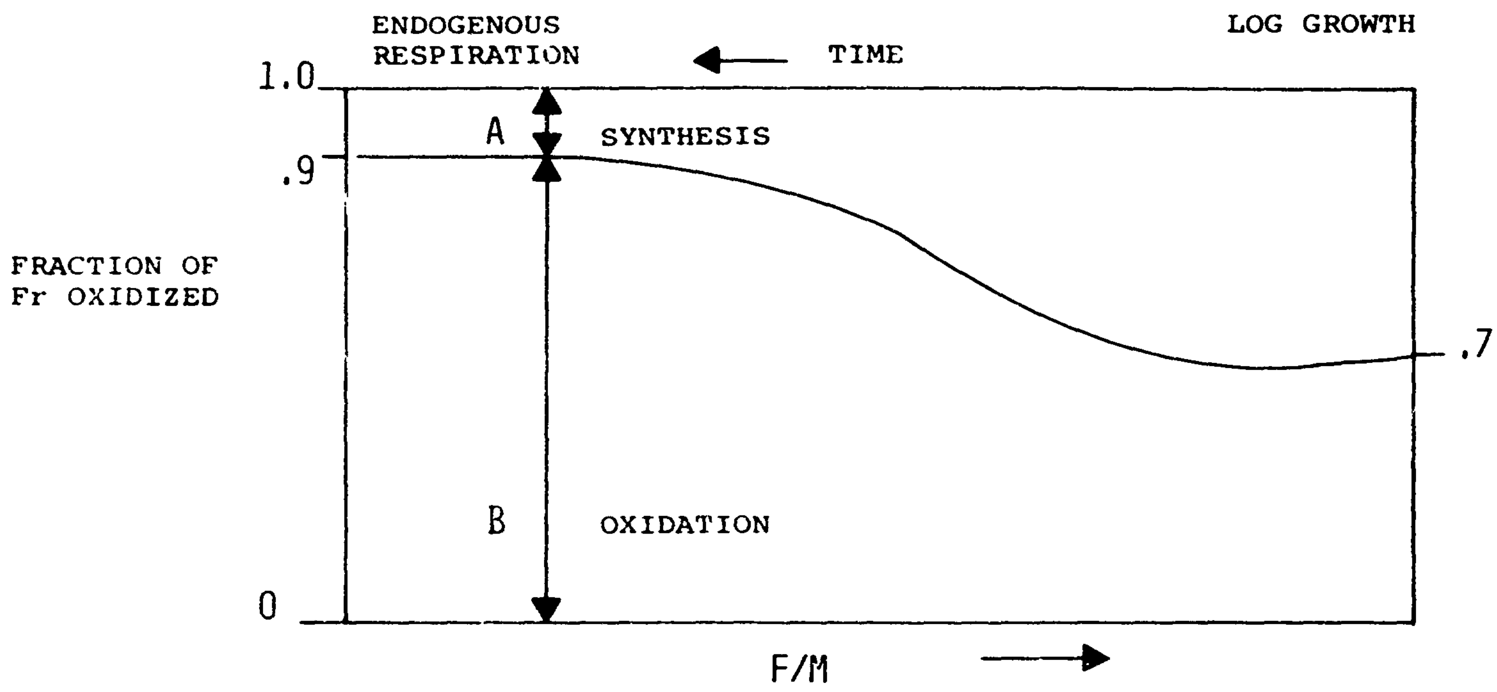



FIGURE 4-5

RELATIONSHIP BETWEEN F/M AND BIO-MASS SYNTHESIS two independent investigators, Mansel Smith of Austin, Texas, and Wesley Eckenfelder of Manhattan College, New York. The contact-stabilization process essentially utilizes the adsorptive characteristics of activated sludge. Primary clarifier effluent is subjected to a high concentration of returned activated sludge (see Figure 4-6) in an aerated contact tank having a minimal detention time of from 20 to 40 minutes. During this initial contact stage, organic material is adsorbed by the sludge floc similar to the clarifier stage of the conventional activated sludge process. Following the contact period the sludge is settled for one hour. A small portion of the sludge is wasted while the remainder of the concentrated sludge flows to a stabilization tank where it is aerated for 1.5 to 5.0 hours during which time previously adsorbed organic material is stabilized. The surfaces of the micro-organisms are therefore "activated" for further adsorption as they are mixed with incoming wastewater.

The contact-stabilization process permits a reduction in aeration basin capacity. In conventional activated sludge the entire volume of the mixed liquor is stabilized, however, aeration in the contact-stabilization process for the purpose of stabilization of organic matter is confined to the return sludge volume. It seems plausible to interpret process phenomenon in terms of bioflocculation mechanisms in which exocellular polymers remove suspended and colloidal organics by flocculation. This interpretation receives further support from the fact that the contact-stablization process performs more efficiently on wastes having a colloidal nature. Soluble organic wastes will not be removed to any appreciable extent using contact stabilization.

4.2.C Step Aeration

The step aeration process is a modification of the conventional activated sludge process introduced

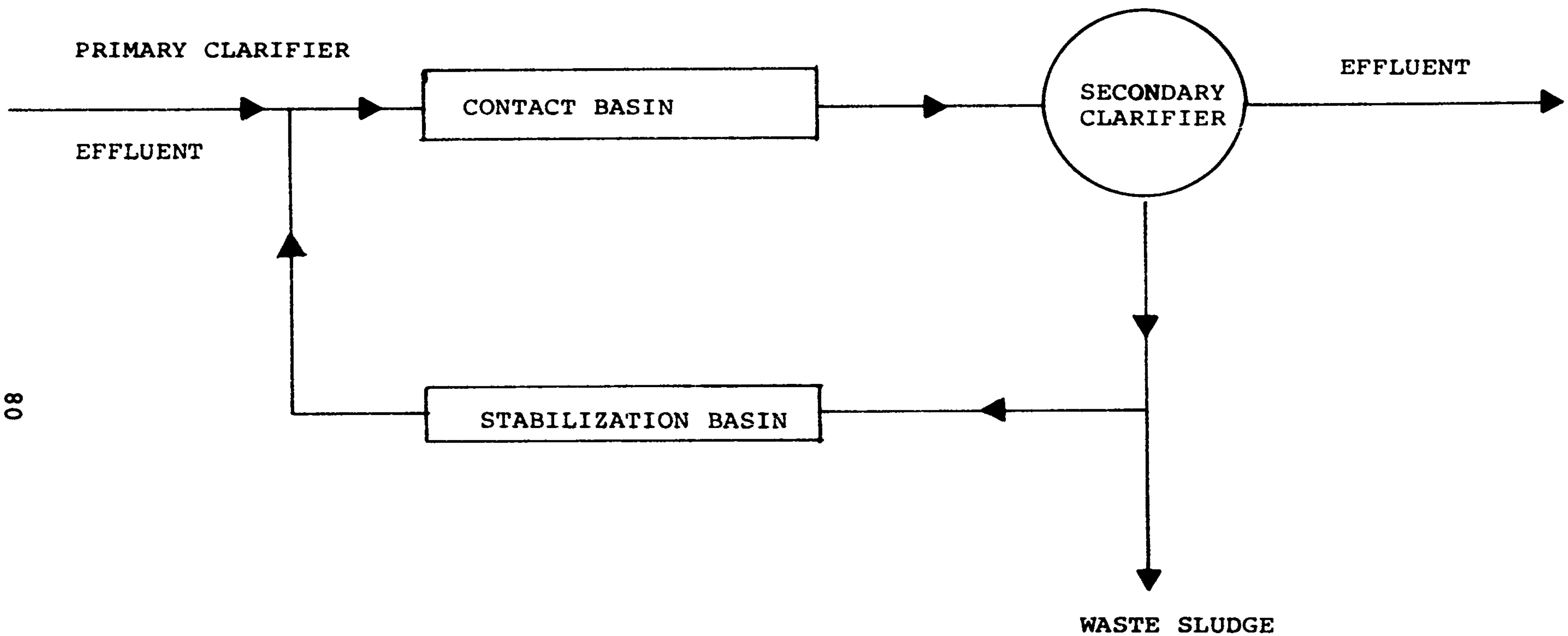



FIGURE 4-6

FLOW DIAGRAM OF CONTACT-STABILIZATION PROCESS originally in New York City. As shown in Figure 4-7, wastewater flow is introduced into the aeration basin in three or four equal increments at different points, equal distances apart, thereby distributing the organic load over the entire basin length. This organic load distrubution reduces the F factor in the F/M ratio therefore lowering the initial oxygen demand at the head end of the aeration basin (Figure 4-8). As a result of this oxygen demand spread, accelerated growth and oxidation is not confined to the head end of the aeration basin as in conventional treatment but, instead, occurs over most of the basin volume.

Step aeration may be utilized as a means of expanding the capacity of existing treatment plants at a minimum of expense. Advantages of step aeration over a conventional treatment in new plant construction are shorter retention times and lower activated sludge concentrations in the mixed liquor due to an organic distribution over the entire length of the aeration basin.

4.2.D Completely Mixed Activated Sludge

The completely mixed activated sludge process has recently found widespread application for the treatment of high organic concentration wastes. In this process the influent wastewater is uniformly distributed throughout the entire aeration basin, thereby providing process stability under commonly occuring shock loads. In a completely mixed system the soluble BOD of the effluent is equal to that in the aeration tank. Process flexibility allows operation with considerable wasting of activated sludge or with almost complete return of all sludge depending on the F/M ratio maintained in the aeration tank. However, at specific growth rates approaching zero there is generally a slow buildup of activated sludge mass due to the production of nonbiodegradable portions in the sludge mass.

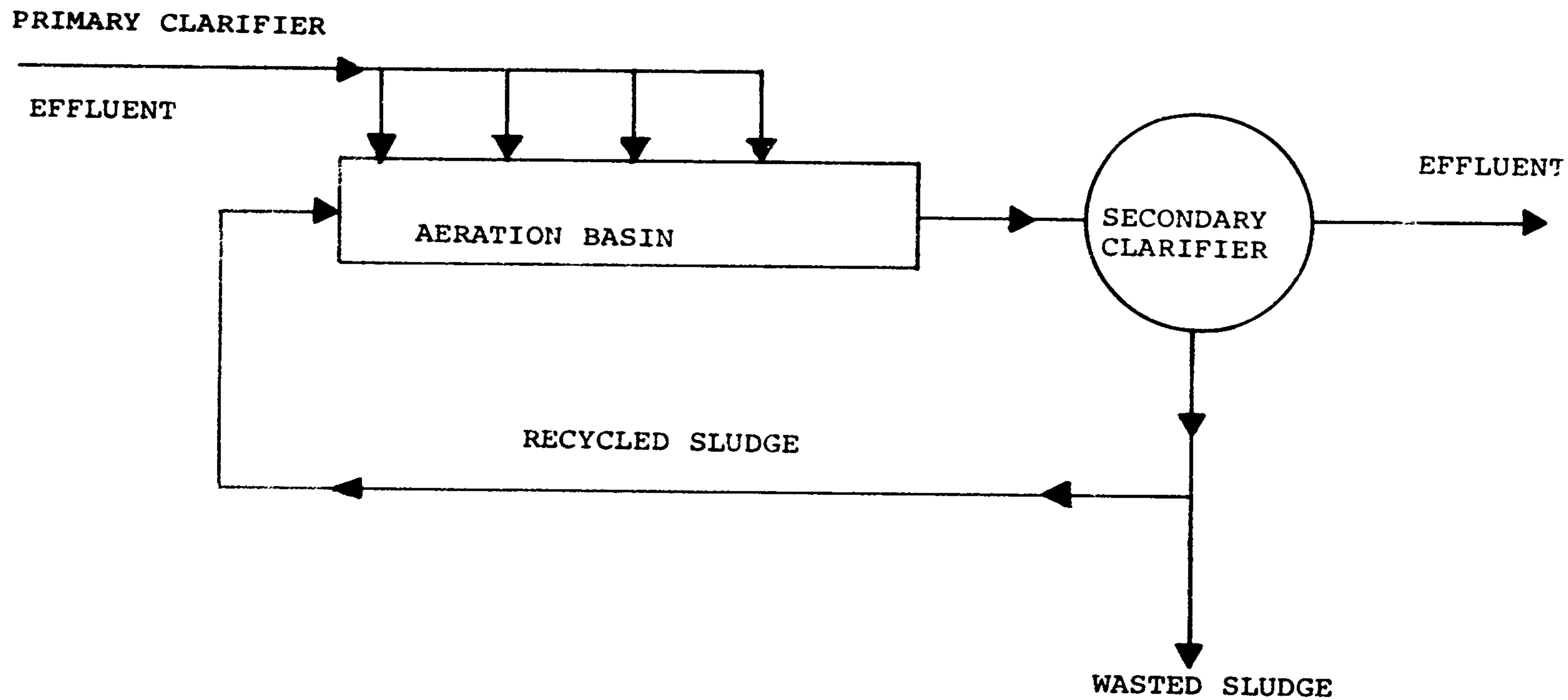



FIGURE 4-7

FLOW DIAGRAM OF STEP AERATION PROCESS

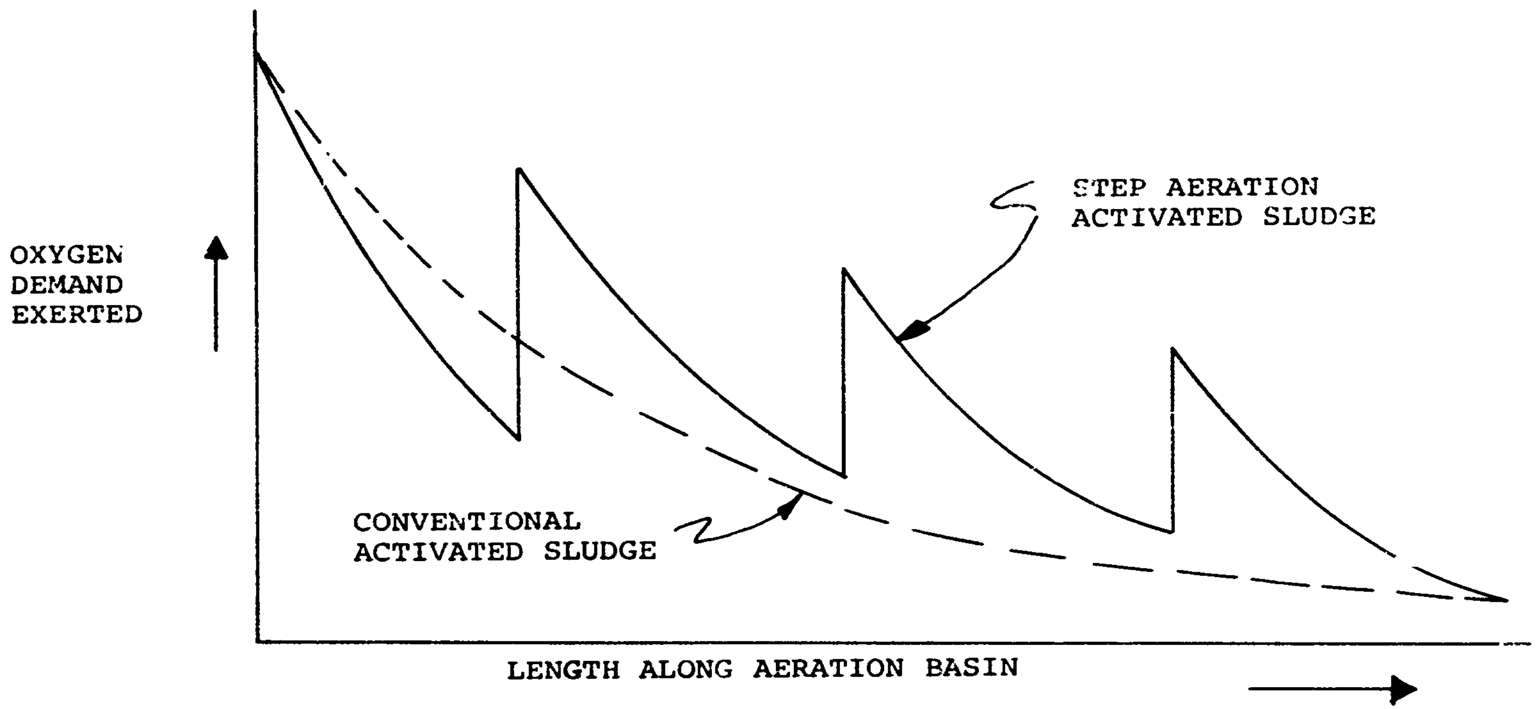



FIGURE 4-8

OXYGEN DEMANDS EXERTED IN CONVENTIONAL
AND STEP AERATION ACTIVATED SLUDGE PROCESSES

4.2.E Extended Aeration

During treatment of wastewater with activated sludge, the microorganisms initially remove the organic matter from solution converting much of it to cellular protoplasm. However, when the food source is dissipated the microorganisms begin to metabolize food reserves within their own cells thereby depleting their own protoplasm.

The application of this basic bacteriological phenomenon to wastewater treatment resulted in the development of extended aeration activated sludge. This process provides a detention time sufficient to allow oxidation of biological solids (microbial protoplasm), thus minimizing the amount of sludge necessary to digest. The sludge derived from an extended aeration unit is theoretically a non-biodegradable residue, however, continuous reactor draw offs also contain an active biological fraction. Sludge produced in extended aeration installations will therefore require additional digestion, dewatering, and disposal.

4.2.F Activated Sludge Control Parameters

All activated sludge processes are in actuality dual processes involving both substrate uptake by the microorganisms and subsequent bioflocculation of the microorganisms to form an easily settleable floc. The substrate uptake phase which is also referred to as the clarification stage by many investigators, merely refers to the adsorptive capabilities of the microorganisms. As the activated sludge enters the aeration tank and is subjected to the waste, there is an immediate adsorption of suspended and collodial organics onto the outer surface of the micro-organisms. This substrate uptake phase only requires a short period of time and usually takes place in the front end of the aeration tank. The remainder of the retention period is taken up by the use of the absorbed organics in the metabolic processes of the microorganisms, that is, in the oxidation and synthesis of the new sludge. This stabilization process takes place in the remaining major portion of the aeration tank and allows the second process of this system to evolve, that of bioflocculation.

Various requirements must be satisfied if the activated sludge process is to operate properly. These parameters will only be mentioned briefly here since they are covered quite extensively in the literature. First, the oxygen requirement of the microorganisms must be satisfied. Since the activated sludge process is an aerobic one, oxygen will be the primary limiting factor of system efficiency. Oxygen requirements are in turn directly dependent on the metabolic process of the microorganisms, greatest oxygen uptake obviously occurring at the head end of the aeration tank where substrate uptake is maximum. A minimum oxygen residual of about 0.5 milligrams per liter (mg/l) is required at all times. Oxygen residuals lower than this value will result in an increase in filamentous bacteria in the sludge, and consequently poorer floc formation.

Also to be considered are the nutritional requirements of the microorganisms present in the sludge. The basic metabolic process of these microorganisms is directly dependent on nutritional elements which may be converted to protoplasm. Major nutrients required are phosphorus and nitrogen. These should be present in the following ratios:

COD to N = 20 to 1        BOD to N = 15 to 1

or

COD to P = 150 to 1        BOD to P = 100 to 1

Trace quantities of the following elements should also be present to insure proper nutritional levels; calcium, potassium, cobalt, iron, magnesium, and molybdenum. It should be noted that domestic wastewater will normally contain all of the above elements in proper quantities, whereas various industrial wastes may require the addition of deficient nutrients.

Another important environmental parameter to be considered is the hydrogen ion concentration or pH. The normal pH range for conditioned activated sludge systems, the $CO_2$ evolved in oxygenation is converted to bicarbonate ions thereby buffering the system around pH 8.0. The activated sludge system must not only have an acceptable pH for metabolism but also a good buffering capacity so that the proper pH range is maintained at all times. pH adjustment is required prior to treatment for instances in which highly acidic or alkaline wastes are encountered.

Temperature also has a marked effect on the microorganisms in the activated sludge process. It is generally accepted that a rise in temperature of approximately 10°C will result in twice as much metabolism taking place. Operation of the system at a high temperature will result in very fast metabolism of the organic waste, but the disadvantages of the high temperature process should also be noted; that is, a large amount of bio-mass produced through synthesis and the possibility of anaerobiosis occurring. The disposal of bio-mass is a large problem at present and most activated sludge system operators would rather have a lower substrate uptake rate than a large amount of bio-mass production. Also since the activated sludge system is aerobic in nature, it is of considerable importance to consider the possibility of a high temperature process demanding such a large quantity of oxygen that anaerobic conditions may set in. Therefore, several parameters must be kept in mind when the temperature design of a system is considered to insure optimum operation.

As previously presented, the organic loading to microorganism ratio (F/M ratio) in the head end of the aeration tank largely determines what part of the growth curve the microorganisms will begin their metabolism. This metabolic growth rate will in turn determine the floc forming ability of the activated sludge mass. F/M ratios therefore may indirectly control process efficiency.

The following parameters must therefore be considered to optimally insure activated sludge process performance:

1. Oxygen
2. Nutritional Requirements
3. Hydrogen Ion Concentration
4. Temperature
5. Food to Microorganism Ratio

4.2.G Monitoring and Control of Oxygen In Aeration Basins

Dissolved oxygen is required at all times by the microorganisms present in an activated sludge process. Oxygen demand, however, is continually varying due to changes in flow and concentrations of organic materials in the wastewater stream. Aeration capacity must therefore be provided which will meet most, if not all, anticipated oxygen demands. Currently, most activated sludge system's oxygen transfer capacities are controlled manually. Usually treatment plant operators will maintain a high level of oxygen transfer to insure adequate oxygenation under critical loading conditions thereby providing more oxygen transfer capacity than is usually required. Automatic pacing of oxygen transfer in proportion to oxygen demand may therefore result in substantial reduction of power costs.

Various dissolved oxygen control systems are available commercially differing essentially in the method of directly or indirectly measuring the oxygen demand of the treatment system. Measurement methods include:

1. dissolved oxygen monitoring probes

2. raw wastewater flow

3. oxidation-reduction potential

4.2.G.I. Dissolved Oxygen Monitoring Probes as a Control Parameter for Dissolved Oxygen Levels in Aeration Basins

The most direct method of measuring oxygen demand in an activated sludge aeration basin is by the continual monitoring of the dissolved oxygen concentration in these basins utilizing dissolved oxygen probes. Most probes are polarographic cells, functioning galvanically, consisting of two metals of different nobility separated from the sample under analysis by a semipermeable membrane. The probe assembly is completed by a container which holds a volume of electrolyte and positions the metals as anode and cathode. The cathode is adjacent to the semipermeable membrane. Most commercially available probes can provide good performance and service.

Polarographic reactions in the probe detect quantitatively the oxygen diffusion rate through the membrane. Under fixed physical conditions the diffusion rate is directly related to the concentration of oxygen, with a precise calibration resulting. Factors affecting oxygen diffusion into the probe include: temperature of the membrane, turbulence at the membrane-sample interface, and the absence of materials which might adhere to the membrane. Membrane temperature variations are usually compensated for by electronically combining a thermistor which detects temperature of a wastewater sample with the readout system thereby providing automatic compensation. Turbulence variations are overcome by providing a fixed degree of turbulence in the sample directly adjacent to the membrane interface. Obviously diffusion of oxygen through the membrane will be affected by the adherence of oils, greases, or biological growths to the membrane. Most commercial probes provide adequate cleaning mechanisms.

Proper probe location is essential to the operation of dissolved oxygen control systems. The probe is usually designed to be placed in situ where transition time of the sample to the probe is essentially zero (see Figure 4-9). If it is desired to locate the dissolved oxygen probe remote from the aeration basin and to pump a sample to the probe, the elapsed time in transfer of the sample must be considered. If mixed liquor from an activated sludge process is to be transferred, the microorganisms in the mixed liquor

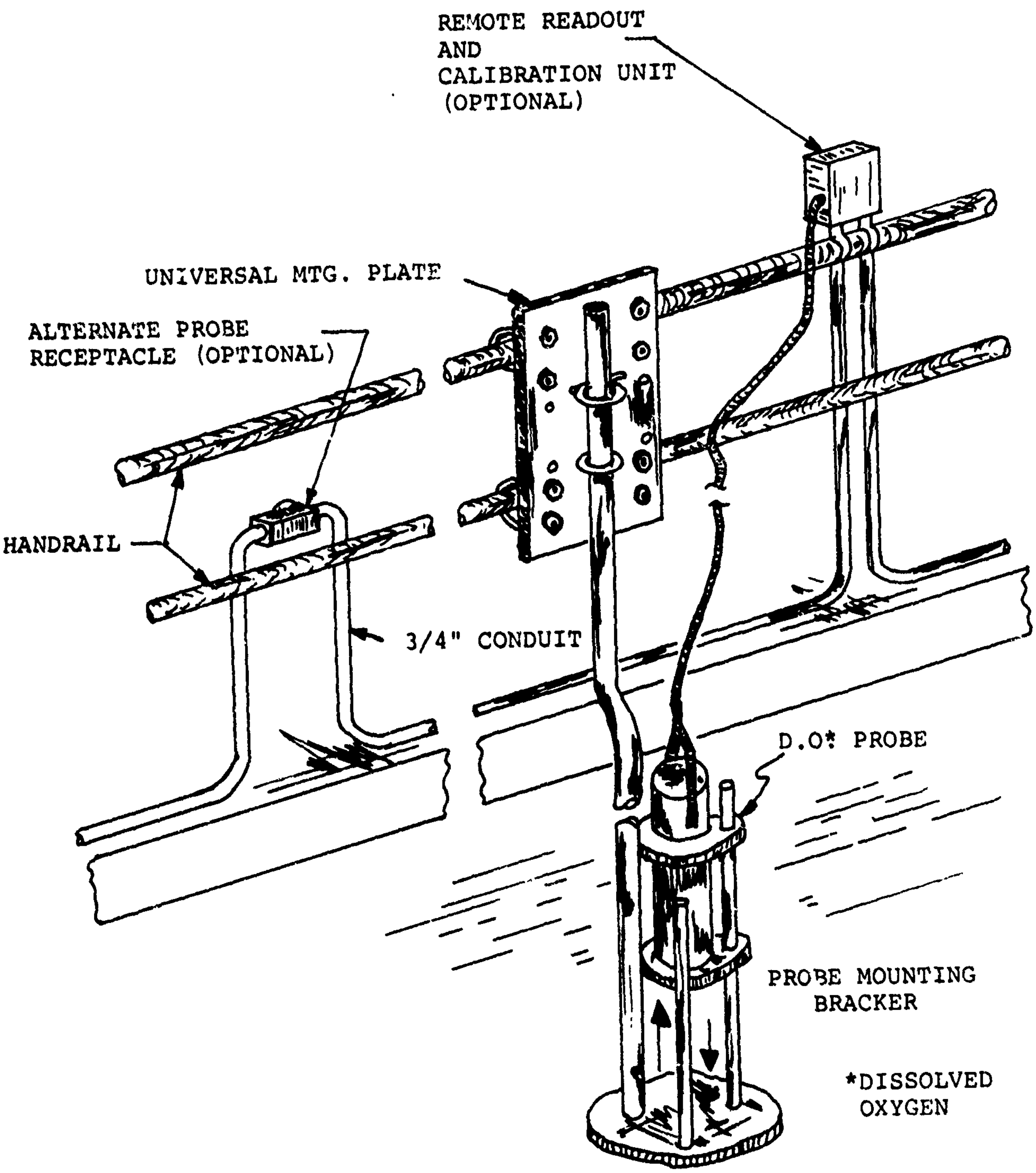



FIGURE 4-9

TYPICAL D.O. PROBE INSTALLATION

COURTESY OF WESTON AND STACK CO.

will decrease the dissolved oxygen level in the sample by the time it reaches the dissolved oxygen probe. Design of transfer systems must therefore recognize and tolerate a decrease in dissolved oxygen concentration. In situ installation of probes is recommended whenever possible.

Two important elements controlling probe location include the method of aeration and configuration of flow. Basic control elements may be categorized as follows:

1. Diffused Air Aeration

a. Plug-Flow, single-pass

Basins with a large length to width ratio are generally designed to pass the aeration mixture through the tank on a plug-flow basis. Biological stabilization proceeds more rapidly near the basin inlet where organic concentration is highest thereby implying highest oxygen demands. Since it is desirable to maintain aerobic conditions at all points in the aeration basin it may be difficult to choose the optimum probe location for monitoring and control of dissolved oxygen. Accordingly, flexibility must be provided for the potential placement of the probe at various points along the aeration basin. It is recommended that alternate probe receptacles be provided near the inlet, middle, and end of a plug-flow aeration basin.

b. Plug-flow, multiple-pass

Multiple-pass aeration basins may be considered the equivalent of a folded, single-pass aeration basin. Therefore control logic applicable to multi-pass basins is essentially the same as in the single-pass basin.

C. Completely mixed

Completely mixed aeration provides for equalization of dissolved oxygen demands throughout the aeration basin and a more uniform dissolved oxygen concentration. In systems actually approaching complete mixing probe location in the aeration basin is less critical. However, long aeration basins may not accomplish complete mixing thereby developing a gradation of oxygen demand from one end of the basin to the other. Flexibility in dissolved oxygen probe location is therefore recommended.

2. Mechanical Aeration

Turbine-type mechanical aerators mix effectively only in their own zone of influence. Mixing in the total aeration basin becomes less efficient when two or more turbine-type aerators are installed in the same basin because hydraulic translation of liquid from the zone of influence of one aerator to the zone of influence of another aerator does not progress rapidly. The isolation between two aerators approaches a partition wall between the aerators. Therefore, where oxygenation in the activated sludge process is provided by turbine-type aerators, and differences in organic load and oxygen transfer capacity by an aerator are adjusted, the change will be observed within the zone of influence of that aerator for several minutes before a change can be observed at other points in the aeration basin.

Control of the oxygen transfer capacity of turbine-type aerators depends largely upon the kind of turbine application. Submerged turbines used to disperse compressed air delivered to the suction of the turbine are controlled by varying the air flow. Turbines of the entrainment type (surface aerators) are normally controlled by changing the speed of the turbine or by changing the hydraulic submergence on the turbine. These methods of control adjust the horsepower consumed by the turbine and alter the oxygen transfer capability essentially in proportion to the horsepower consumed.

a. Plug-flow

Aeration basins possess large length to width ratios and, containing several turbine aerators, approach plug flow conditions. Wastewater entering such a basin is completely mixed around the first aerator only in its zone of influence. Hydraulic translation of the wastewater from the first aerator's zone of influence to the zone of influence of the second aerator progresses slowly with this situation being repeated down the basin to the effluent. The result is similar to plug flow rather than complete mixing. Probe locations should therefore have the flexibility previously described for plug flow systems.

If adjustment of oxygen transfer capacity is applied to the entire basin (by procedures such as raising and lowering the effluent weir to change submergence on the turbines), the location of the dissolved oxygen probe should be left to the discretion of the operator, and flexibility should be provided so that he may place the probe near the influent, near the effluent, or near the middle of the basin.

If changes in aeration capacity are to be accomplished by speed changes of the individual turbines, the most advantageous control logic may not necessarily be speed changes on all turbines at the same time.

Increased organic carbon concentrations in the influent will largely affect the oxygen demand of the aerators near the head end of the basin. Such aerators can be grouped for control of oxygen transfer capability based on demand while all other aerators may be handled as another group. In general adequate monitoring and control of dissolved oxygen can be accomplished by placing the probes in the zone of influence of any aerator.

b. Rectangular basins

In applying turbine aeration to rectangular basins the direction of turbine rotation should be selected which does not establish a strong flow pattern along the line between aerators. Therefore all aerators should rotate in the same direction. Probe location is practically accomplished in rectangular basins by selecting a location in the zone of an aerator such that acceptable information for control purposes is obtained.

Most practical dissolved oxygen control systems have developed a step time-pulse logic unit. The step time-pulse unit permits the time constant in the aeration system (reflected basically as the rate of change of oxygen demand in the aeration system) to be matched by step in aeration capacity taken at adjustable intervals of time.

The magnitude of step change in aeration capacity is engineered in the system as a selected practical size. The step can be accomplished by a predecided change in the position of a valve in an air system; the selected speed change on a positive displacement blower; a selected change in submergence on a mechanical aerator; or any other operating step which will change the oxygen transfer capacity in the system.

Step time-pulse logic may be explained as follows. Time indicated as $\Delta T$ is adjustable by the operator to correspond to the rate of change in oxygen demand which he anticipates or has observed in the aeration system. For example, if he is aware that a very significant change in oxygen demand can occur within five (5) minutes, he would select $\Delta T$ at five (5) minutes. Within the time interval of $\Delta T$, a control window would open and the signal from the probe would be read by the analyzer. The reading would be compared simultaneously to set points at preselected high and low levels of dissolved oxygen. If the dissolved oxygen level detected by the probe were within the set points, no adjustment of oxygen transfer capacity would be made. If the dissolved oxygen concentration were greater than the high set point a step downward in oxygen transfer capacity would be made.

In most closed-loop control systems dissolved oxygen sensor output is transmitted to an oxygen analyzer in a control cabinet (see Figure 4-10). When the sensor's reading falls below or exceeds a specified oxygen content, a power unit is actuated to pace the aeration equipment accordingly. Such pacing minimizes consumption of electrical power while maintaining the dissolved oxygen in the treatment process at a desired level. The control mode for automatically pacing the aeration equipment within selected units can be accomplished in several ways:

1. Varying the air volume discharged through the diffusers, spargers, or socks by automatically varying the flow at the inlet to the turbocompressors by means of a servo-actuated valve (and/or air distribution) on discharge side of blowers. Throttling will decrease $O_2$ transfer. In essence this control mode increases or reduces oxygen into the wastewater by diffusion transfer.

2. Varying the oxygenation capacity of the turbine aerators by automatically adjusting the depth of submergence of the turbine impeller blades. This variation of blade submergence can be accomplished via:

(a) motorized horizontal weir which can be automatically operated such that the liquid level in the aeration basin will be raised or lowered in accordance with the process requirements.

(b) Varying the impeller elevation by means of an automatically controlled spline type vertical drive shaft on the turbine aerator.

The operation described here is based on the submergence of the aerator blades. The greater the blade submergence, the greater the oxygenation capacity of the aerator and vice-versa. The most popular control mode is accomplished by lowering or raising a mechanized rotary weir.

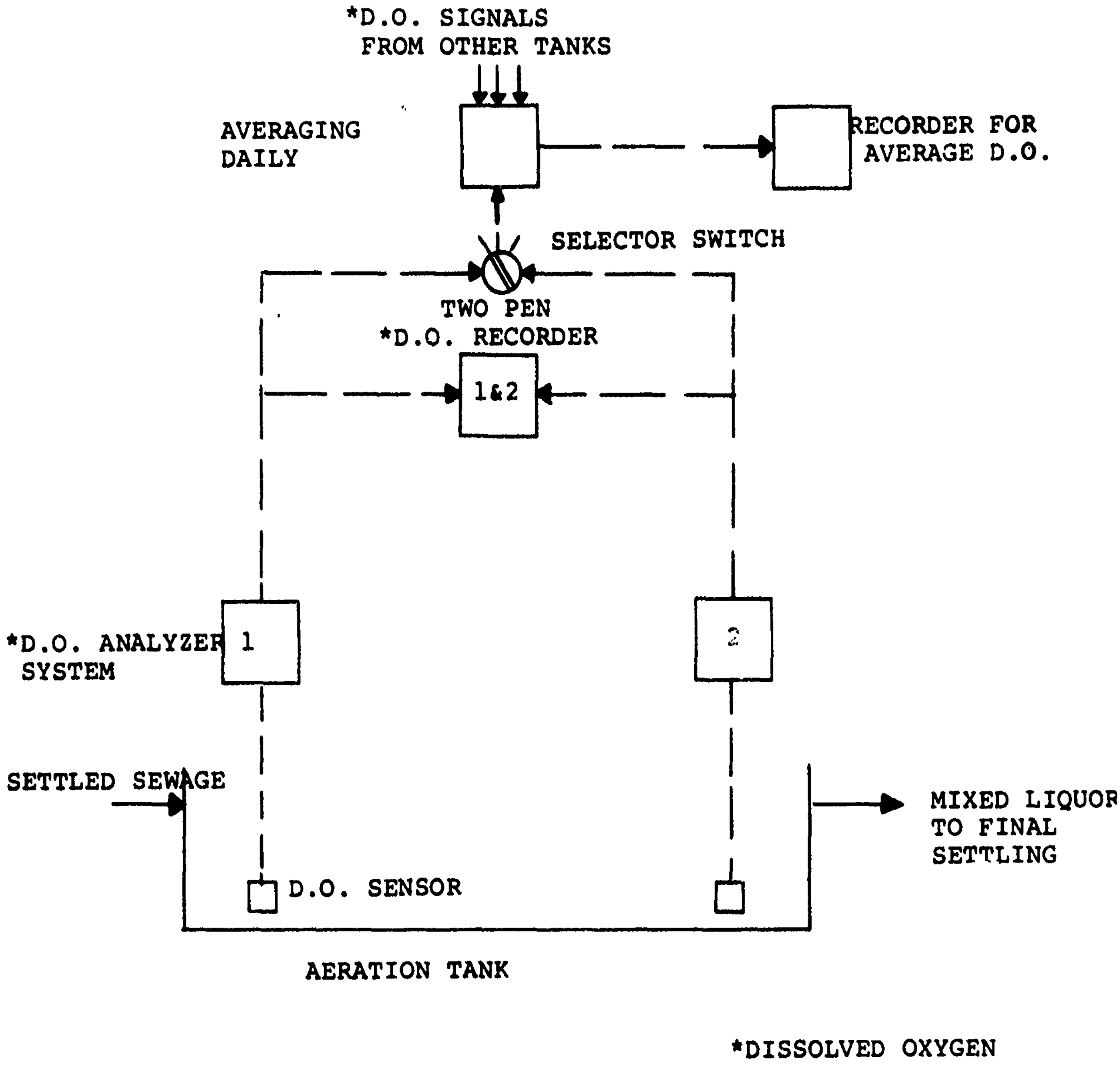



FIGURE 4-10

CONTINUOUS MONITORING OF
DISSOLVED OXYGEN IN AN AERATION BASIN

COURTESY OF FISCHER & PORTER CO.

The positioning of the weir is accomplished by using a reduction gear and a motorized speed reducer. The amount of weir movement is controlled automatically by the dissolved oxygen sensor and the various electronic components to maintain the dissolved oxygen level within set limits (See Figure 4-11). The dissolved oxygen sensor in the aeration tank constantly monitors the D.O. in the liquid. This concentration is transmitted to the oxygen analyzer. The analyzer is set to maintain a dissolved oxygen level within any prescribed limits, say between 2 to 3 parts per million. Should the oxygen level drop below 2 parts per million, the analyzer will close a low dissolved oxygen level switch energizing a time delay relay which starts the motorized gear and weir mechanism for approximately one minute, thus raising the weir approximately 0.1'. At the end of one minute the time delay relay contacts open, opening the circuit to the motorized gear, thus stopping the weir. As the normally closed contacts of the relay open the motorized gear circuit, another set of contacts close, energizing a clock type timer. This timer takes over the operation of the weir and can be set to start the motorized gear for any preset time and also stop the motorized gear for any preset time until dissolved oxygen level in the aeration tank liquid is back to the normal 2 parts per million level.

An adjustable timer allows the dissolved oxygen in the liquid to level out over a period of time, otherwise the weir could rise to the extreme level before the aerator had sufficient time to transfer the oxygen throughout the liquid. High and low weir level limit switches are provided to prevent over-riding the weir.

Should the oxygen exceed the 3 part per million level, the same procedure as above would follow, the only difference being the motorized gear and weir reduction drive would lower the weir, exposing more of the aerator blades and reducing the oxygenation capacity of the aerator.

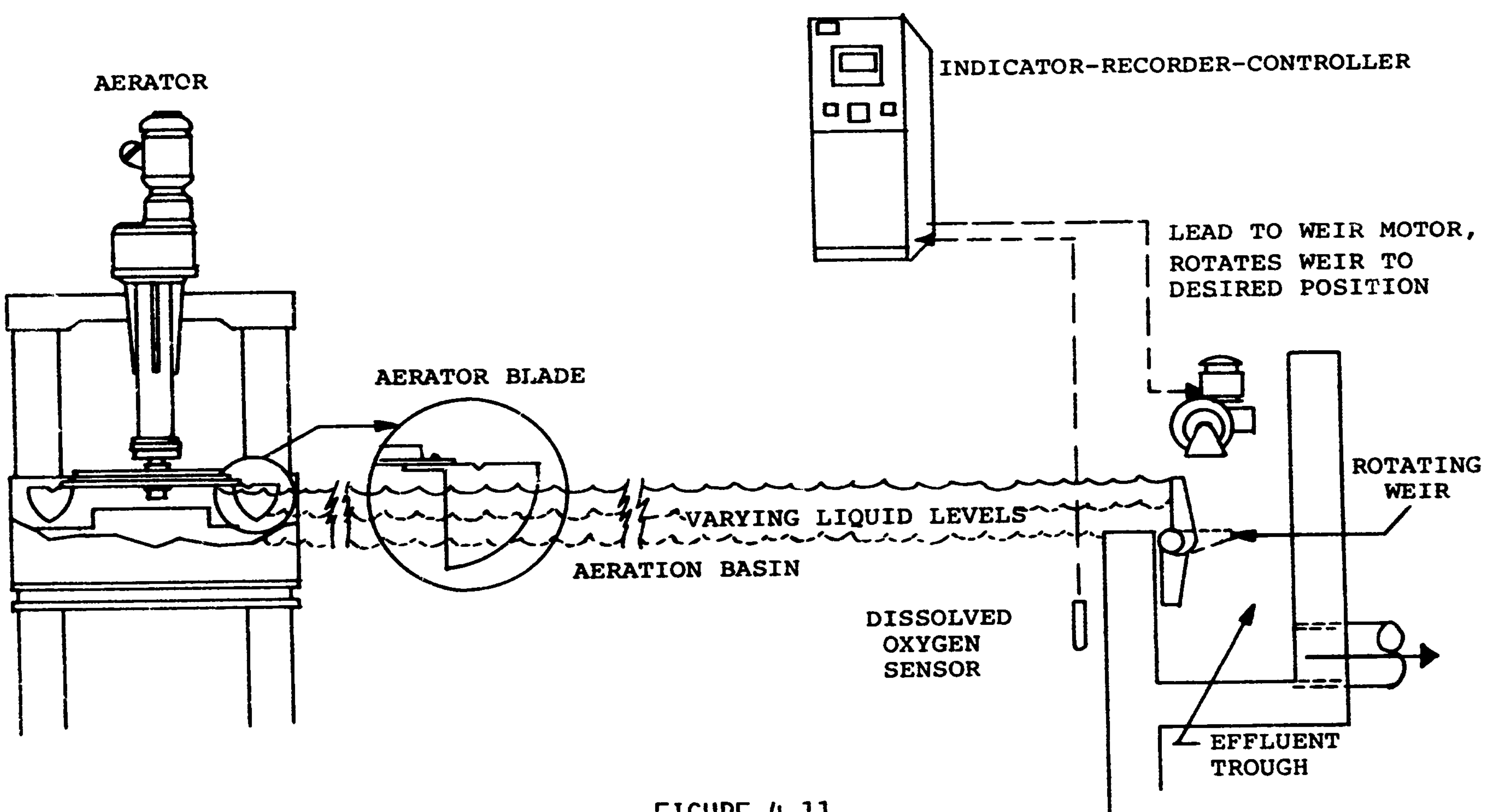



FIGURE 4-11

DISSOLVED OXYGEN CONTROL FOR MECHANICALLY AERATED BASINS-ROTATING WEIR

COURTESY OF CLOW CORP.

3. Varying the speed of the blowers (See Figure 4-12) or turbine type mechanical aerators in accordance with process needs, by means of:

(a) Two speed induction motors and appropriate magnetic starters or,

(b) Variable speed DC motors

4. "On-Off" mode of operation for the plurality of turbine type mechanical aerators; additional units to be brought on-line or shut off on a stepping basis.

The major components of dissolved oxygen control systems using dissolved oxygen probes include the following:

1. Dissolved oxygen probe
2. Sampler
3. Dissolved oxygen analyzer
4. Remote readout and calibration unit
5. Timer
6. Recorder
7. Console with analyzers, recorders, and logic units
8. Load center for interfacing with aeration equipment

Cost of installing a complete dissolved oxygen monitoring and control system for a 10 MGD plant would average approximately $8,000 to $10,000. It is estimated that the savings in electrical power costs would pay for such a system in 2 to 4 years.

4.2.G.II Raw Sewage Flow as a Control Parameter for Dissolved Oxygen Levels in Aeration Basins

The most commonly used method for dissolved oxygen control in aeration basins is based upon

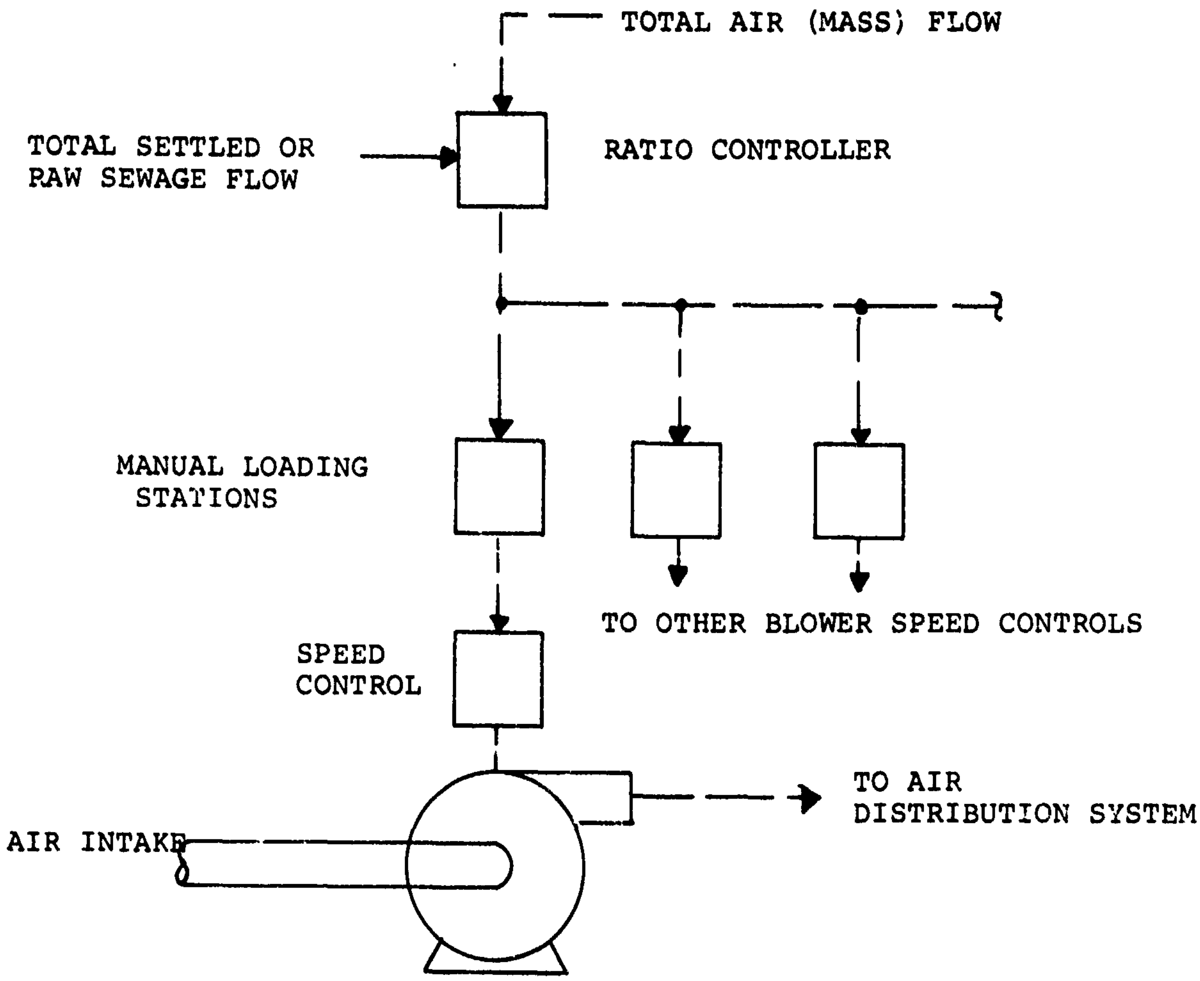



FIGURE 4-12

AIR BLOWER SPEED CONTROL

COURTESY OF FISCHER & PORTER CO.

automatically maintaining a constant ratio between raw wastewater flow and air flow. Raw wastewater flow is obviously an indirect method of determining the oxygen demand assuming uniform compositional characteristics of the wastewater stream at all times. In ratioing air to mixed liquor in the aeration tank, it is customary to maintain the ratio somewhere between 1/2 and 1 1/2 cubic feet of free air to gallon of wastewater treated. Present practice in most treatment plants merely involves manual adjustment of air feed to maintain the desired ratio. Since the wastewater flow through a treatment plant will undergo extremely large fluctuations in the course of a 24-hour day, considerable plant operator attention must be devoted to maintaining proper air-wastewater flow ratios. In these plants in which 24-hour supervision is impossible, operator procedure usually consists of merely raising the air flow in the morning and decreasing it at night. Under such operational procedure, changes in wastewater flow will result in either over- or under-aeration accompanied by improper treatment.

Dissolved oxygen control systems utilizing raw wastewater flow as the method of determining oxygen demand provide the following control functions:

1. Maintaining a constant air-wastewater flow ratio at a desired value regardless of influent flow variations,

2. Remote setting of air-wastewater flow ratios from laboratory or office facilities,

3. Ratio cutout mechanisms providing a ratio controller functioning as a rate-of-flow controller which can maintain the air flow rate at a fixed ratio regardless of influent wastewater flow rates.

4. Automatic starting and stopping of air equipment in sequence so that only a minimum number will be required to satisfy the oxygen demand at any time. Such control will increase air equipment power savings and increase equipment life.

An automated oxygen control system is shown in Figure 4-13 consisting of primary devices, pneumatic transmitter, control valves, and ratio controllers on the air line. The raw sewage flow is determined by a flow meter which activates a pneumatic transmitter with float and cable. This influent rate measurement is transmitted to a ratio controller which is set for a specific air-wastewater flow ratio. The air signal from the differential pressure flow detector is transmitted to a square root extractor which provides an indication of flow rate in addition to the transmission signal which varies uniformly with flow. The air signal proceeds to the ratio controller which sends a signal to the butterfly valve so as to maintain constant air-wastewater flow ratios regardless of influent rate variations.

If remote control of the ratio setting of the ratio controller is desired it can be provided through remote setting stations. These may be located in the office or laboratory so that the superintendent or chemist can provide the proper ratio setting without going to the main instrument panel.

To conserve power and increase blower life, blowers may be operated in sequence by pressure switches on the control line to the butterfly valve. Therefore, only the number of blowers required to satisfy the air demand are operated. The blowers automatically stop and start in response to changes in air requirement.

Figure 4-14 depicts an automated dissolved oxygen control system in which mass air flow is transmitted to the ratio controller. The butterfly valve in this system therefore controls the mass air flow-wastewater flow ratio. Mass air flow is determined through the use of temperature and pressure transmitters on the air line from the blowers in addition to the usual differential pressure flow transmitter.

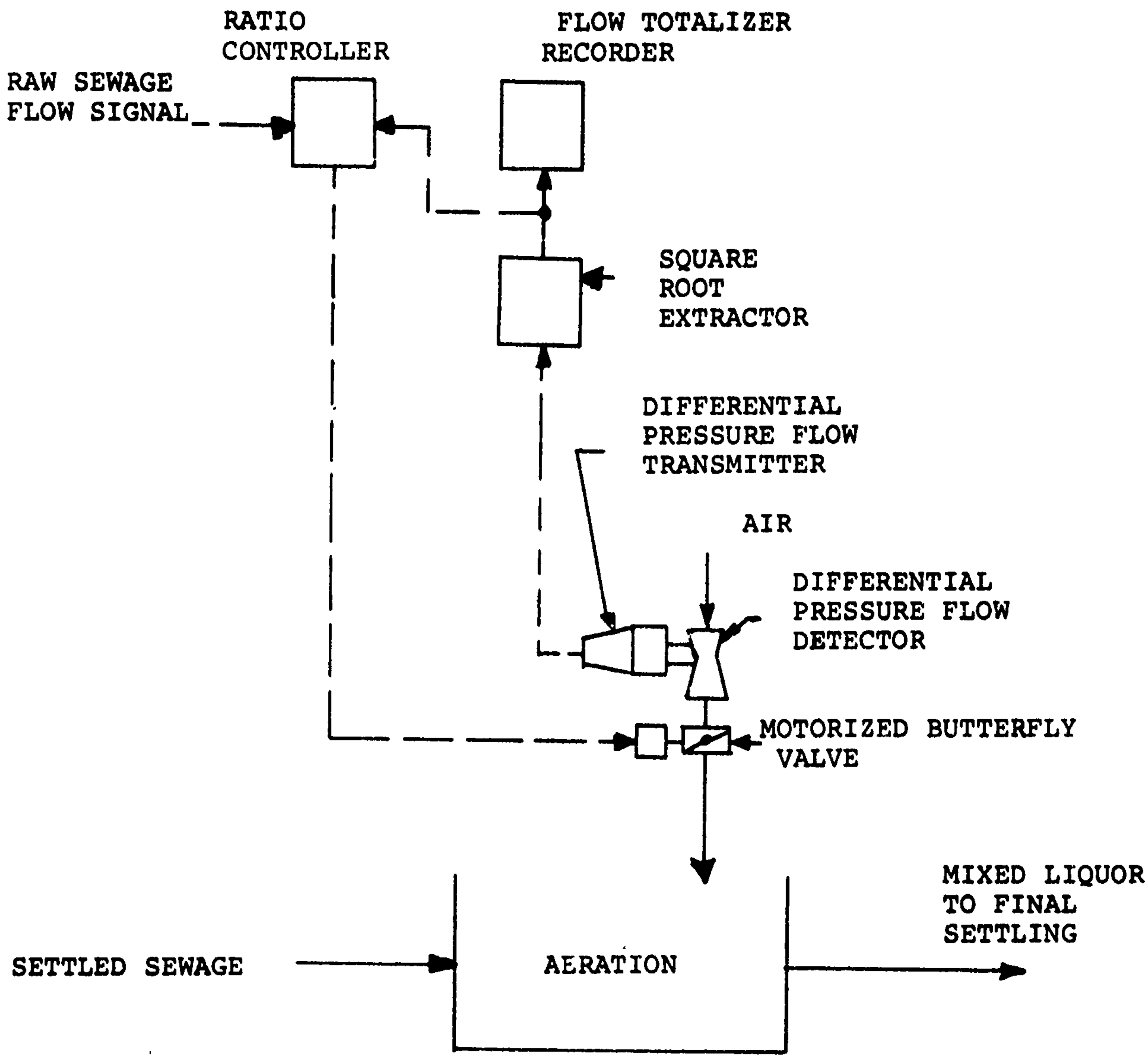



FIGURE 4-13

AIR FLOW TO AERATION TANK
W/RAW SEWAGE FLOW CONTROL

COURTESY OF FISCHER & PORTER CO.

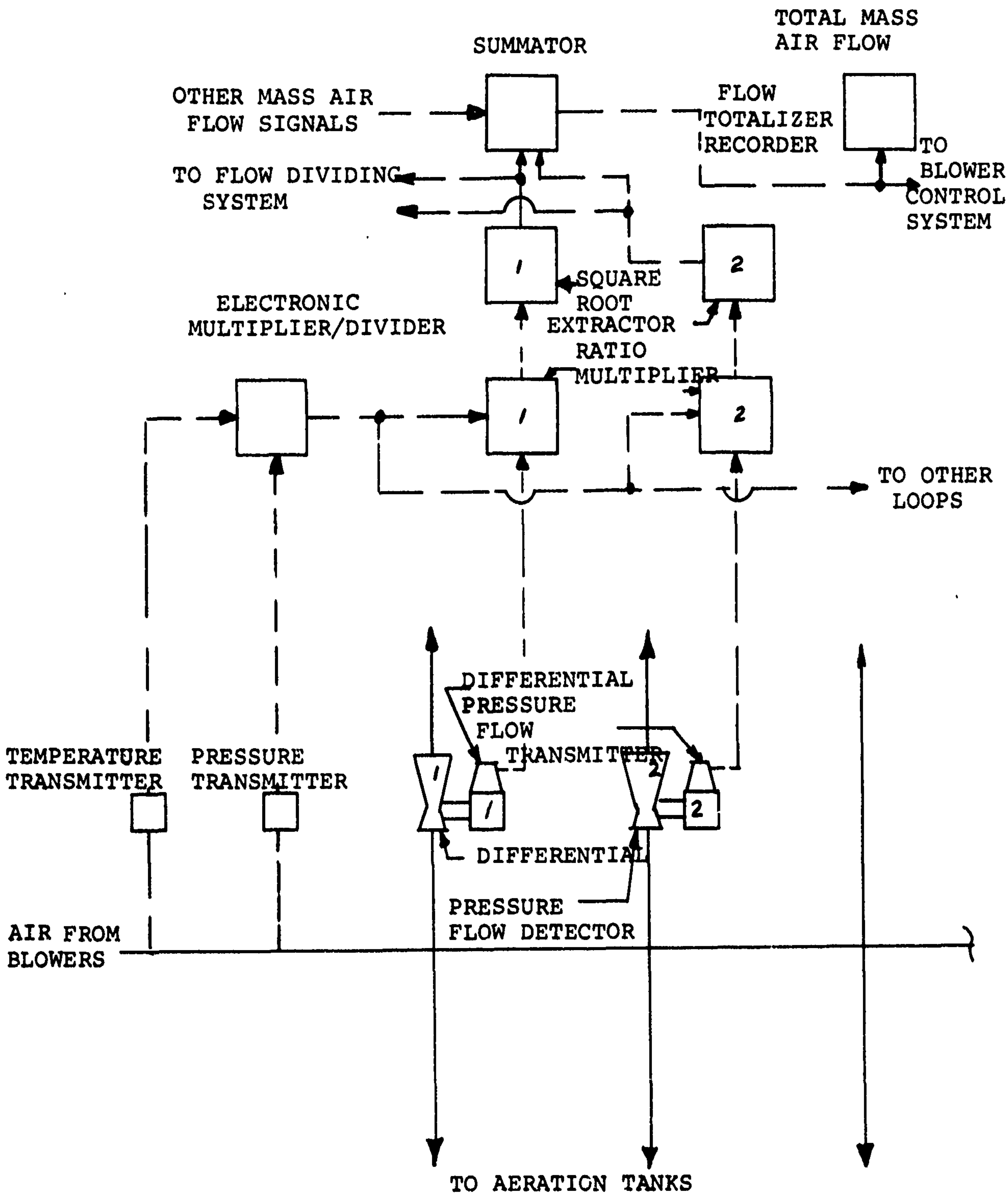



FIGURE 4-14

CONTROL OF MASS
AIR FLOW TO AERATION TANKS

COURTESY OF FISCHER & PORTER CO.

Figure 4-15 outlines an air flow dividing system in which two separate air flow lines may be controlled separately by means of a ratio station. This ratio station can regulate the air flow in two separate lines according to any desired ratio.

Automated control of dissolved oxygen in aeration basins using wastewater flow as an indirect determination of the oxygen demand is an approximate method at best. Oxygen demands of wastewaters will usually fluctuate to some extent during an average 24-hour day. Consequently, it is recommended that automated dissolved oxygen control systems based on influent flow be utilized only for those wastewaters having a relatively uniform oxygen demand throughout the typical treatment day.

### 4.2.G.III. Oxidation-Reduction Potential as a Control Parameter for Dissolved Oxygen Levels in Aeration Basins

The oxidation-reduction potential is a potential between the oxidants and reductants in a system without regard for the total quantity of either constituent or their biological activity. Biological activity considerations are important since inert oxidized salts may be recorded as oxidants although their effect on biological reactions will be minimal. Therefore, a high oxidation-reduction potential can develop even though the biological reaction is predominantly reductive in nature. Since the oxidation-reduction potential is an indication of the oxidants and reductants, it is actually a result of the measurement of the cause of biological reactions. It must be remembered that although it may be possible to correlate the oxidation-reduction potential of any given activated sludge plant to its operating characteristics (oxygen demand), however, it is not possible to correlate oxidation-reduction potentials directly between systems.

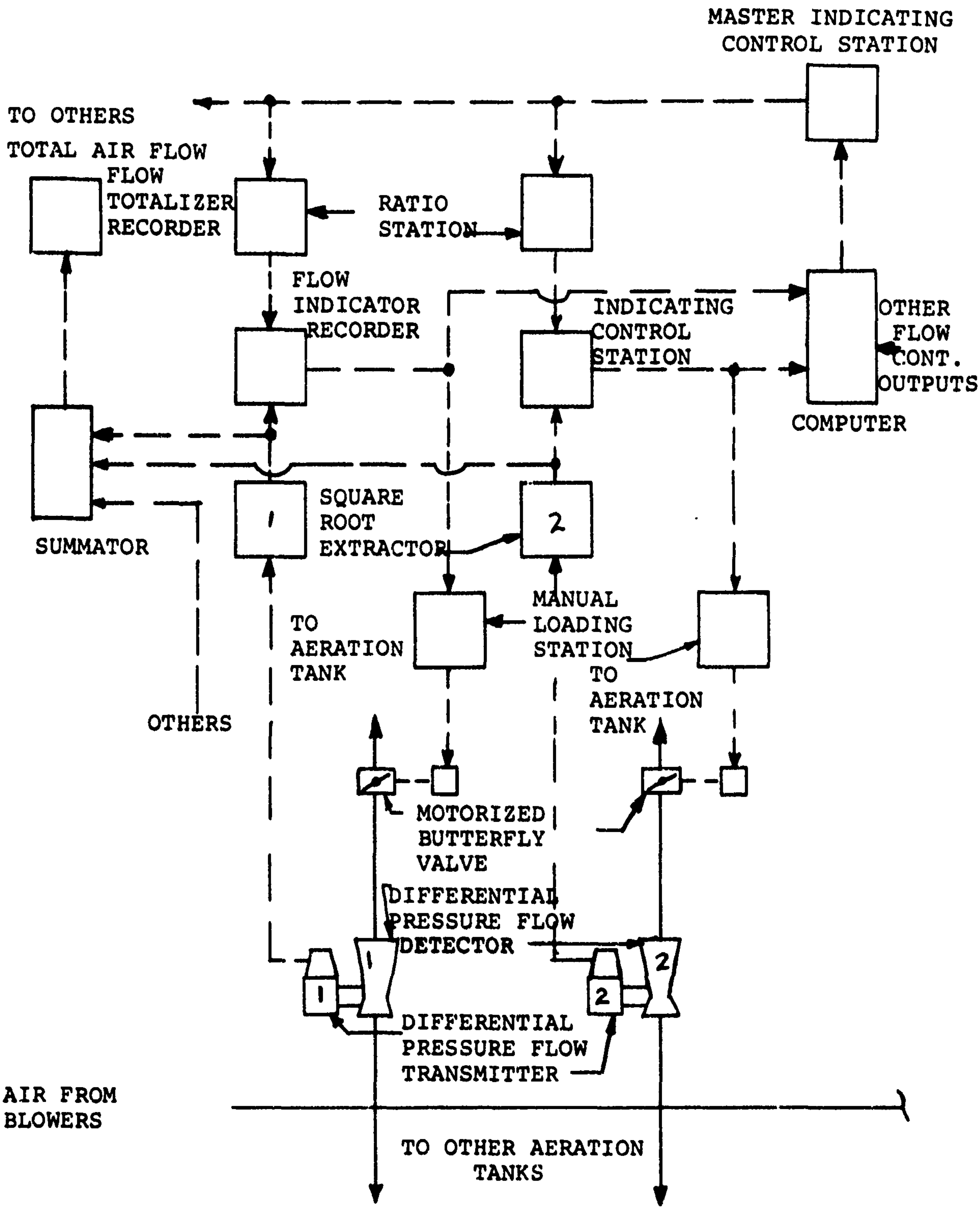



FIGURE 4-15

AUTOMATICALLY CONTROLLED
AIR FLOW DIVIDING SYSTEM

COURTESY OF FISCHER & PORTER CO.

Figure 4-16 describes an automated dissolved oxygen control system in which the oxidation-reduction potential serves as a means of indirectly measuring oxygen demand. ORP values are determined by cells located at the aeration basin. These ORP values are transmitted to a recorder and then forwarded to blower control equipment. Again it must be remembered that the oxidation-reduction potential must be correlated to the oxygen demand of the activated sludge system and is not a direct measurement of this demand.

4.2.H Monitoring and Control of Nutrients

The two major nutrients required for proper metabolic functioning of activated sludge microorganisms in a treatment system include phosphorus and nitrogen. Wastewater streams deficient in nutrients will exert adverse effects on biological predomination. For example, a partially nitrogen-deficient wastewater will stimulate the growth of fungi over that of bacteria, since the fungi formulate protoplasm with a lower nitrogen content than bacteria. Fungi, being characteristically filamentous will impede settling efficiency. Fungi can stabilize organic carbon material similar to bacteria, however, their inherently poor settling characteristics make their presence undesirable in any activated sludge system. A wastewater deficient in phosphorus will also produce the above process characteristics.

Monitoring and control of nutrients (phosphorus and nitrogen) is currently practiced almost exclusively in industrial wastewater treatment facilities possessing nutrient deficiencies. Automated control systems utilize either specific ion electrodes or automated wet-chemical analysis for determination of phosphorus and nitrogen. Several manufacturers produce nitrate specific ion electrodes, however, phosphate specific ion electrodes are not commonly available. The determination of nitrate with specific ion electrodes encompass 6000 to 0.6 mg/l in a pH range of 2.0 to 12.0. It should be

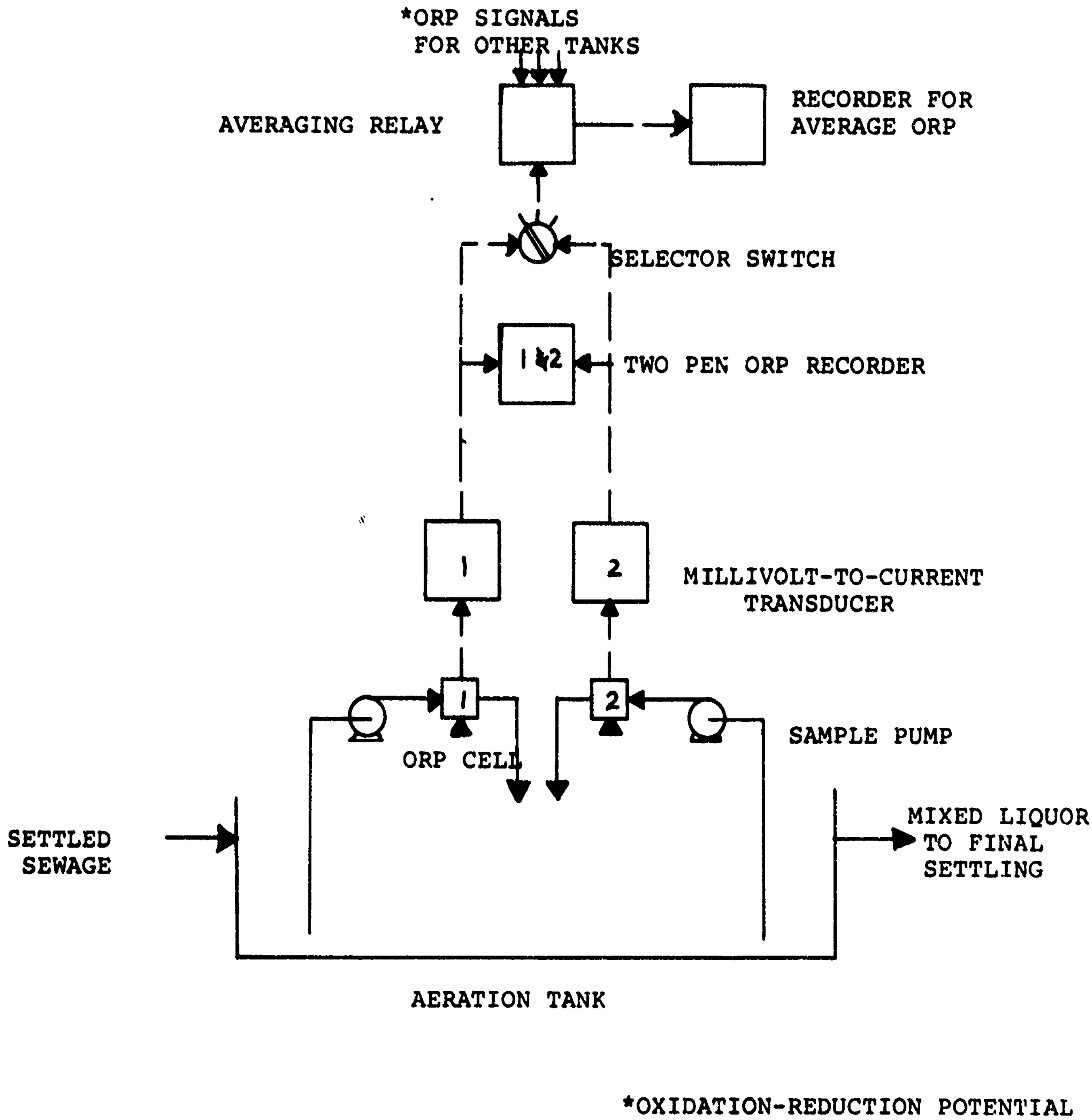



FIGURE 4-16

CONTROL OF AERATION BASIN DISSOLVED OXYGEN CONCENTRATION USING OXIDATION-REDUCTION POTENTIAL

COURTESY OF FISCHER & PORTER CO.

remembered that specific ion electrodes have been primarily utilized for process control in the chemical industry as opposed to direct analytical measurements. Ion selective systems must therefore be applied with care. Many of these electrodes have interferences. This means that the electrode will produce a potential in the presence of ions other than that for which it is being used. Consequently, these electrodes are becoming more generally termed "ion-selective," rather than "specific ion" electrodes. Interferences vary according to the particular electrode and with the activity of the ion species present. Careful application engineering should be exercised before installing specific-ion electrodes on a process stream. The minimum amount of information that should be known prior to specific-ion electrode selection should include:

1. Desired measurement

2. Accuracy and range of measurement

3. pH range of stream to be analyzed

4. Analysis of the stream

5. Operating conditions of the stream including: viscosity, flow rate, pressure, and temperautre.

6. Determination of the quantity of materials present in the stream which might clog or coat the electrodes.

Automated wet-chemical methods can provide specific chemical information regarding phosphate, nitrate, nitrite, and ammonia. Automated wet-chemical analysis refers to a system in which a sample is automatically introduced and prepared, followed by reagent addition in proper sequence, and automatic data read out following reaction completion. For example, a wastewater prepared for automatic wet analysis for phosphate undergoes the following automated procedure:

1. Hydrolysis with sulfuric acid at elevated temperatures.

2. Addition of appropriate chemicals.

3. Spectrophotometric measurement of a blue colored complex and recording.

Automated wet-chemical analyzers can usually be converted from discrete sampling to continuous monitoring by replacing the sample module by a continuously introduced sample of water which is conveyed to the analytical system by devices constructed to suit the particular application.

The feasibility of wet-chemical analysis has been reported at several treatment plants in the United States including the Hyperion Sewage Treatment Plant in Los Angeles, the Metropolitan Sanitary District Facilities in Chicago, and the Minneapolis-St. Paul Sanitary District Plant in Minnesota. Automated wet-chemical analysis performed at these plants include:

1. phosphates

2. ammonia

3. nitrate

4. nitrite

5. chlorides

6. iron

7. organics

8. urea

9. detergents

In treatment plants having nutrient deficient wastewaters, automated control of nutrient content in aeration basins is feasible. Such control systems can maintain a constant oxygen demand-nutrient ratio in the aeration tank utilizing the following components:

1. In-situ specific-ion electrode or wet-chemical analyzer to continuously monitor aeration basin nutrient levels,

2. Continuous oxygen-demand monitoring by one of the following methods:

a. influent wastewater flow
b. oxidation-reduction potential
c. dissolved oxygen probes
d. automated COD or TOD analyzers

3. Ratio controller set at a desired oxygen demand-nutrient ratio which would send a signal to the nutrient feeders to maintain the necessary ratio at all times. Automatic phosphate and nitrogen feed systems are available from several manufacturers.

Present state of the art of automated wastewater treatment provides little nutrient control. It should also be remembered, however, that an additional benefit derived from nitrate monitoring is an indication of aeration basin efficiency while ammonia and nitrite measurements can be used in nitrogen balance studies to further control the treatment process to produce a desirable effluent quality with a minimum of operating expense.

4.2.I. Monitoring and Control of Hydrogen Ion Concentration

It is of utmost importance that the hydrogen ion concentration (pH) be maintained at the proper level in the activated sludge process. Below pH 6.5 fungi will begin competing with the bacteria with full predominance at pH 4.5. Above pH 9.0 bacterial metabolic retardation begins. Consequently, a pH range of 6.5 to 9.0 is required for normal process performance.

pH control, despite its apparent simplicity, is most likely the poorest controlled process parameter in waste treatment for two reasons:

1. System rangeability problems

2. The logarithmic shape of the pH curve.

System rangeability problems arise due to the need to neutralize over a wide range of possible influent pH values, sometimes varying from 2 to 12. Securing reagent delivery systems to encompass this large of a range often becomes a major problem. Narrow rangeability requirements (such as a pH change of one unit and 2:1 flow change) can be efficiently handled by a single valve, chemical feeder, or pump; however, problems may arise when system rangeability exceeds a single valve, feeder, or pump capacity. For example, an influent pH variation between 3 and 6 will produce a system rangeability of 1000 to 1 because of its logarithmic nature. In addition, an influent flow change of 6:1 will produce a total system rangeability of 6000:1 ratio. It is possible to sequence valves to handle this range.

The logarithmic shape of the pH curve also imposes severe accuracy on the control system. For example, an influent wastewater having a pH of 3 to be neutralized to a pH of $8 \pm 1$, imposes a required accuracy of 10 parts in $10^5$, or 0.01 percent.

There currently exists two basic methods of pH control:

1. Feedback control
2. Feedforward control.

In feedback control a measurable error in the effluent of the neutralization basin must be monitored before pH control is applied. In such a system perfect pH control is not possible. The feedback controller does not possess sufficient information to solve pH control in any way except trial and error. Oscillatory responses may therefore result. Figure 4-17 depicts a feedback control system for a wastewater stream having a stable flow rate and a pH rangeability within the capabilities of the reagent addition system. Figure 4-18 outlines a similar feedback control system incorporating control for unstable wastewater flow conditions.

In feedforward control systems (see Figures 4-19, 4-20, 4-21, and 4-22) influent wastewater flow and influent and effluent pH are monitored. This information is transmitted to a computer which forwards required acid or caustic feed information to the reagent feed tank. Theoretically, perfect control is obtainable using feedforward control.

Automated hydrogen ion control systems are available from several manufacturers, however, all systems utilize essentially feedback or feedforward control procedures.

Feedforward control appears to yield superior quality control. Also more precise reagent addition is possible thereby providing substantial chemical savings. Holding tank costs are also minimized because of the system's ability to provide almost immediate neutralization.

4.2.J Monitoring and Control of Temperature

The effect of temperature on biological metabolism in the activated sludge process has already been discussed in detail (see section 4.2.F). At high temperatures the rate of biological metabolism can exceed the ability of the system to remain aerobic. Conversely, a low temperature will result in a low biological metabolic rate, and, consequently, poor process effluent quality.

At present the state of the art of automated control of activated sludge systems has not seriously addressed itself to temperature control. Several factors apparently have permitted this lack of temperature control, however, the primary concern

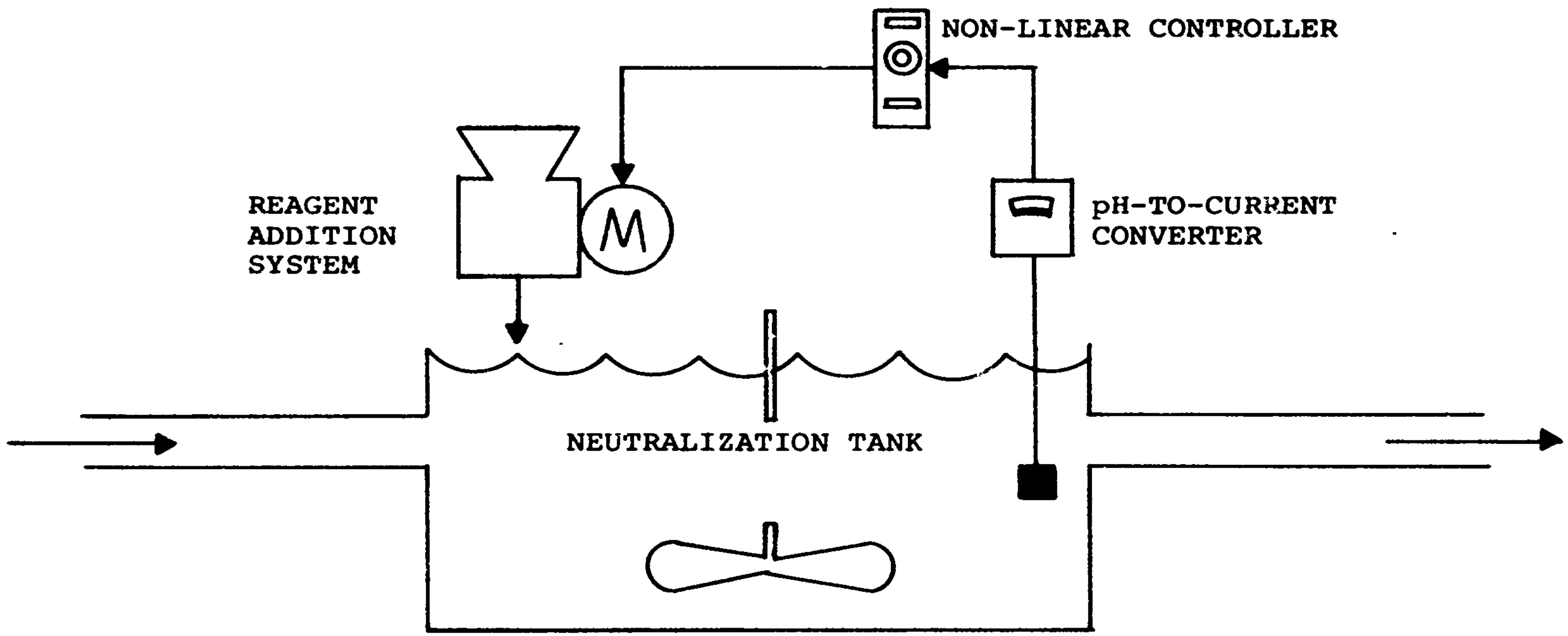



FIGURE 4-17

FEEDBACK
MEDIUM RANGE SYSTEM
STABLE FLOW RATE
RANGEABILITY 10 to 20:1

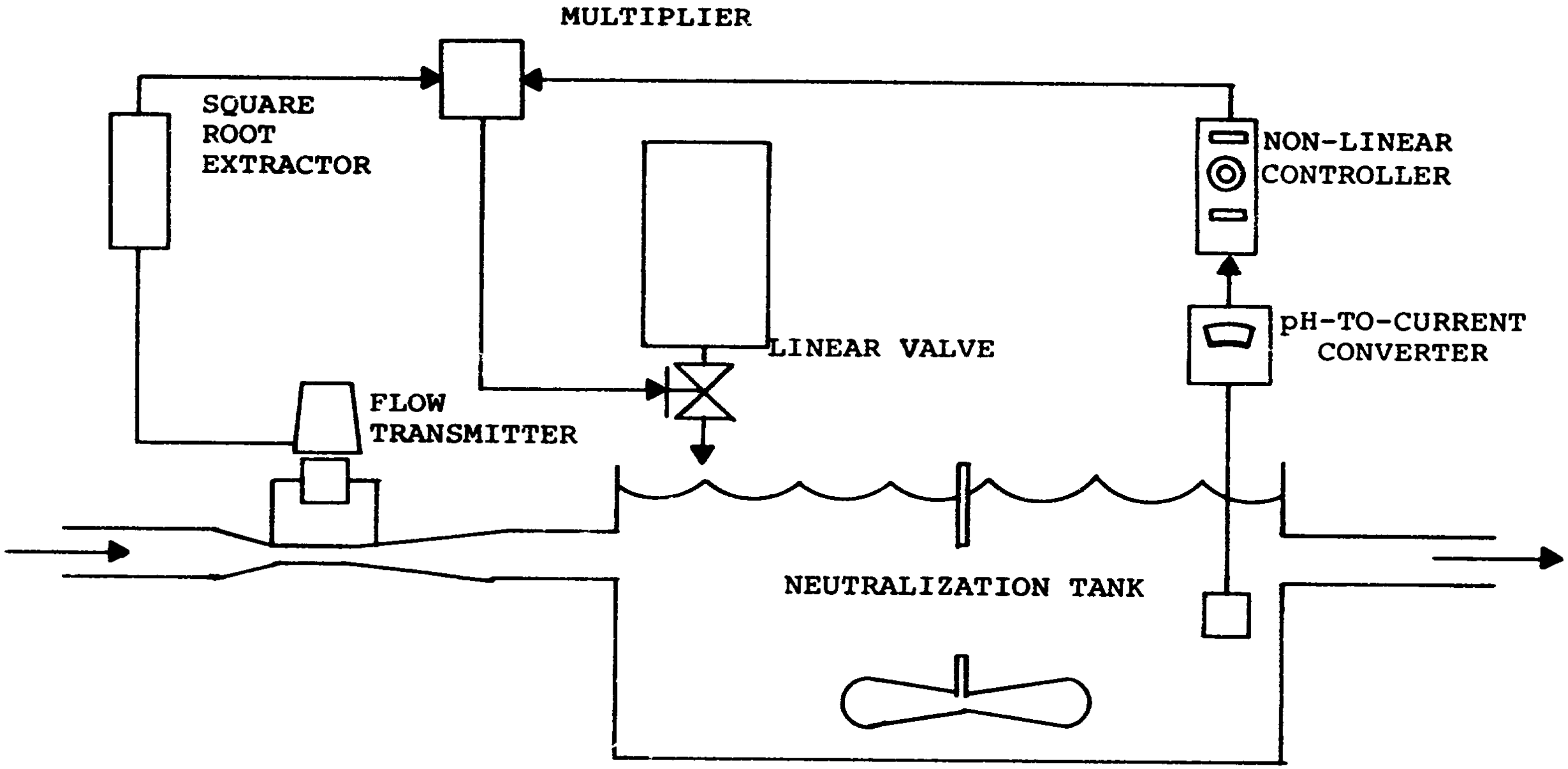



FIGURE 4-18

FEEDBACK
MEDIUM RANGE SYSTEM
UNSTABLE FLOW RATE
RANGEABILITY 10 TO 20:1

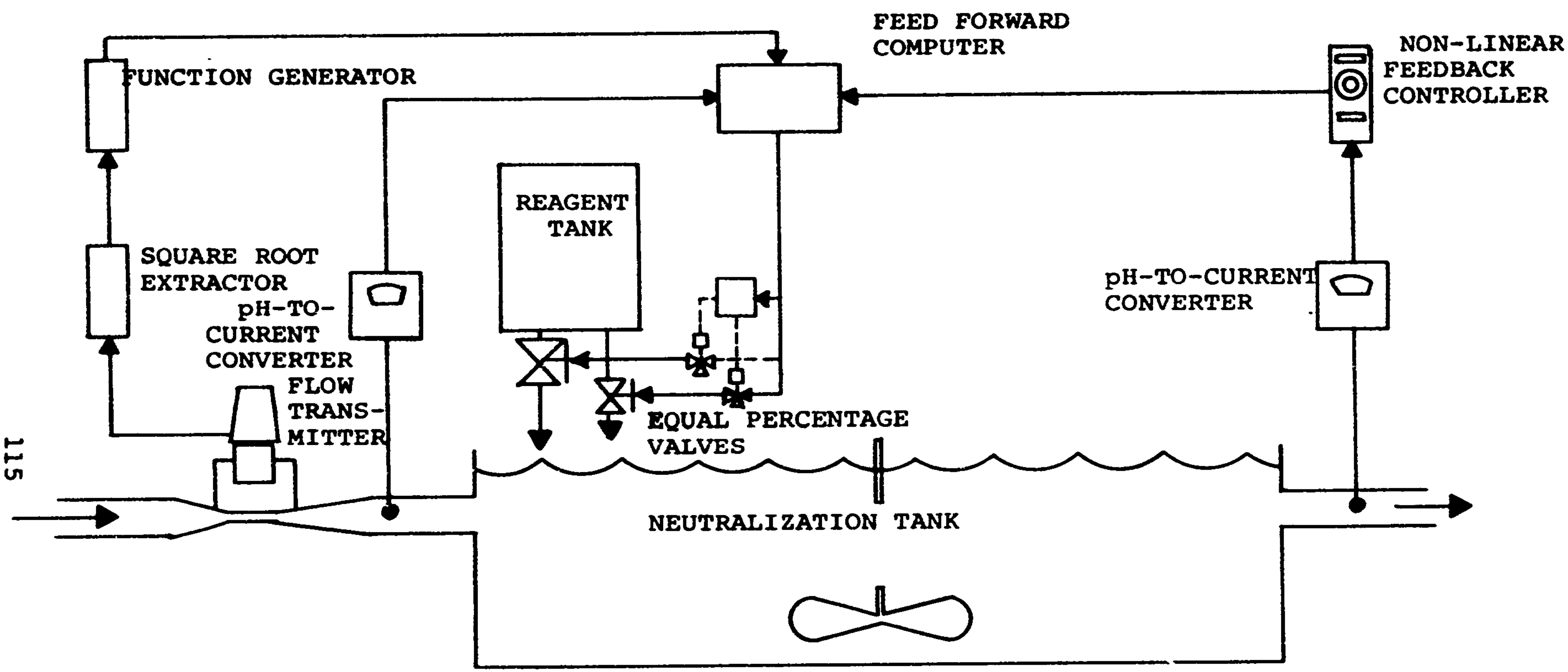



FIGURE 4-19

FEEDFORWARD SYSTEM
(CONTROLLING ON ONE SIDE OF NEUTRALITY ONLY)
RANGEABILITY 1500:1

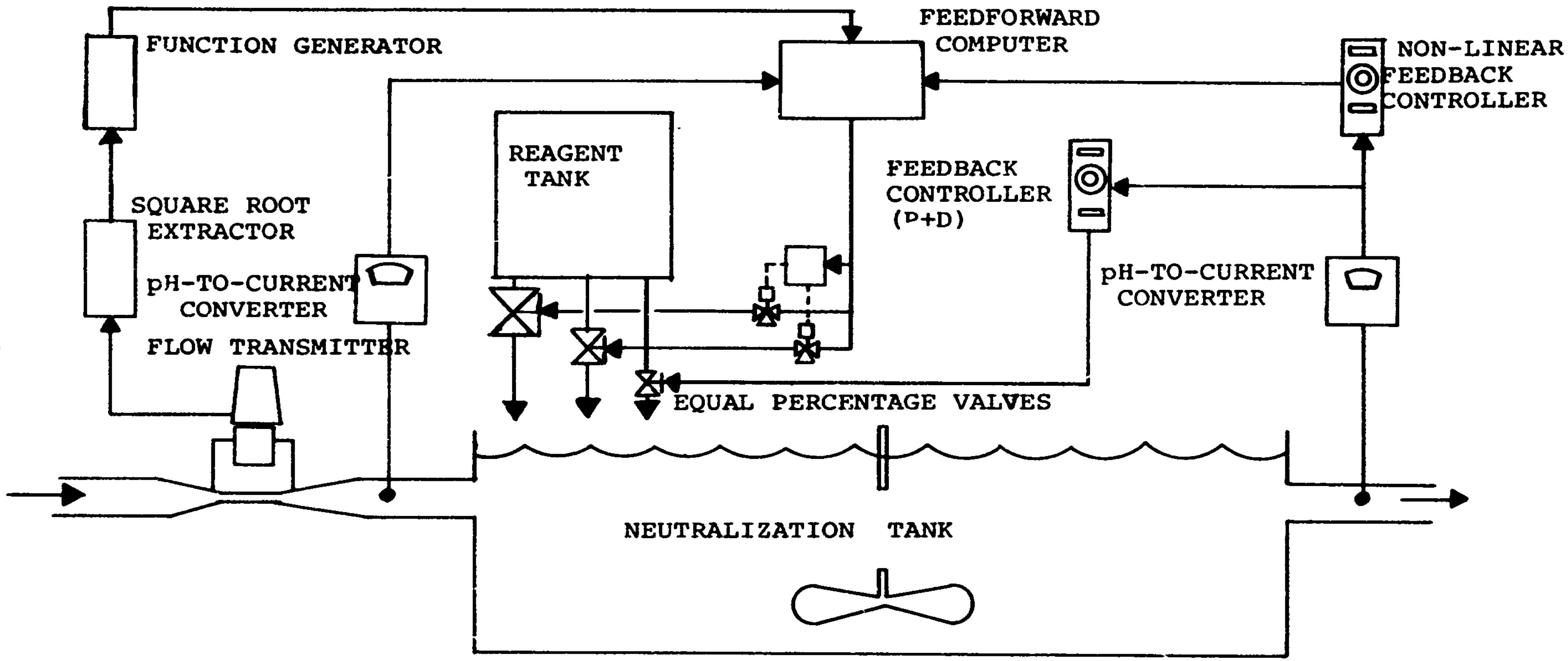



FIGURE 4-20

FEEDFORWARD SYSTEM
(CONTROLLING ONE SIDE OF NEUTRALITY ONLY)
RANGEABILITY 10,000:1

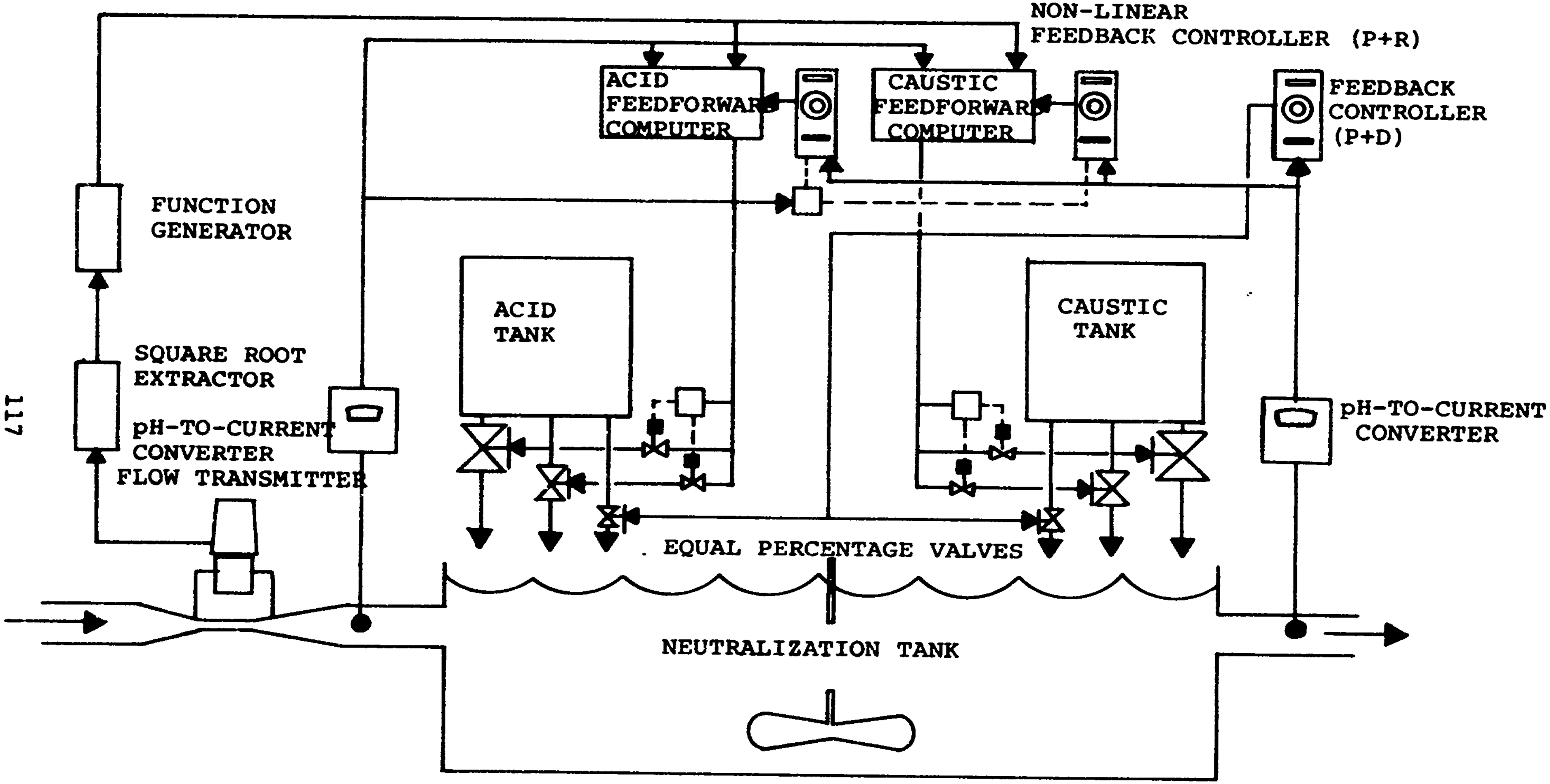



FIGURE 4-21
FEEDFORWARD SYSTEM
RANGEABILITY 250,000:1

is that of economical considerations. The costs of thermally controlling wastewater flows to optimize biological treatment would understandably be prohibitive. Most probably the benefits derived from automated temperature control would not justify the expenditure.

### 4.2.K. Monitoring and Control of Organic Loading to Microorganism Mass Ratio

The ratio of organic loading (food) to microorganism mass (F/M ratio) in the aeration basin will indirectly formulate the floc forming capabilities of the activated sludge mass in the final clarifier thereby controlling process efficiency.

The organic loading, or food fed to the microorganisms, may be determined by several direct or indirect methods. The most commonly used method of indirectly determining the total organic loading to the aeration basin merely consists of influent wastewater flow measurements. It should be remembered that influent flow measurements are only a good approximation of organic loading if the compositional characteristics of the wastewater stream are constant. Other more direct methodology for automatically determining organic loading may consist of:

1. Total oxygen demand analyses which quantitatively measure the amount of oxygen required to combust the impurities in an aqueous sample at 900°C. Results of TOD analyses for a number of different compounds indicate that the measured oxygen demand is usually closer to the theoretically calculated demand than is the case for chemical methods. This instrument permits the measurement of the oxygen demand for hydrogen, nitrogen, and sulfur in addition to carbon.

2. Total carbon analyzers which quantitatively measure the amount of carbon dioxide produced upon combustion of impurities at 950°C. Such instruments will include inorganic carbon interference in their results, therefore

background inorganic carbon interference must be determined using a total organic carbon analyzer in the laboratory. Total organic carbon data can then be correlated with BOD or COD data.

Microorganism mass returned to the aeration basin may be estimated indirectly using return sludge flow measurements or directly using mass return sludge flow measurements. Obviously the latter method is preferred.

Figure 4-22 depicts an automatically controlled F/M ratio in a treatment plant utilizing raw sewage flow as an indirect measure of F and return sludge flow as an indirect measure of M. As shown a magnetic flow meter monitors the return sludge flow and forwards this information to a ratio controller which also receives data regarding raw sewage flow. The ratio controller signals the butterfly valve to adjust the return sludge flow so as to maintain the desired influent flow/sludge flow ratio.

Figure 4-23 outlines an automated F/M control system utilizing raw sewage flow as an indirect measure of F and mass return sludge flow as a direct measure of M. This system is identical to the previous one except that a density detector transmitter is also installed on the return sludge line thereby enabling the ratio controller to control the influent flow/mass sludge flow ratio by means of signaling the butterfly valve.

Figure 4-24 shows a more elaborate control system in which the sludge level in the secondary clarifier is controlled in conjunction with the influent flow/mass sludge flow ratio. The only difference between this system and the previous one is the absorbance turbidimeter control of sludge depth in the secondary clarifier and the flow meter transmitter installed in the waste sludge flow to more efficiently control both return and waste sludge flows.

Optimum system control would consist of automatic TOD or TOC analyses coupled with mass return sludge flow analyses to more closely approach true F/M ratio control.

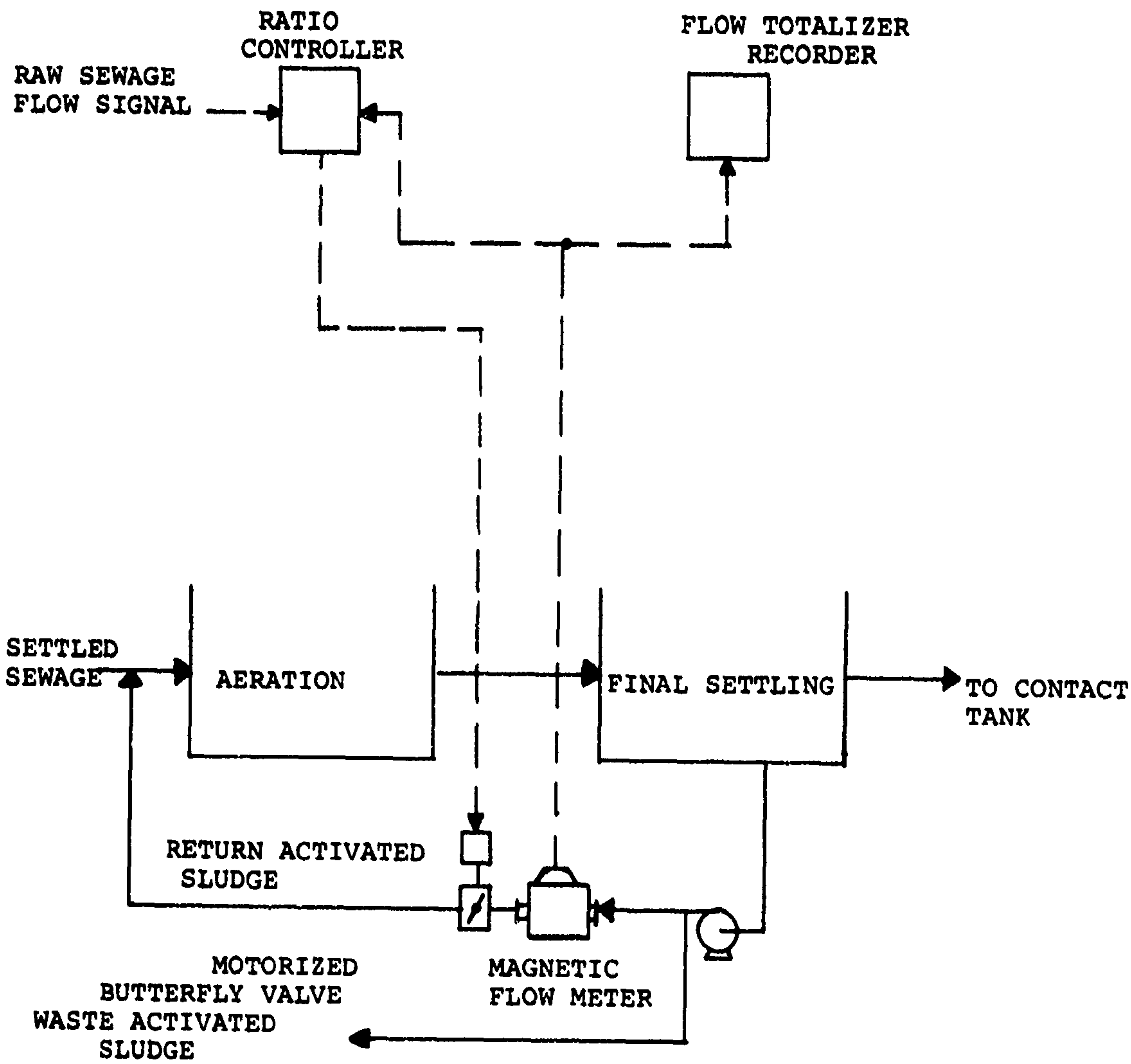



FIGURE 4-22

CONTROL OF RECYCLED ACTIVATED SLUDGE RATIOING
RAW SEWAGE FLOW AND RETURN SLUDGE FLOW

COURTESY OF FISCHER & PORTER CO.

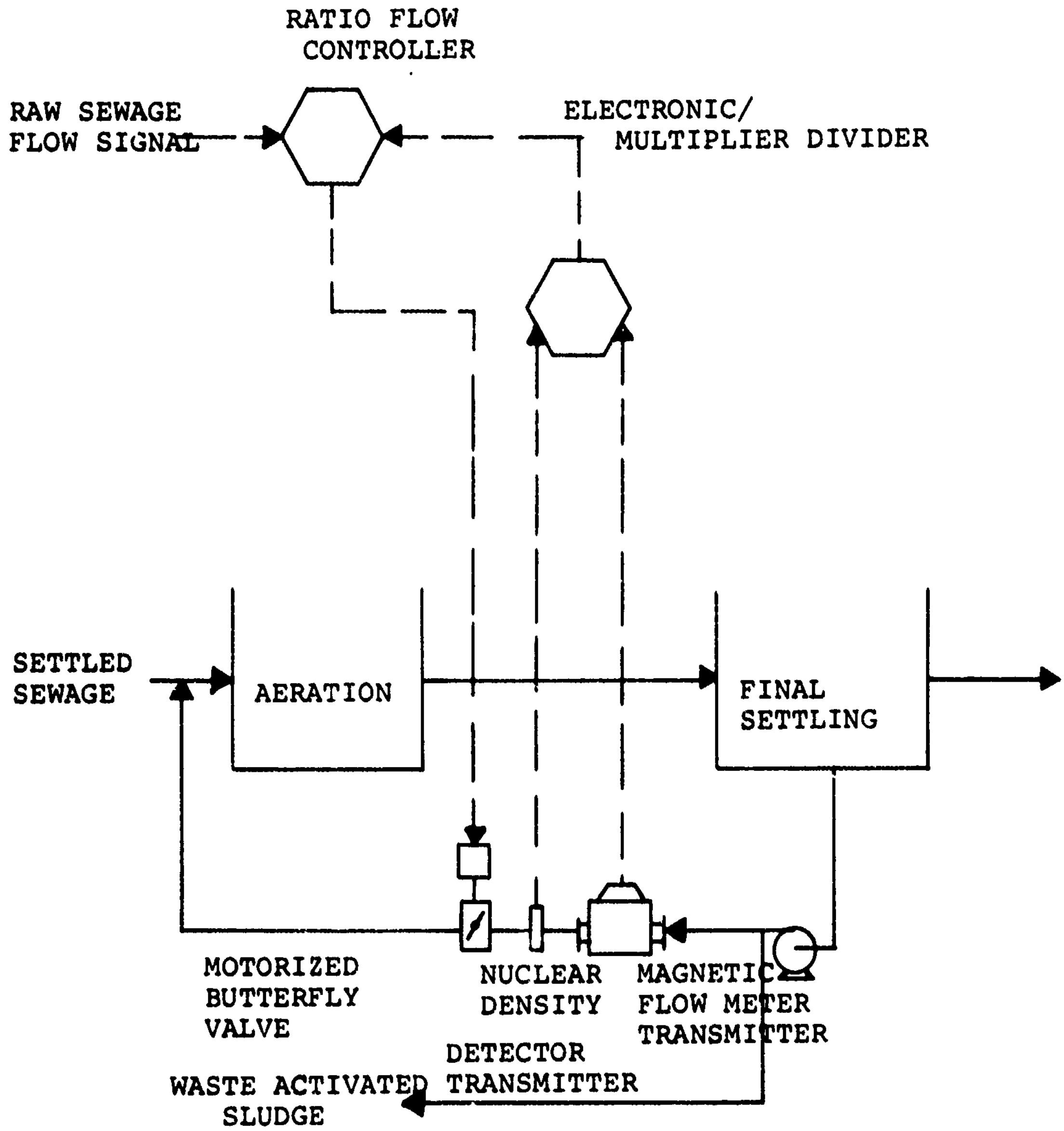



FIGURE 4-23

CONTROL OF RECYCLED ACTIVATED SLUDGE RATIOING RAW SEWAGE FLOW AND MASS RETURN SLUDGE FLOW

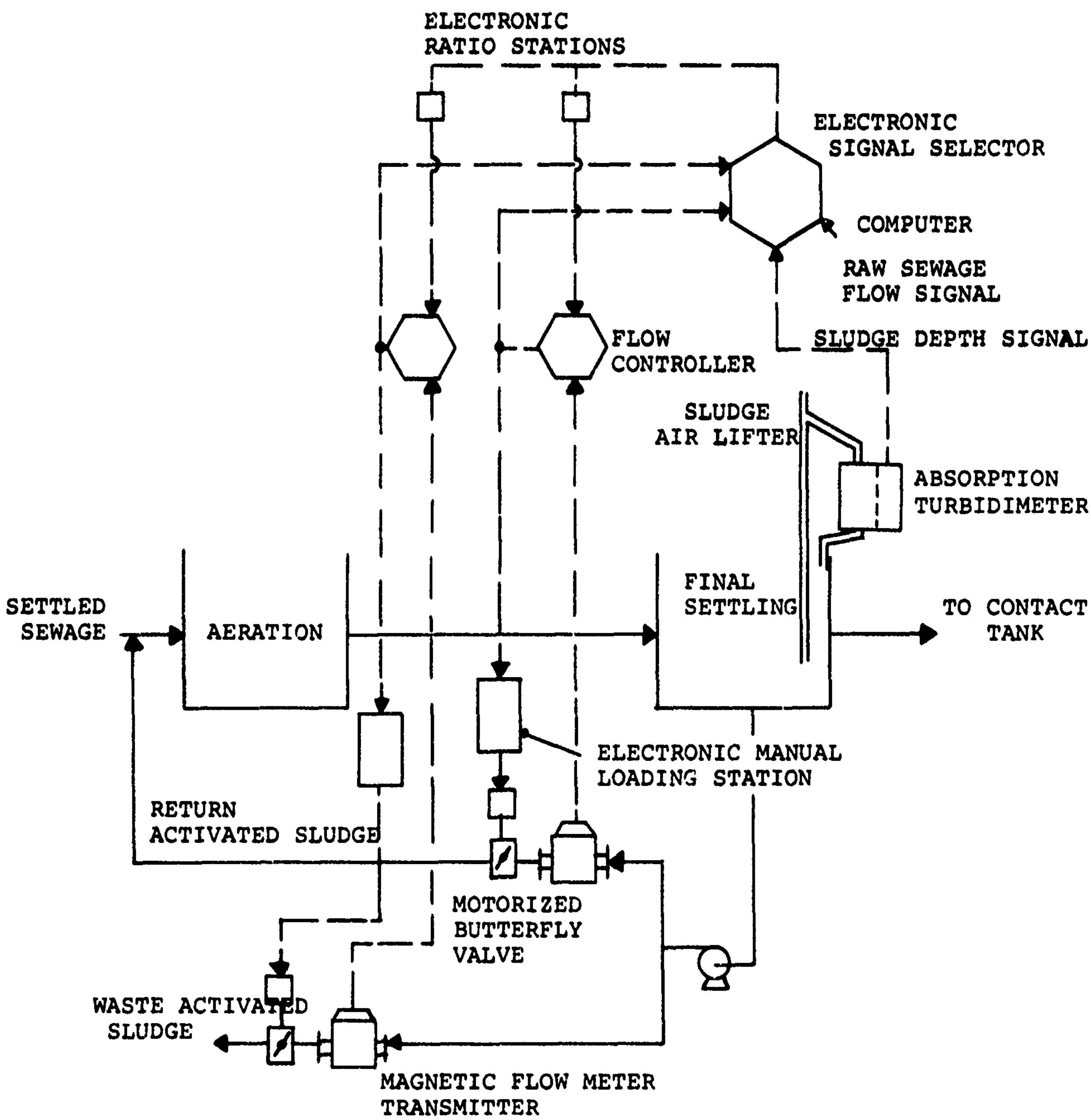



FIGURE 4-24

RETURN ACTIVATED SLUDGE FLOW CONTROL SYSTEM
UTILIZING SLUDGE DEPTH CONTROL

## 4.3 TRICKLING FILTERS

The trickling filter is currently the most widely used aerobic biological treatment system. Its treatment efficiency depends upon the metabolism of a microbial culture to oxidize organic material in the presence of oxygen. Trickling filters have been adequately described as merely a pile of rocks, or plastic media, over which organic wastes slowly trickle. The influent wastewater stream introduced onto the filter by either a fixed or rotary distributor which is either driven by an electric motor or hydraulic impulse. Wastewater is distributed at a uniform volume per unit of filter surface, flows by gravity over the media, and into an underdrain system. The trickling filter effluent is then collected and sent to a secondary clarifier (see Figure 4-25).

Filter media may consist of 1 to 4 inch diameter stones, slag, or plastic modular units. Bed depth usually may range between 3 and 40 feet, with 6 feet being the average. The underdrain system is usually constructed of vitrified clay block on a reinforced concrete floor and designed to allow for maximum outflow of liquid and inflow of air. The large masses of biological growth which drop from the filter media are separated from the effluent stream in the secondary clarifier. This separation accounts for approximately twenty percent of process efficiency.

The predominant class of microorganisms occurring in typical filter media include aerobic, facultative, and anaerobic bacteria. Aerobic bacteria are found on the upper media surfaces whereas the anaerobic bacteria predominate at the media-slime interface. The great majority of bacteria in the trickling filter are facultative in nature, living aerobically when dissolved oxygen is present and anaerobically when the oxygen is depleted. Fungi, algae, and protozoa are also present in the filter, but are usually predominated over by the bacterial population. Figure 4-26 illustrates the functioning of the microorganisms on the trickling filter media.

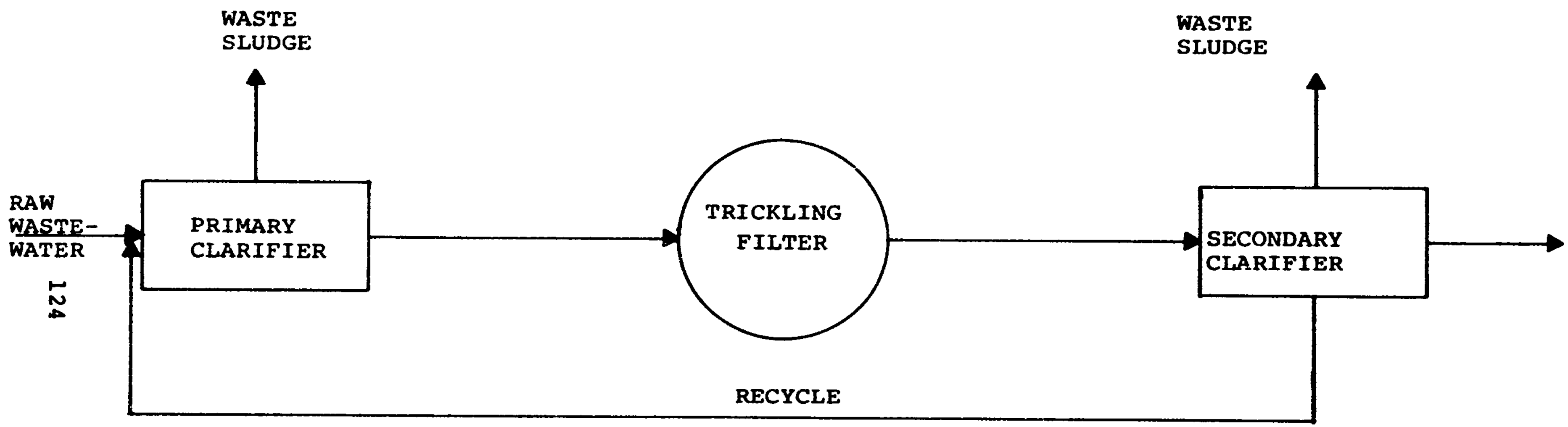



FIGURE 4-25

FLOW DIAGRAM OF TRICKLING FILTER TREATMENT PLANT

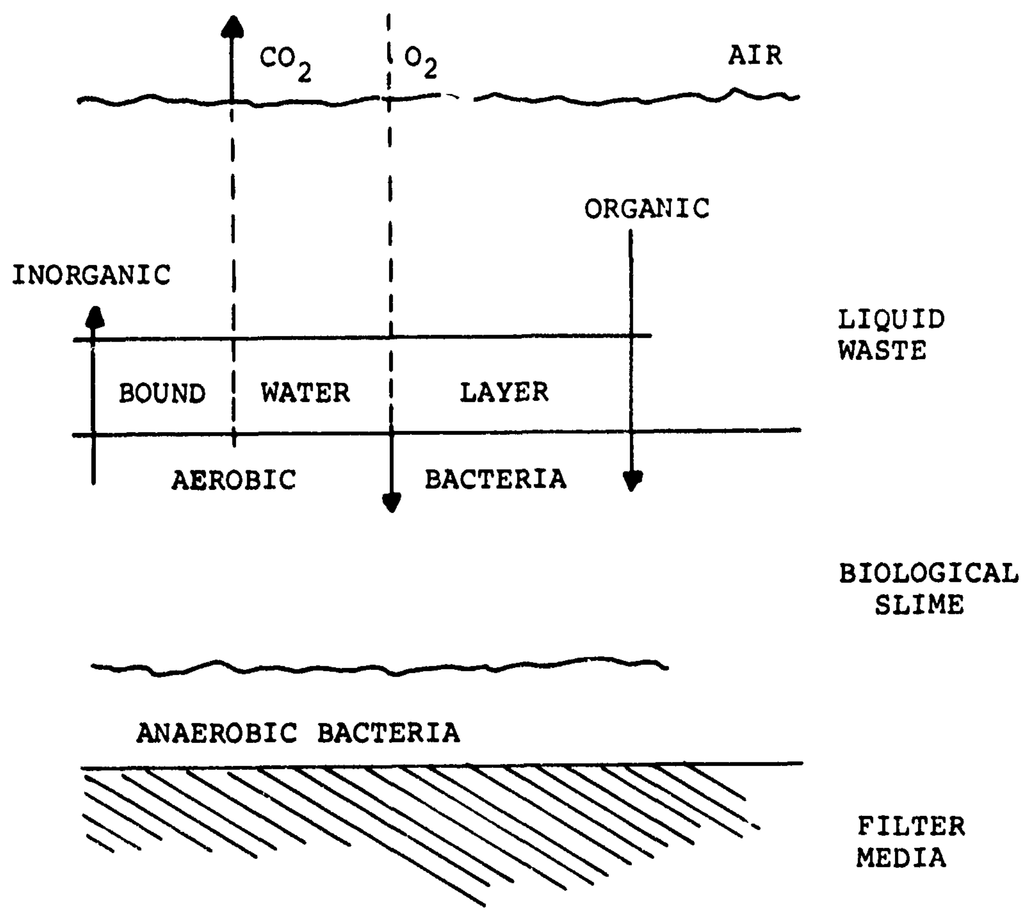



FIGURE 4-26

MICROBIAL ACTIVITY AT STONE-LIQUID INTERFACE IN A TRICKLING FILTER PLANT

Trickling filters are usually classified according to their loading rate:

1. A low-rate trickling filter possesses a hydraulic loading rate from 2 to 4 million gallons per acre per day (MGAD), an organic loading rate from 10 to 20 lb. of 5-day BOD per 1000 cubic feet of media, a BOD removal efficiency of about 85 percent, and a depth of approximately six feet.

2. A high-rate trickling filter possesses a hydraulic loading rate from 10 to 40 MGAD, an organic loading rate up to 90 lb. of 5-day BOD per 1000 cubic feet of media, a BOD removal efficiency of about 75 percent, and a depth of approximately six feet.

3. A super-rate trickling filter possesses a hydraulic loading rate up to 100 MGAD, an organic loading rate 100 lb. of 5-day BOD per 1000 cubic feet of media, a BOD removal efficiency of approximatley 90 percent, and a depth of up to 40 feet.

4.3.A Trickling Filter Control Parameters

The basic control parameters of trickling filter systems are essentially the same as those for activated sludge systems, that is, dissolved oxygen content, nutrients, hydrogen ion concentration (pH), temperature, and organic loading/microorganism mass (F/M) ratios. A detailed explanation of each parameter may be found in section 4.2.F.

4.3.B Automated Control of Trickling Filter Systems

A paucity of information exists regarding the state of the art of automated control of trickling filter systems. Very little, if any, automated control has been applied to trickling filters. Automated control of dissolved oxygen does not appear to be feasible in trickling filters. To date no dissolved oxygen control systems have been applied to operational trickling filters. Automated control of nutrients and hydrogen ion concentration, although feasible (see sections 4.2.H and 4.2.I), is seldom practiced. Automated control of temperature is not economically feasible either with trickling filters or activated sludge systems (see section 4.2.J).

Current state of the art of trickling filter plant automation consists largely of controlling return sludge flow and recirculated effluent flow. Return sludge flow is usually proportioned to influent wastewater flow. Recirculated flow, may originate either in the final effluent stream, the final clarifier, or the underflow from the trickling filter to the secondary clarifier. Recirculation provides the advantage of keeping reaction-type distributions in motion, filter media moist, and contact times with top film long. It also improves distribution, obstructs the entry and egress of filter flies, freshens incoming and applied sewage, reduces filter chilling, and reduces the time variation of passage through the secondary clarifier. Although recirculation schemes do provide the above mentioned process improvements, the major reason for recirculating flow in trickling filters is the equalization of organic loading and unloading, or the indirect control of the F/M ratio. Recirculation rates may be held constant or be adjustable to more than a single value, however, in most automated recirculation processes the recirculated flow rate is proportioned to raw wastewater flow.

Since the microbial mass adhering to the trickling filter media more or less fixes the microorganisms mass (M) portion of the F/M ratio, the only method by which this ratio can be controlled is through the control of organic loading (F). As previously stated (see section 4.2.K) raw wastewater flow may be considered an indirect measure of organic loading (F) assuming uniform compositional characteristics of the wastewater stream. Automated control of effluent recirculation will therefore enable the plant operator to control the total loading rate (F) by regulating the ratio between recirculated and raw wastewater flows. Although other more direct methods exist for automatically determining and controlling organic loading rates (see section 4.2.K), raw wastewater-recirculated flow ratioing is almost exclusively used in current trickling filter automation.

Figure 4-27 depicts an automatically controlled F/M ratio in a trickling filter plant utilizing a desired raw wastewater-recirculated flow ratio. As shown a magnetic flowmeter monitors the recirculated flow and forwards this information to a ratio controller which also receives raw wastewater flow data. The ratio controller signals the butterfly valve to adjust the recirculated flow so as to maintain the desired raw wastewater recirculated flow ratio.

Figure 4-28 illustrates a more elaborate control system in which recirculated flow from the trickling filter is accumulated in a wet well and recirculated at the desired rate by means of an air pressure level variable speed pump regulating system. In this system an air pressure level device signals the control station which adjusts the variable speed pumps so as to maintain the desired recirculation flow rate.

## 4.4 OXIDATION PONDS

Wastewater stabilization ponds are artificial earthwork structures open to the sun and air which formulate the resources required by the pond ecosystem to affect satisfactory treatment. Stabilization ponds can be broadly classified as:

1. Aerobic - in which organic material is degraded through the symbiotic relationship existing between aerobic microbial populations and algae. Dissolved oxygen may be provided by algal photosynthetic reactions, gas transfer at the pond surface and mechanical or diffused-air aeration.

2. Anaerobic - in which organic material is degraded by microbial populations in the continuous absence of oxygen.

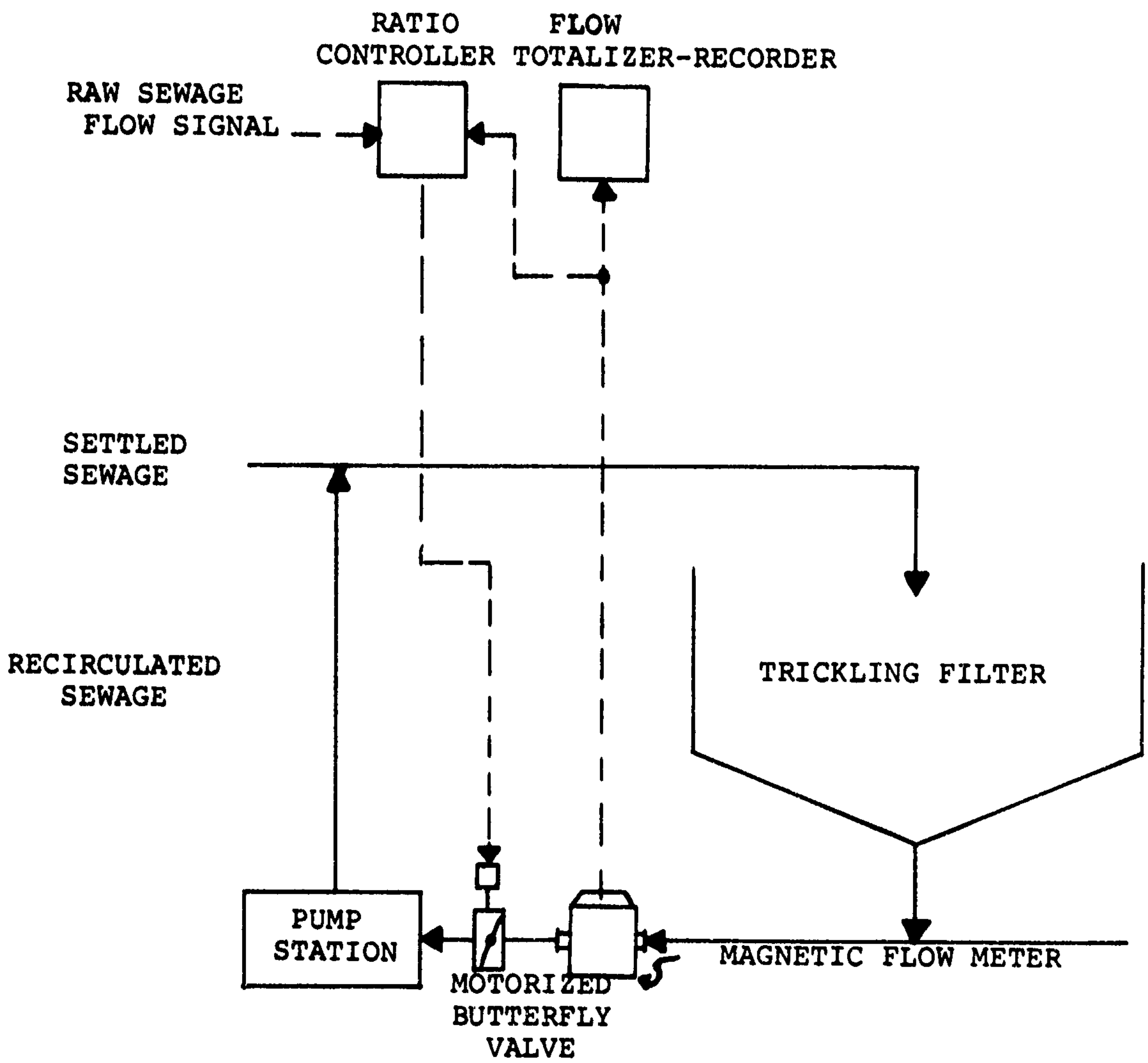



FIGURE 4-27

RECIRCULATED SEWAGE FLOW CONTROL
FOR TRICKLING FILTERS

COURTESY OF FISCHER & PORTER, CO.

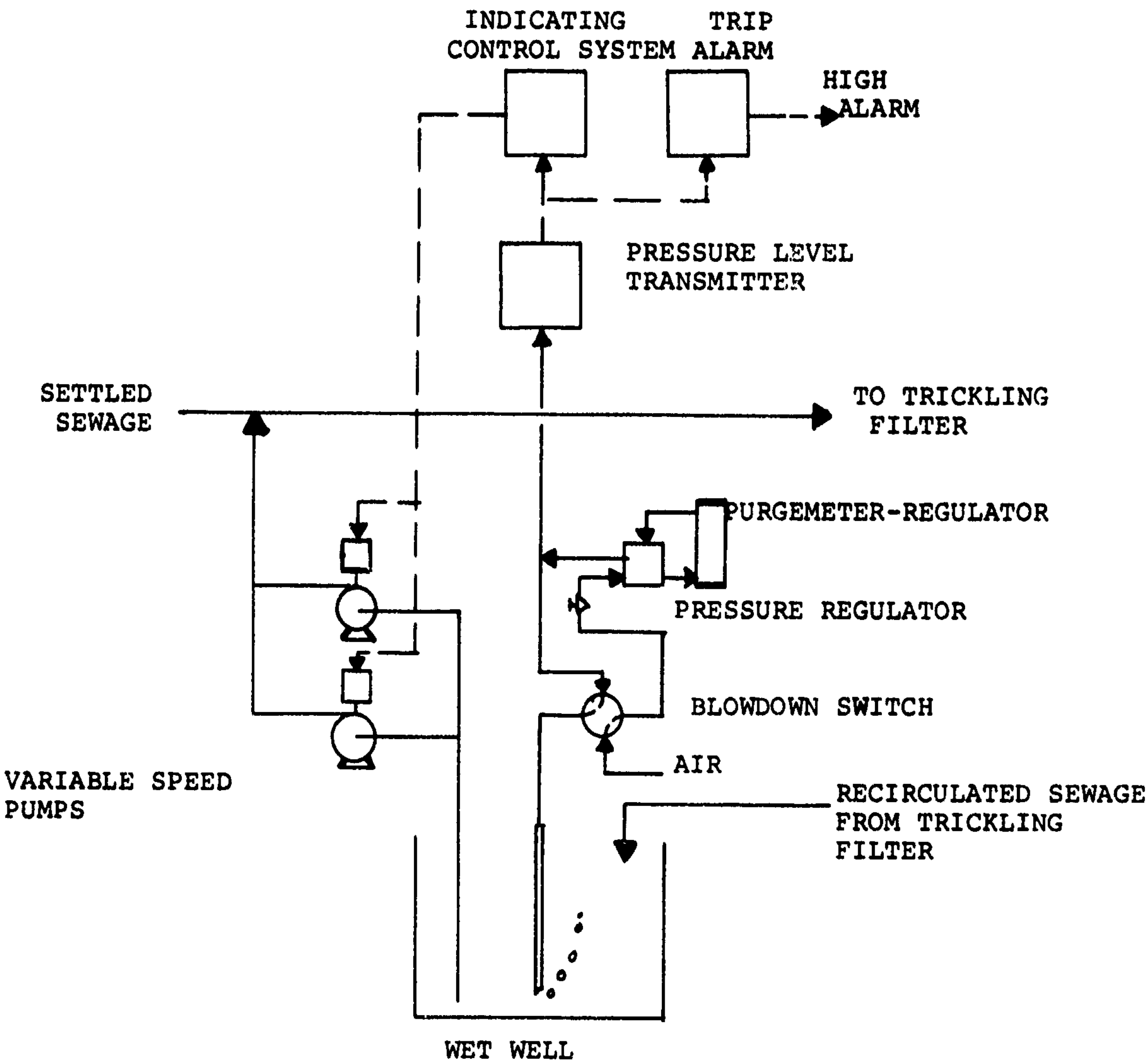



FIGURE 4-28

RECIRCULATED SEWAGE PUMP CONTROL
FOR TRICKLING FILTERS

COURTESY OF FISCHER & PORTER CO.

3. Facultative - in which organic material is degraded by facultative microbial populations which function aerobically or anaerobically depending on system conditions.

Wastewater stabilization ponds are generally classified according to their influent quality and treatment objectives as follows:

1. Stabilization ponds - for complete treatment of raw wastewater.

2. Oxidation ponds - for secondary treatment of settled wastewater.

3. Anaerobic ponds - introduced in advance of aerobic ones to control odor problems.

4. Polishing ponds - for nutrient removal to prevent eutrophication.

For the purposes of this investigation, discussion will be confined to oxidation ponds.

Ecologically speaking the plant and animal composition of oxidation ponds is both plentiful and varied. Organic stabilization is performed by aerobic bacteria which supply carbon dioxide to algal growths. Algal blooms in turn help to keep the pond aerobic through photosynthetic oxygen release. Pond ecology is influenced primarily by organic loading and depth. Most ponds receive settleable solids and produce settleable biomass consisting largely of dead microbial cells. Thick accumulations of bottom deposits may produce anaerobic conditions with organic digestion similar to that occurring in anaerobic sludge digestion tanks. Settleable solids will therefore be attacked first in the benthal environment by acid-forming bacteria with the resultant production of organic acids which may be utilized by either methane forming bacteria or algae present in overlying waters. Anaerobic gasification releases carbon dioxide to the overlying water and the algae, and methane gas to the atmosphere.

General oxidation pond design criteria include organic loading rates of 40 to 50 lb. of BOD daily per acre of surface area, detention periods of about 30 days, and pond depths of 3 to 4 feet.

Oxidation ponds are utilized where land is inexpensive and population densities are small. Pond facilities should be located at least a quarter of a mile from the nearest resident on relatively impervious soil thereby minimizing the possibility of groundwater contamination.

### 4.4.A Oxidation Pond Control Parameters

Basic oxidation pond control parameters closely parallel those discussed previously with regard to activated sludge and trickling filter processes. These parameters include dissolved oxygen, nutrients, hydrogen ion concentration (pH), temperature, and organic loading/microorganism mass (F/M) ratios. A thorough discussion of the above mentioned control parameters may be found in section 4.2.F.

### 4.4.B Automated Control of Oxidation Ponds

Automated control of oxidation pond systems is currently nonexistent. It would appear that automatic control of oxidation pond dissolved oxygen levels would be an area worthy of investigation. Such an automated process would parallel one described in section 4.2.G and consist of dissolved oxygen monitoring probes and indicator-recorder-controllers which would regulate the oxygen transfer capacity of mechanical aerators. Such automation would provide exceptional improvements in oxidation pond effluent quality. At present effluent quality control is imprecise at best.

## 4.5 THE USE OF HIGH PURITY OXYGEN AERATION IN THE CONVENTIONAL ACTIVATED SLUDGE PROCESS

The potential for the use of high purity gaseous oxygen in biological wastewater treatment processes, and by the activated sludge process in particular, has been the subject of a number of technical and economic studies published over a period of more than twenty years. Pure oxygen systems can be economically competitive with air aeration if a means is available so that oxygen in a relatively pure state can be efficiently and effectively dissolved in mixed-liquor.

Investigators have reported constantly superior treatment performance with pure oxygen systems in direct comparison to parallel air aeration systems. Oxygenation power requirements appear to be minimal. High treatment efficiency has been accomplished at a cost of only 0.03 to 0.14 HP/1000 gallons of wastewater treated. Biomass generated in oxygenation systems appears to have maximum flocculation characteristics resulting in sludge volume indices as low as 36. Evaluation of oxygenation system treatment costs in comparison to conventional air aeration reveals significant potential savings attributable to high purity oxygen use. These savings are the result of reduced aeration tank volume requirements for equivalent treatment and a reduced production of waste activated sludge. Total treatment savings amount to over 3 cents/1000 gallons for a 10 MGD plant. It would appear that future expansion of existing wastewater treatment plants might be accomplished at a reduced cost through utilization of pure oxygen systems.

Automation of such treatment facilities would basically be identical to that outlined previously for conventional air aeration systems with the major exception that dissolved oxygen concentrations in mixed liquor would be more precisely controlled.

CHAPTER 5

# SLUDGE HANDLING AND DISPOSAL

## 5.1 CHARACTERISTICS OF SLUDGE

Many people have made the statement that sludge handling and disposal is the most difficult part of wastewater treatment and it is well to remember that it is often the most costly. This is of particular consequence considering that the total gallons of sludge produced is frequently less than 1% of the total gallons of wastewater collected in treatment. Sludge may be defined as a semi-liquid paste having a total solids concentration of at least 2500 ppm. It flows, it can be pumped and it exhibits hindered settling characteristics in gravity settling basins.

Sludge handling and disposal includes:

1. Collection of the sludge.

2. Transportation of the sludge.

3. Processing the sludge to convert it to a form suitable for disposal.

4. Final disposal of the sludge.

Final disposal is accomplished only when the material has been entirely removed from the treatment plant in a manner that is sanitary, permanent and satisfactory to all parties concerned.

All of the suspended solids and some of the organic dissolved solids that come to a sewage treatment plant, except the grit and the relatively small portion of the effluent, must be cared for as sludge in some stage of the treatment. Final sludge disposal is therefore an important phase of sewage treatment and choice of a treatment method for the sewage may hinge upon the expected presence or absence of difficulties in handling and disposal of the sludge.

Sludge consists of suspended sewage solids having a specific gravity of 1.2 combined with water in varying amounts. The amount of suspended solids in a domestic sewage should be obtained by tests for any sewage involved in a problem, but if estimation is necessary, it can be assumed that the per capita production of suspended solids will be about 0.20 pounds per capita daily. If there is a moderate amount of industrial wastes, this may rise to 0.22 pounds and if it is a combined sewage with considerable industrial wastes, it may be 0.25 pounds.

The dry weight of waste solids is the weight of solids settleable at the time of solids separation or phased transfer from the suspending water. Included are:

1. Solids naturally present and settleable in waters and wastewaters.

2. Additives, chemical coagulants, and precipitants, for instance, converting unwanted non-settleable solids into settled solids.

3. Sluffed biological films and wasted biological or other bio-masses generated by living organisms from dispersed and dissolved nutrient organic matter during wastewater treatment.

Some common properties of sludges are deserving of special consideration or determination. Among them are:

1. Moisture-to-weight-to-volume relationships.

2. Density and other flow characteristics.

3. Response to concentration or thickening and to filtration.

4. Fuel value.

5. Digestability.

6. Fertilizer value.

Primary sludge is frequently known as raw sludge and is produced by primary settling tanks. It has an offensive fecal odor and its water content will be 94% to 96%; volatile matter is usually about 70% of the dry solids; and it will not readily dry on beds. These fresh solids from primary treatment contain most of the settleable solids and about 60% of the suspended solids in the raw wastewater. The disposal of excess activated sludge is a serious problem in some plants. Its moisture content will vary from 98.5% to 99.5% although it is sometimes even higher. High rate plants will produce thicker sludges from 95% to 97.5% moisture. Volatile solids will be from 68% to 70% of the dry solids.

Excess activated sludge does not give up its moisture readily and accordingly it is not easily dried on beds. The recovery of excess sludge in secondary settling units is from 80% to 90% of the rated nonsettleable suspended solids load. Trickling filter sludge, sometimes called humus, is the sludge that settles in the sedimentation tanks that clarify trickling filter effluent. Volatile solids are widely varying and range from 45% to 70%; higher values may be expected in high rate filter plants. The average moisture content of the sludge is 96% to 97%. Most of the dissolved organic matter and many of the otherwise nonsettleable solids in wastewaters which are applied to trickling filters are rendered settleable by adsorption and biological flocculation on the trickling filter film.

## 5.2 PROCESS DESCRIPTION

Sedimentation is generally described as incorporating three steps: clarification, zone settling, and compression. Factors that are thought to influence the concentration of settled sludge and sedimentation basins include:

1. Settled solids characteristics - their density, shape, flocculant structure, viscosity, percentage of volatiles, and electrostatic charge.

2. Solids concentration of the original suspension.

3. The depth and surface area of the sludge blanket.

4. The sludge detention time.

5. Structural modifications of the sludge blanket by pressure, vibrations and mechanical action.

The first two factors are independent of the design of the sedimentation tank but the next three are dependent on the shape and other design features.

Secondary sedimentation normally captures 50% to 60% of the non-settleable suspended solids reaching the low rate filters, whereas capture values for high rate filters are 80% to 90%. The trickling filter humus is generally added to primary solids for digestion.

The characteristics of the domestic sewage and the type of treatment received has a great influence on the buildup of solids. The solids from the domestic sewage are in two major forms: suspended and soluble. The suspended solids fraction, 60% settleable, and 40% colloidal, equals 0.20 to 0.25 pounds per capita per day, and the soluble fraction equals 0.20 to 0.35 pounds per capita per day. Thus the total dry solids in domestic sewage ranges from 0.5 to 0.6 pounds per capita per day.

The accepted procedure for the disposal of solids wastes has been direct or indirect disposal to the ground. Such practices are becoming less acceptable for a variety of reasons and presently pressures are building up for complete disposal of solids wastes. Sludge is considered a liability rather than an asset in waste management. There is no known technique for making a profit on its collection or treatment. A system that is acceptable to all parties and the most economical is generally preferred.

The wastewater solids requiring treatment and disposal first must be collected in some kind of basin or screening mechanism. In sewage treatment plants most of the solids are separated in primary sedimentation basins from the liquid transporting them. In addition to raw wastes, disintegrated screenings and secondary sludges from the biological stage of the treatment process may be settled in primary sedimentation basins. The secondary or biological sludges may also be captured in final or secondary sedimentation tanks.

Flotation rather than sedimentation is often prescribed for removing certain industrial wastewater solids but it is rarely used for clarifying raw sewage. The design and operation of sedimentaion basins has emphasized BOD and suspended solids removal rather than the production of the thickest and freshest sludge possible.

Sludge thickening is usually considered to be the second function of settling tanks. It is desirable to produce the freshest and most concentrated sludge possible (where digesters are utilized) for the following reasons:

1. It saves pumping and digester capacity.

2. It reduces the heat requirement for digester.

3. It saves chemicals and operating time when dewatering solids.

## 5.3 SLUDGE BLENDING - MONITORING AND CONTROL

As in all continuous processes, the uniformity of the feed greatly influences the efficiency of the entire process chain. Under present conditions, thickening and other pretreatment aspects of sludge handling generally rely on the mixing of primary and waste activated sludge or trickling filter humus. These two different types of sludges vary widely in their dewatering, biodegradability, and incineration characteristics. Therefore, the more consistently these sludges may be blended, the more predictable will be their handling and reaction characteristics. One of the major parameters for which sludge handling is characterized is the total solids content. After thickening has occurred and prior to further sludge processing steps it is possible to control the total weight of sludge that proceeds to subsequent steps. Two parameters which can be remotely monitored are flow and sludge density. The electronic multiplication of these two parameters is the mass quantity of sludge passing through the pipe. This concept has been discussed previously in Section 3.3.1.

Utilizing the data from both the magnetic flow meter and the nuclear density detector it is possible for an analog computing device to electronically multiply these values to arrive at the quantity of sludge which is being transported.

## 5.4 SLUDGE THICKENING

Sludge thickening is the concentration of primary sludges and sludges from secondary processes in a thickening tank. Thickening helps to reduce the volume of liquid sludge to be handled in the subsequent processes. Reduction of the volume of sludge brings about savings due to the reduction of the plant size, labor, power, and chemicals. In addition, the treatment of sludge by thickening smooths out fluctuations in quantity and quality.

The degree of concentration that can be expected depends upon the various thickening processes and several other variables. The method of wastewater treatment is very important, as is the initial composition of the raw wastes. The difference between biological sludge and raw sewage provides a good example of the variations that can result from different treatment methods. Biological sludges are bulky and concentrate to a lesser extent than raw primary sludge. Important characteristics of the sludge to be thickened are the initial concentration, the density of the particles, their size, and shape. The temperature and age of sludge, and the ratio of organics to inorganics are also important factors determining the final sludge concentration.

Sludge thickening is accomplished in one of three processes:

1. Gravity thickening

2. Flotation

3. Centrifugation

5.4.A Gravity Thickening

Even though flotation and centrifugation produce a higher percentage of solids recovery than gravity thickening, the cost is comparatively expensive. Gravity thickening is the most common type of sludge concentration. Even though it does not produce as high a solids concentration as other thickening processes, it is a simple and inexpensive method. Thickening is generally achieved in two ways. One method is to provide a deep primary clarifier where primary solids are collected and secondary sludge is recycled and then settled. As far as fixed equipment costs are concerned this is the least expensive method. Another method is to provide a separate thickener to collect the primary and secondary sludges. This is the Densludge system (a trademark of Dorr-Oliver). Thickening in these units can produce a more concentrated and thicker sludge than in the initial wastewater clarifier. Sludge concentration becomes the primary objective, and overhead clarity assumes a secondary role. The situation is in reverse of sedimentation-clarification. This method generally includes cyclones for grit removal and a sludge disintegrater to insure uniform sludge consistency.

Since fresh sludge is easier to handle in later process steps, the two methods briefly described above for gravity thickening have been designed towards that end. The Densludge system involves continuously pumping low volumes of dilute, relatively fresh sludge from the sedimentation basin to separate thickening tanks. Better efficiencies of primary sedimentation tanks are said to be possible when the sludge is pumped continuously at a low rate. Use of a separate thickener allows better control of the sludge. Its operation has little effect on the clarification step. Most wastewater treatment plants are designed in accordance with the second school of thought which holds that thickening as well as clarification should be attempted in sedimentation basins. The usual basin design depends on optimizing the removal of BOD and suspended solids from the wastewater. Designs are available, however, that attempt to produce above average sludge thickening by including special equipment.

One manufacturer accomplished this by placing a circular sludge hopper 1/3 to 1/2 the diameter of the circular sedimentation tank at the bottom of the tank (see Figure 3-10). Theoretically, clarification occurs in the upper part of the tank and sludge thickening at the bottom. The hopper is provided with pickets for slow agitation of the sludge. Provision is made for adding aerated plant effluent or chlorine to the sludge blanket to prevent sepsis.

Sedimentation tank modifications which thicken sludge to a greater degree than is possible with the conventional basins make these tanks more expensive to construct. Recalling that sedimentation is defined as the removal of suspended particles heavier than water by gravitational settling, many of the recommended parameters for efficient suspended solids settling will also benefit sludge thickening. These parameters include the basin depth and shape, sludge detention periods, type of baffeling utilized, and operating conditions.

As will be noticed in Figure 3-10, the trade name that EIMCO uses for its thickening pickets in its combination clarifier-thickener, are called "thixo posts". Thixo is apparently derived from the word "thixotropic". Many wastewater sludges are non-Newtonian fluids with plastic rather than viscous properties, i.e., thixotropic, where flow resistance is a function of concentration. Under these conditions the sludge's plastic properties change during stirring and turbulence.

If solids are uniformly dispersed and sufficiently concentrated, settling is hindered. Sludges build up from the bottom and are compressed under their own mounting weight. So long as the solids remain in suspension the settling and building proceed at a uniform rate. A shift to continuous inflow, outflow, and underflow (solids or sludge withdrawal) does not change the fundamental batch relationships provided the surface area of the vessel is large enough to keep the rate of liquid displacement less than the hindered settling velocity.

Sludge blanket thickness in a thickener is an important parameter in that it affects the ultimate solids concentration. Sludge blanket depths beyond three feet do not seem to increase the solids concentration, whereas it is known that solids concentration decreases as the depth of the compression zone increases. This may be due to the increase in resistance to the flow of water in the sludge blanket. Further, sludge at greater depths causes the sludge blanket to become septic which produces gas, causing the sludge to bulk and rise to the surface.

5.4.B Automatic Control of Gravity Thickening

Anaerobic conditions in gravity thickening basins can be minimized by the addition of aerated effluent, dilute biological sludges or chlorine and by proper sludge pumping procedures. These control parameters, plus the one previously mentioned, allow sludge treatment to be controlled by various means of remote instrumentation. Sepsis can be prevented by the control of dissolved oxygen. Dissolved oxygen can be monitored by any of several D.O. probes now available on the market. The dissolved oxygen concentration as determined by the probe is relayed to an indicator-controller which then activates a pump control system for recycling aerated plant effluent so that it may mix in the thickening basin. Since chlorine has also been used to control sepsis, as an alternative it should be possible to monitor ORP instead of D.O. Once operating experience has led to correlations between ORP and the tendency for sludge to bulk, it is possible to control the addition of chlorine to either fresh sludge or recycled sludge.

Since it is very desirable to control the depth of sludge beds in clarifiers and thickeners, two automatic methods have been developed to aid in this process. Both methods rely upon photoelectric detectors, but one is active, the other passive. In the active system, a sample stream is air lifted from a fixed depth withi. the settling tank. The sample then passes through a falling stream turbidimeter (manufactured by Hach Chemical Company) where an approximation of suspended solids is made (see Figure 5-1). In this turbidimeter the intensity of a transmitted light is inversely proportional to the solids concentration. When the solids concentration exceeds a set point on an accompanying controller, a valve controlling the rate of return for activated sludge is activated to allow increased sludge removal. When the desired sludge level is attained, i.e. the turbidimeter detects a paucity of solids, the valve is repositioned to decrease the rate of activated sludge return.

The second sludge depth detector is much more passive in nature. As illustrated in Figure 5-2, this sludge level control system, the sensing probe is immersed in the settling tank. The probe contains an infrared diode light source and a photocell sensor mounted facing each other and separated by an open gap. When the probe is installed in the tank liquid, the photocell is illuminated by the infrared diode. Any sludge particles in the water will absorb light, decreasing the amount that reaches the photocell. As with the falling stream turbidimeter, the amount of light that reaches the photocell decreases exponentially with the concentration based on response to activated sludge in the final clarifier.

As the sludge level increases and blocks light from the diode, the photocell resistance will increase sharply. This starts a timer which in turn actuates the sludge pump or other device. The pump remains activated until the timer reaches the end of its preset interval. The purpose of the timer

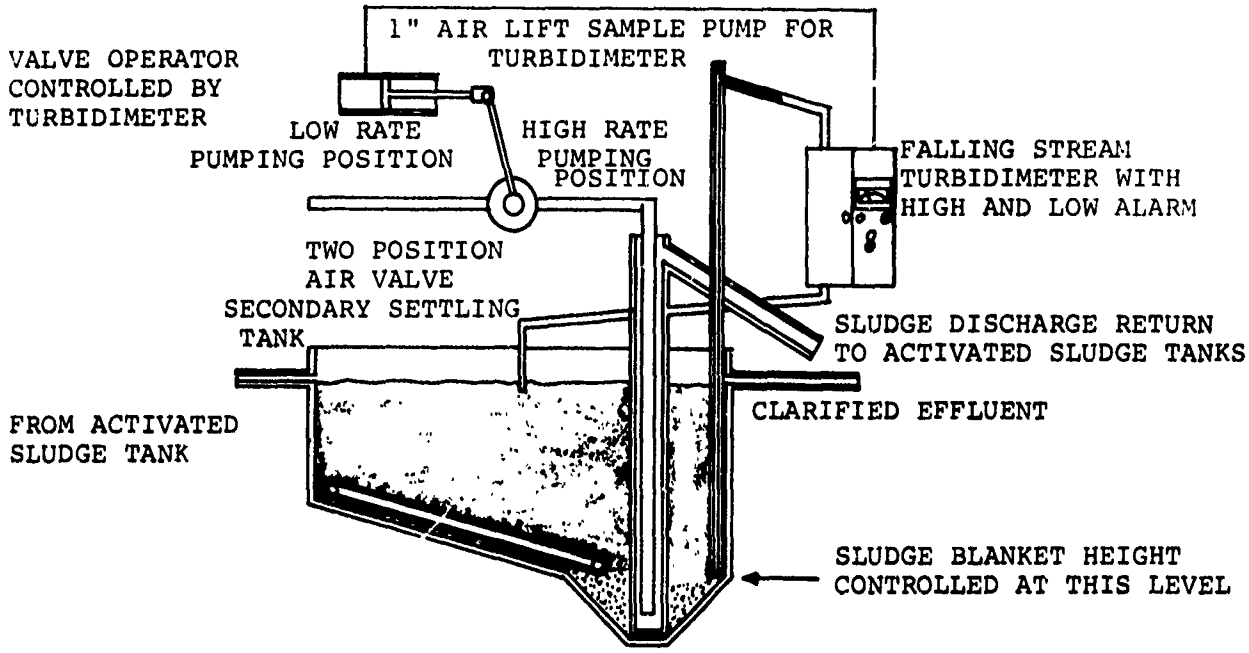



FIGURE 5-1

FALLING STREAM TURBIDIMETER FOR SLUDGE BLANKET CONTROL

COURTESY OF HACH CHEMICAL CO.

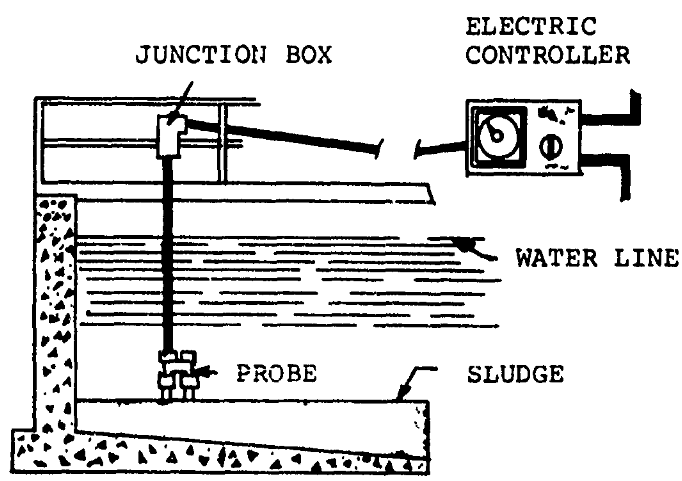



FIGURE 5-2

INFRARED SLUDGE DEPTH DETECTOR

circuit is to prevent frequent on-off operation of the pump or valve which could cause undue wear to the mechanical components. If at the end of the timing cycle the control relay is still energized (sludge level still at probe), the pump will stay on until the control relay releases. Otherwise, if the control relay is already de-energized (sludge level has dropped below probe) at the end of the timing cycle, the pump will be shut off and the timer will be reset.

A time-delay relay is incorporated in the circuitry to prevent temperary fluctuations in the sludge level from activating or de-activating the sludge pump.

Keene Corporation, Water Pollution Control Division, and Biospherics, Inc., market the above system for a net price of $1200.

### 5.4.C. Monitoring of Sludge Flow

While we have discussed the methods of controlling sludge bed depth, we have disregarded where the sludge goes once it leaves the clarifier or thickening tank. Whether the sludge goes directly to a digester (or other means of disposal), or to a thickener from a clarifier, it is necessary to monitor the volume of sludge that is pumped in order to determine solids and volume loadings on the subsequent sludge disposal processes. Figures 5-3 and 5-4 are shown as examples of how magnetic flow meters could be used in open loops to accomplish the monitoring of waste sludge flow from an activated sludge system or a trickling filter plant. Venturi type flow tubes have also been successfully applied to this same function, but with some increase in maintenance problems.

### 5.4.D. Disadvantages and Economics of Gravity Thickeners

Gravity thickening has important advantages and possible disadvantages. First, thickening tanks must be well operated or odors will develop. Septic, bulky sludge will form, resist compaction and float to the

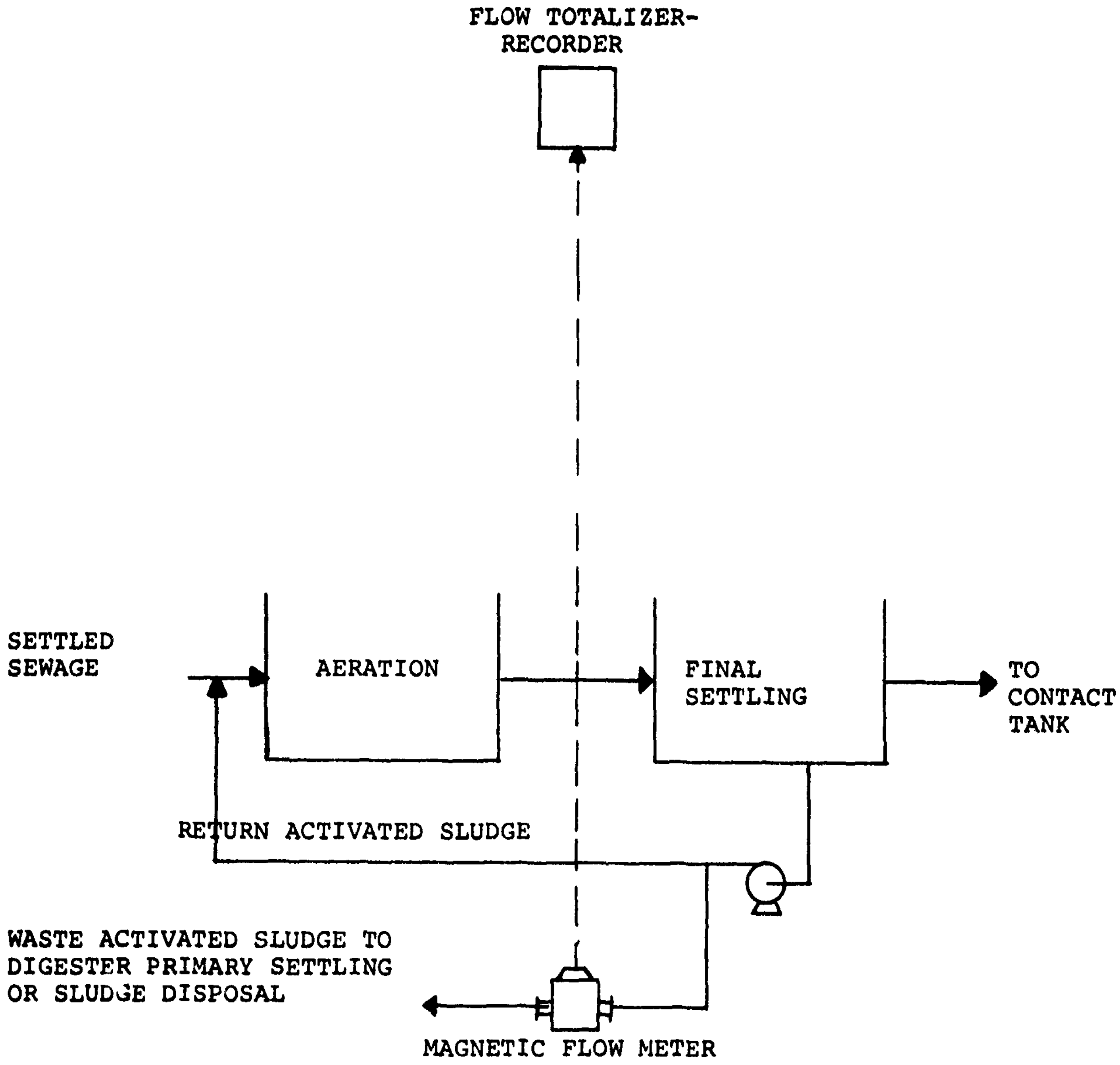



FIGURE 5-3

WASTE ACTIVATED SLUDGE FLOW

COURTESY FO FISCHER & PORTER CO.

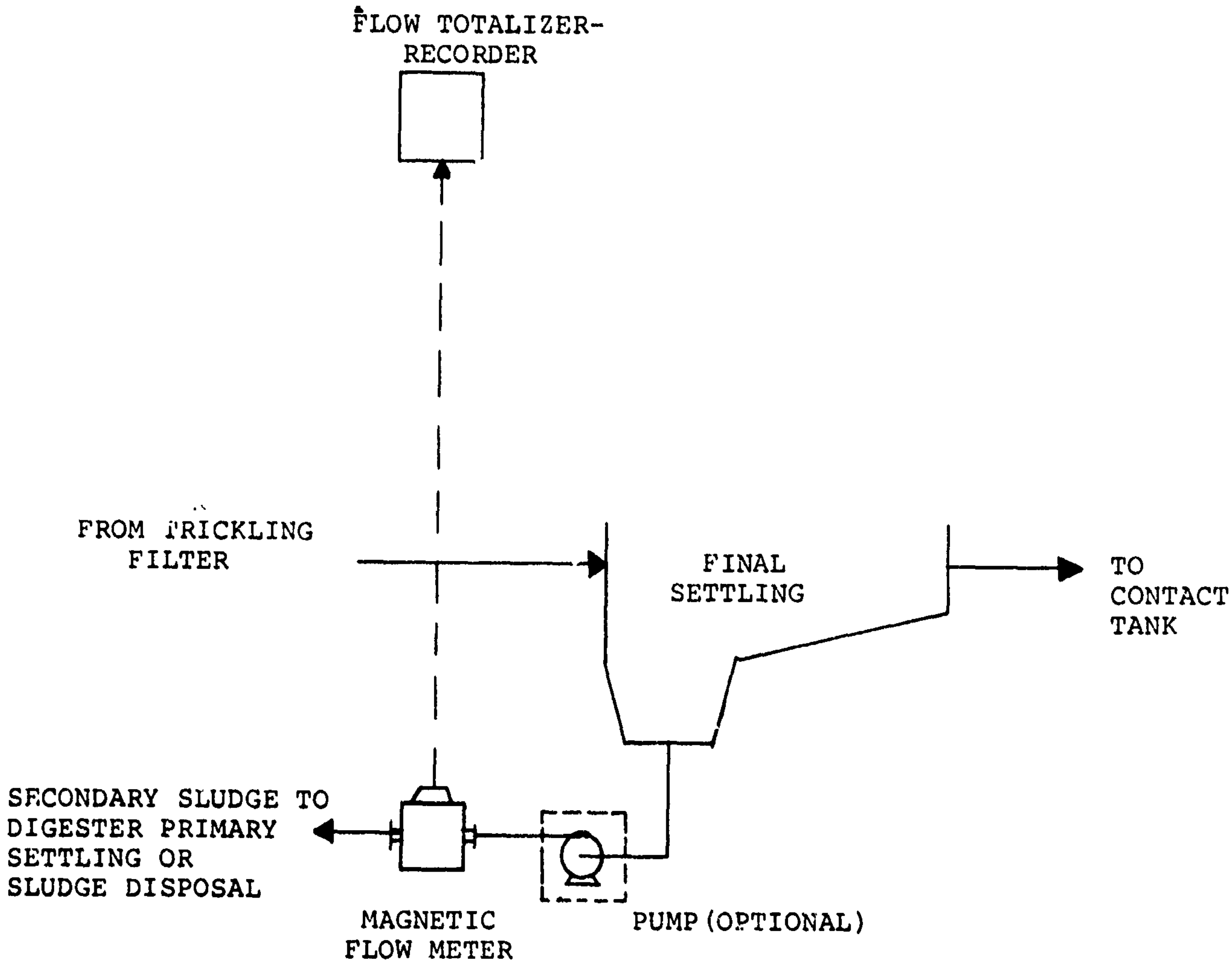



FIGURE 5-4

SECONDARY SLUDGE FLOW
TRICKLING FILTER

COURTESY OF FISCHER & PORTER CO.

surface of the tanks. The entire treatment plant efficiency could be impaired by the recycle of the thickener overflow containing a high concentration of BOD and suspended solids. Another disadvantage is the capital cost of gravity thickening units. It is substantial but often justifiable because of other process cost savings.

The total operating cost (capital and operating) for gravity thickening varies from $1.30 to $5.00 per ton of dry solids, depending on the size of the plant and local conditions. Gravity thickening has a future in the handling of wastewater solids and offers a good way to thicken sludge at low operating costs.

### 5.4.E. Air Flotation

Flotation is used for the removal of suspended solids from wastes and for the separation and concentration of sludges. The waste flow or a portion of clarified effluent is pressurized and this air-liquid mixture is released to atmospheric pressure in the flotation unit causing minute air bubbles to be released from solution. The sludge flocs and the suspended solids are floated by these minute air bubbles which attach themselves to and become enmeshed in the floc particles. The air-solids mixture rises to the surface where it is skimmed off. The clarified liquid exits the flotation tank over a weir. In some instances there will be sludge particles that will not rise to the surface but will fall as in an ordinary clarifier. In these cases settled sludge is usually removed to a sludge hopper by flights of sludge scrapers. Part of the clarified liquid may be recycled back to the pressure chamber.

When flocculant sludges are to be clarified, pressurized recycle will usually yield a superior effluent quality since the flocs are pressurized prior to their entrance into the flotation tank, and are not subject to shearing stresses experienced in passages through pumps. Complete flow pressurizations are usually used where there are no large amounts of solids to be separated but only emulsified oils and greases to be removed. The fact that air bubbles with their attached solids rise faster than the small suspended solids can settle, means that only a short retention time is needed in the flotation chamber, usually less than 30 minutes. According to Steel, efficiencies and removal of suspended solids is rather low. Usually less than 50%. On the other hand, air requirement is low, 0.025 to 0.05 cubic feet per gallon.

The principal components of a flotation system are a pressurizing pump, air injection facilities, a retention tank, a back pressure regulating device and a flotation unit.

Flotation thickening of activated sludge can increase the solids content up to 3 1/2 to 4%. For those plants already in existence utilizing anaerobic digestors for sludge digestion, a decrease in the water content of sludge by 3% to 3 1/2% would greatly increase the digester residence time. In addition, an added benefit is the marked reduction in both heating costs and supplemental gas production in the digester.

### 5.4.F Control of Air Flotation

At the Hite Creek Tertiary Treatment Plant in Louisville, Kentucky, flotation thickening is applied to aerobically digested sludge. The sludge is first treated with a flocculant then passed into the flotation unit. Finally the chemically-flocation thickened sludge is dried on a vacuum filter. When conditions warrant the use of flotation aids, they are blended with the pressurized flow and feed sludge for optimum mixing before the combined flows are introduced into the flotation chamber. Without chemical aids, the activated sludge can be concentrated from 0.6% to over 6%. Mixtures of activated and primary sludge have been concentrated to over 8 1/2% resulting in approximately 60% reduction of sludge volume pumped to digesters.

The control functions associated with the Hite Creek air flotation system are basically motor controls, which are supplied by the flotation unit manufacturer. These controls are:

1. Thickened Sludge Pump
2. Flotation Thickener Skimmer
3. Flotation Thickener Sludge Collector
4. Recirculation Pump
5. Thickener Reaeration Pump
6. Compressor
7. Polyelectrolyte Polymer Feeder

The problem of water clarification and the thickening of sludge solids is the same: to reduce or neutralize the repulsive forces on colloidal particles so that they will more effectively agglomerate. In treating dispersions, considerable reliance must be placed on the empirical techniques supported by observations and jar tests. Two instruments have been developed which can be used to continuously monitor the electrokinetic properties of dispersions. Originally, they were designed to aid water purification plants by regulating the clarification process, but their application to thickening wastewater sludges should also be feasible. The Zeta-Meter is the oldest and best known of these instruments. It has evolved from a research laboratory instrument to a process control device. Basically, its principle of operation is the measurement of floc movement in an electric field. This is also the basis of electrophoresis, i.e. the migration of a charged particle in an electric field. Since one is attempting to reduce as much as possible the charges on the surface of the colloid, coagulants and aids (such as polyelectrolytes) are added until the net charge is zero and migration ceases.

The second instrument for this type of application was developed by Leeds & Northup and is called the "Hydroscan." This unit operates on the principle of a streaming current detector. A colloidal particle possesses an absorbed surface charge of potential determining ions with a negative charge most often found in nature. It is surrounded by a diffuse layer of counter ions which are ions of opposite charge, acquired from the bulk solution. If a colloidal particle in solution is immobilized on a capillary wall by adsorption, then fluid motion in the tube will physically shear the counter ions from the parent particle. This ion motion is a streaming current which can then be amplified and measured. This current is then used empirically to determine the optimum amounts of coagulants and/or polyelectrolytes needed for floc formation.

With the costs of polyelectrolytes approaching $1 per pound, and applications of 20 lbs. per ton of floated solids, it is easy to see the need for close control of chemicals in order to minimize waste.

### 5.4.G. Centrifugation

The use of centrifuges to thicken and dewater sludge is not a new development. For many years, this equipment has been successfully used by the process industries. Centrifuges were first evaluated for waste treatment applications nearly 40 years ago. Only recently were they installed for regular use at wastewater treatment plants. In this section, both the thickening and dewatering applications of centrifuges will be discussed. Dewatering can be distinguished from thickening by assuming that it is the dehydration stage where solids are not fluid and cannot be pumped. Thickened solids are fluid and can be pumped.

When using a centrifuge for the purpose of sludge thickening, the use of cationic polyelectrolytes significantly improves the centrifuge's performance. The use of these flocculants has allowed significant increases in cake production and solids concentration. The cost associated with the use of centrifuges for thickening have brought the annual operating costs to \$3 - \$8 per ton if chemicals are not required. The thickening of waste activated sludge by itself can probably be done with less cost in air flotation units, unless chemicals are required in the flotation unit operation, but not the centrifuge. Chemicals could add \$3 - \$10 per ton to the operating cost of centrifuges.

Centrifuges are of different types: horizontal, cylindrical-conical, solid bowl, basket, and disc. Disc-type machines do a poor job of dewatering even though they are good for clarification. The basket centrifuges on the other hand dewater sludges effectively, but the liquid clarification obtained is poor. All the other types of centrifuges are very effective for dewatering sludges. Basically, centrifuges separate solids from the liquid through sedimentation and centrifugal force. In a typical unit, sludge is fed through a stationary feed tube along the center line of the bowl through the hub of the screw conveyor. The screw conveyor is mounted inside the rotating conical bowl. It rotates at a slightly lower speed than the bowl. Sludge leaves the end of the feed tube, is accelerated, passes through the ports in the conveyor shaft and is distributed to the periphery of the bowl. Solids settled through the liquid pool are compacted by the centrifugal force against the walls of the bowl and are conveyed by the screw conveyor to the drying or the beach area of the bowl. The beach area is an inclined section of the bowl where further dewatering occurs before the solids are discharged. Separated liquid is discharged continuously over adjustable weirs at the end of the bowl.

In centrifugation process variables are:

1. Feed rate
2. Sludge solids characteristics
3. Feed consistency
4. Temperature
5. Chemical additives

Machine variables are:

1. Bowl design
2. Bowl speed
3. Pool volume
4. Conveyor speed

Two factors usually determine the success or failure of centrifugation, mainly cake dryness and then solids recovery. Below is summarized the effect of the various parameters on these two factors:

| To Increase Cake Dryness | To Increase Solids Recovery |
|---|---|
| 1. increase bowl speed | 1. increase bowl speed |
| 2. decrease pool volume | 2. decrease pool volume |
| 3. decrease conveyor speed | 3. decrease conveyor speed |
| 4. increase feed rate | 4. decrease feed rate |
| 5. decrease feed consistency | 5. increase feed consistency |
| 6. increase temperature | 6. increase temperature |
| 7. do not use flocculants | 7. use flocculants |

Low dosages of organic polyelectrolytes greatly increases solids recovery. Chemical treatment, however, usually lowers the cake dryness (probably due to the capture of the fine solids) so a compromise of objectives is necessary, that is, dryness versus recovery. Generally, polymers permit higher unit loadings as well as higher solids recovery. The use of polymeric flocculants in the centrifuge to dewater primary and waste activated sludge has improved the efficiency of cake production by 100%; solids capture by 50-65%; and has reduced the solids in the overflow centrate by 99%. Efficiency improvements of a similar magnitude have been reported for the dewatering of digested primary and secondary sewage sludge.

Centrifuge dewatering costs vary with the sludge to be treated, the volume, the consistency of the sludge, and whether fine centrate solids must be captured in the machine. Centrifuge dewatering costs range from $5 to $35 per ton. A typical average being $12 per ton.

Centrifuges are being installed in more and more wastewater treatment plants for the following reasons: 1) capital cost is low in comparison with other mechanical equipment; 2) the operating and maintenance costs are moderate; 3) the unit is totally enclosed so odors are minimized; 4) the unit is simple and will fit in a small space; 5) chemical conditioning of the sludge is often not required; 6) the unit is flexible in that it can handle a wide variety of solids and function as a thickening as well as a dewatering device; and 7) little supervision is required.

The disadvantages associated with centrifugation are 1) without the use of chemicals solids capture is often very poor and chemical costs can be substantial; 2) trash must often be removed from the centrifuge feed by screening; 3) cake solids are often lower than those resulting from vacuum filtrations; and 4) maintenance costs are high.

Flocculants can be used to increase solids captures often to any degree desired, as well as to materially increase the capacity of the solids loading of the centrifuges. However, the use of chemicals nullifies the major advantage claimed of the centrifuges, namely moderate operating costs.

## 5.4.H. Control of Centrifuges

The basic control functions that are included with a centrifuge are ammeters, a guard for the main drive motor, a pressure switch for the oil system, limit switches, and indicating lights. Almost all control in a centrifuge is directed to protecting the main drive motor, mainly by preventing current overloading. Over and above its function to bring the machine up to full speed and prevent overloading while running, or to shut down upon shear pin failure or to tie in feed control, the starter may also include these additional features: 1) In some centrifuge installations, there are electric controls on the solids conveyor system. With these additional controls it is recommended that the main drive motor and solids conveyor be in operation before the feed control can function. A normally open contact in the conveyor motor controls must be connected into the feed control circuit.

2) The load control and recording instrument is often used to provide a continuous record of the torque load exerted on the centrifuge conveying mechanism. The instrument and system also function as an automatic overload protection. When the torque load reaches a preset level (LO), an alarm is actuated alerting the operator that the centrifuge is approaching the full load condition. If the load continues to increase to a higher preset load level (HI-LO) then the instrument activates a relay which can be wired to cut off or divert the feed. If the torque continues to increase with the feed cut off and reaches a preset (HI) the entire mechanism shuts down at a point below that at which the shear pin would fail.

It is quite important that the volume of feed can be well controlled and is not subject to objectionable fluctuation. Volume regulation by varying the output of a centrifugal pump is highly satisfactory but not practical if frequent adjustments have to be made for process control reasons. Varispeed screw pumps or diaphram pumps where applicable are suited to this condition. If a throttling valve is used for feed regulation, this would be of the type which does not tend to plug when partially opened. A gate valve is especially unsatisfactory in this regard unless it is practically wide open. Remote control power operated valves are highly recommended, especially where the feed valves ties in with other control points.

# CHAPTER 6

## INSTRUMENTATION OF ANAEROBIC DIGESTERS

### 6.1 PROCESS DESCRIPTION

The major justification for digestion is that it stabilizes raw sludge and makes it more acceptable for final disposal. Other arguments for digestion, such as volume reduction and the production of usable gas, are insignificant in comparison with the conversion of noxious raw material, including fats, proteins, cellulose, and pathogenic organisms, into a more acceptable form. This important justification has made anaerobic digestion the most common method of processing organic sludges, and digestion will continue to be popular at small sewage treatment plants.

Anaerobic digestion can be defined as the decomposition of organic matter in the absence of free oxygen. The decomposition is accompanied by gasification, liquefaction, stabilization, colloidal structure breakdown, and release of moisture. Digesiton occurs in a mixed culture of microorganisms where particular species are most active in different stages such as acidification and gasification. In the digestion process, decomposition is not complete: the products of intermediate metabolism include organic acids, ammonia, methane, hydrogen, sulfide, carbon dioxide, and carbonates.

Sludge digestion is solely a biological process; it is the most complex and sensitive of all biological waste processes, and most problems in sewage treatment plants stem from it. The decomposition of the sludge is considered by many to be a two-stage operation, the first stage being the breakdown of the complex waste materials into relatively simple organic molecules. During this stage no waste stabilization occurs, only the conversion of carbohydrates, fats, and proteins to organic acids and alcohols. It is during the second stage that true waste stabilization occurs, resulting in the methane and carbon dioxide production from the organic acids and alcohols. The entire process is very dependent on the conditions of its environment, particularly temperature and pH.

## 6.2 OPERATIONAL CONTROL PARAMETERS

Temperature exerts a profound effect on digestion. Heat is introduced to shorten the digestion period through the resulting biological activity. Generally the gas produced by the digester is used to fire a furnace. The furnace either heats the sludge directly (by circulation through it) or by passing heated water through coils in the tank wall.

Another important environmental requirement is proper pH control. While a few bacteria can grow under acid or alkaline conditions, the largest number of these organisms grow best at or near neutrality. The optimum range is generally given as pH 6.8-7.2.

Complete mixing of the tank contents is also quite important. Proper mixing provides the maximum opportunity for physical contact between the bacteria and the organic matter. There are presently two basic systems for mixing 1) gas recirculation and 2) mechanical stirring.

## 6.3 INSTRUMENTATION FOR CONTROLLING DIGESTER OPERATION

The bacteria associated with sludge digestion react quite slowly to changes in environment. For this reason it is desirable to strive for optimum environmental conditions, so that more efficient and rapid treatment may be obtained. As there is no single parameter which will always tell of the onset of unbalanced conditions, several parameters must be watched for good control.

Unfortunately, digester control today is an art rather than a science, and a great deal of research is still needed before optimum control can be achieved.

Since digester tanks are quite large, for practical purposes very little mixing is actually obtained. For this reason the measurement of parameters must be taken at several locations to arrive at results that approach a cross section of the tank's environment.

6.3.A Temperature Measurement

The only parameter which can truly be controlled in digesters at the present state of technology is temperature. Generally, digesters are maintained at 96-97°F. Thermometers should be provided to show temperature of sludge, hot water feed, return (on internally heated digesters), and boiler water (on the heat exchanger on externally heated units). The measurement of sludge temperature in the digester can be used to control sludge recirculating pumps and an override boiler water temperature. Figure 6-1 illustrates the way in which this and two other parameters might be monitored, either separately or in concert.

6.3.B Measurement of Sludge Gas Components

Since gas production results from the breakdown of many compounds by numerous interdependent and interacting reactions, one of the first indications of poor operation is a decrease in total gas production and/or an associated decrease in the percentage of methane. Theoretically, one pound of organic matter @ 25°C would yield 21 cu ft of digester gas, and since the incoming sludge is not totally convertible organic matter, about 12.6 cu ft of gas is produced. This production of gas should be metered, particularly when the gas is going to be utilized for heat or power. The gas produced by the digester is quite corrosive and the gas metering system must be resistant to corrosion.

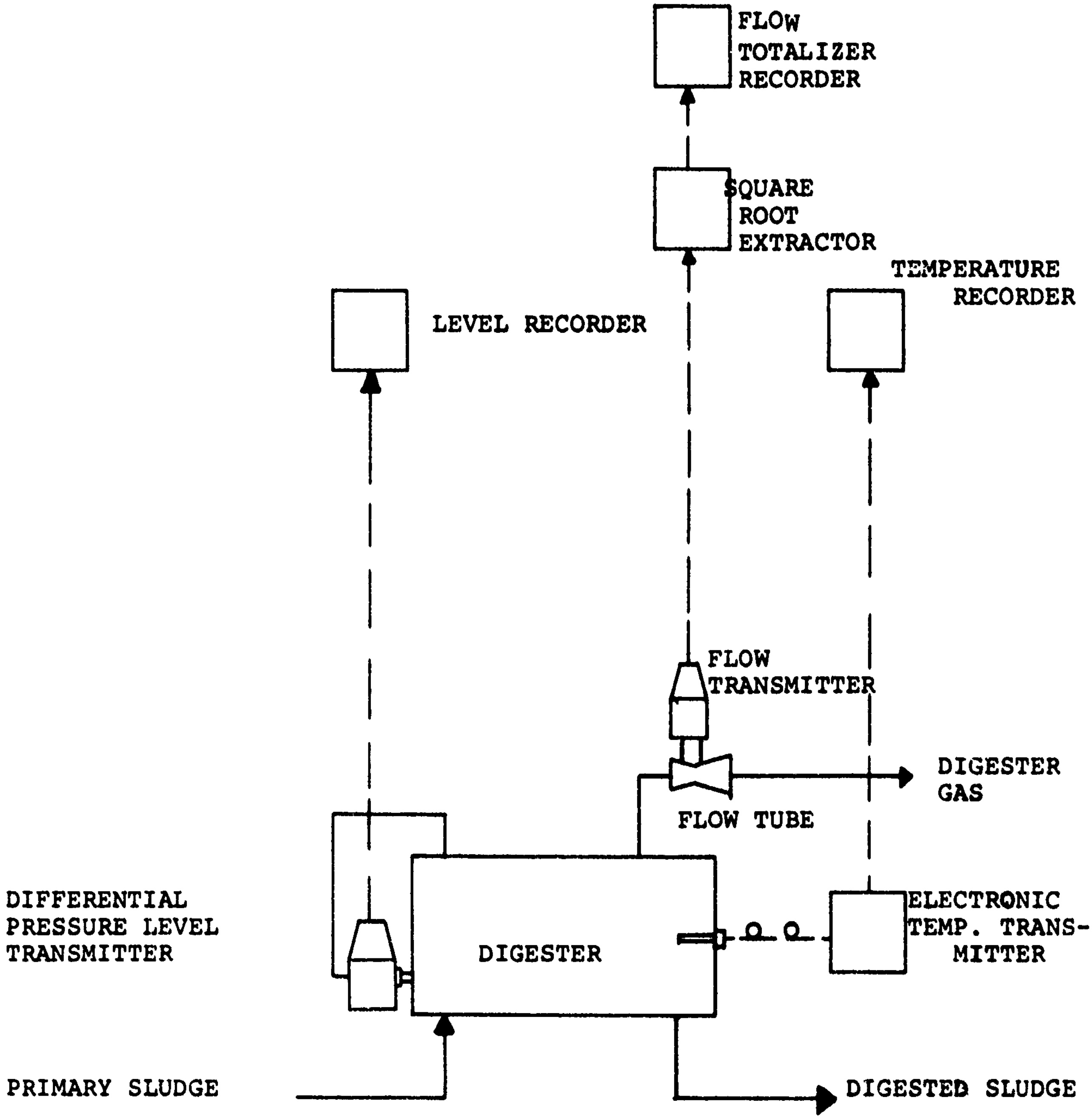



FIGURE 6-1

DIGESTER MONITORING
LEVEL (DIFFERENTIAL PRESSURE), TEMPERATURE
(FILLED BULB DETECTOR), GAS FLOW (VENTURI TUBE)

COURTESY OF FISCHER & PORTER CO.

Monitoring the percent methane may be accomplished in one of two ways. First, it is possible to analyze the gas by a hydrocarbon analyzer. Beckman Instruments manufactures a hydrocarbon analyzer that utilizes a flame ionization detector. A potential difference is imposed across the hot gases produced by a small hydrogen-air flame. Into the base of the burner is aspirated the gaseous sample. As the sample passes through the hot flame of the detector it is ionized, that is, as combustion proceeds electrons are stripped from the molecules of the sample. As this occurs, the positive ions are attracted to the collector screen having a negative charge. The ions complete the circuit and generate a current directly proportional to the concentration of the gaseous material. Figure 6-2 illustrates how a hydrocarbon analyzer (or any other analyzer) may be incorporated into a digester.

The second method utilizes the difference in specific gravity between sludge gas and air. In this system the $CO_2$ production is monitored instead of the methane, a sudden rise in $CO_2$ from its normal 35% being taken as an indication that total gas production may soon fall off. The $CO_2$ monitoring system developed by the Ranarex Division of Permutit Company is a mechanical device which measures the specific gravity of the gas. It will, therefore, provide analysis for a two-component gas system. The instrument consists of two hollow cylindrical chambers each of which contains a motor-driven impeller and an impulse wheel. The lower impeller draws in a continuous sample of gas and discharges it against the vanes of the companion impulse wheel creating a torque proportional to the density of the gas.

Similarly, the upper impeller draws a continuous sample of ambient air and discharges it at the same speed, but in opposite direction to the gas creating an opposing torque proportional to air density. The difference between the opposing torques is a measure of the specific gravity and is transmitted through impulse wheel pivot shafts to a pointer and a recording chart pen.

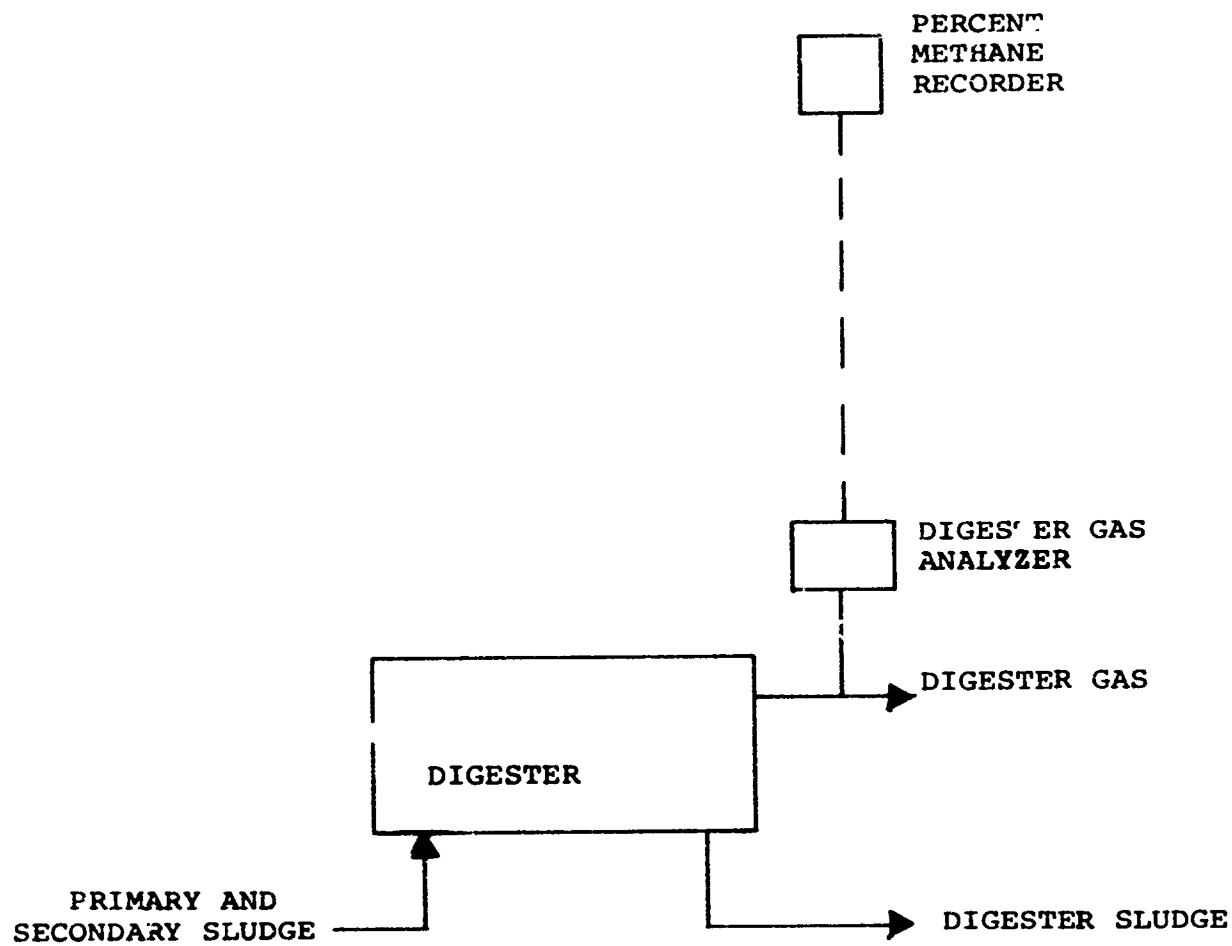



FIGURE 6-2

DIGESTER GAS MONITORING
(HYDROCARBON ANALYZER, OR
DIFFERENTIAL GAS DENSITY ANALYZER)

The operational conditions that must be met for this instrument are: the gas should be essentially at atmospheric pressure and ambient temperature and both gas and air should have the same humidity. Some advantages claimed for this instrument are rapid response, rugged construction, simplicity, and low installation cost. The cost for this instrument is about $1,500.

### 6.3.C Digester Level Measurement

Digester covers may be either fixed or floating. The floating cover rises and falls with the liquid contents preventing air from entering the digester and spoiling its operation. The fixed cover digester is usually accompanied by a separate tank for gas storage. Figure 6-3 and 6-1 illustrate the two alternatives presently available for measuring cover position or the top of the digester supernatant. The cover position may be determined directly by a cover position transmitter, or by inference using a differential pressure cell and transmitter. The differential pressure cell is also applicable for use with fixed cover digesters. These cells are available with recorders from Foxboro and from Fischer & Porter at about $800.

### 6.3.D Measurement of Sludge Gas Volume

Since it is desirable to know the amount of gas produced on a per capita and solids weight basis, the most efficient method is with a primary gas measuring device. Figure 6-1 depicts a venturi-type flow tube applied to this function. As mentioned earlier, its construction should be such that it can withstand the corrosive nature of sludge gas. An alternate type of differential gas flow measurement is by the use of an orifice plate. Orifice plates are supplied by Foxboro, Fischer & Porter, BIF, and Meriam.

The more traditional bellows-diaphram type of gas meter has also been applied to the measurement of sludge gas. In addition, Rockwell Company has developed a turbine-type gas meter for service in sewage plants. With this type of device it is essential to have laminar gas flow impinging upon the turbine blade. To accomplish this, it is necessary to eliminate all valves or other obstructions ten

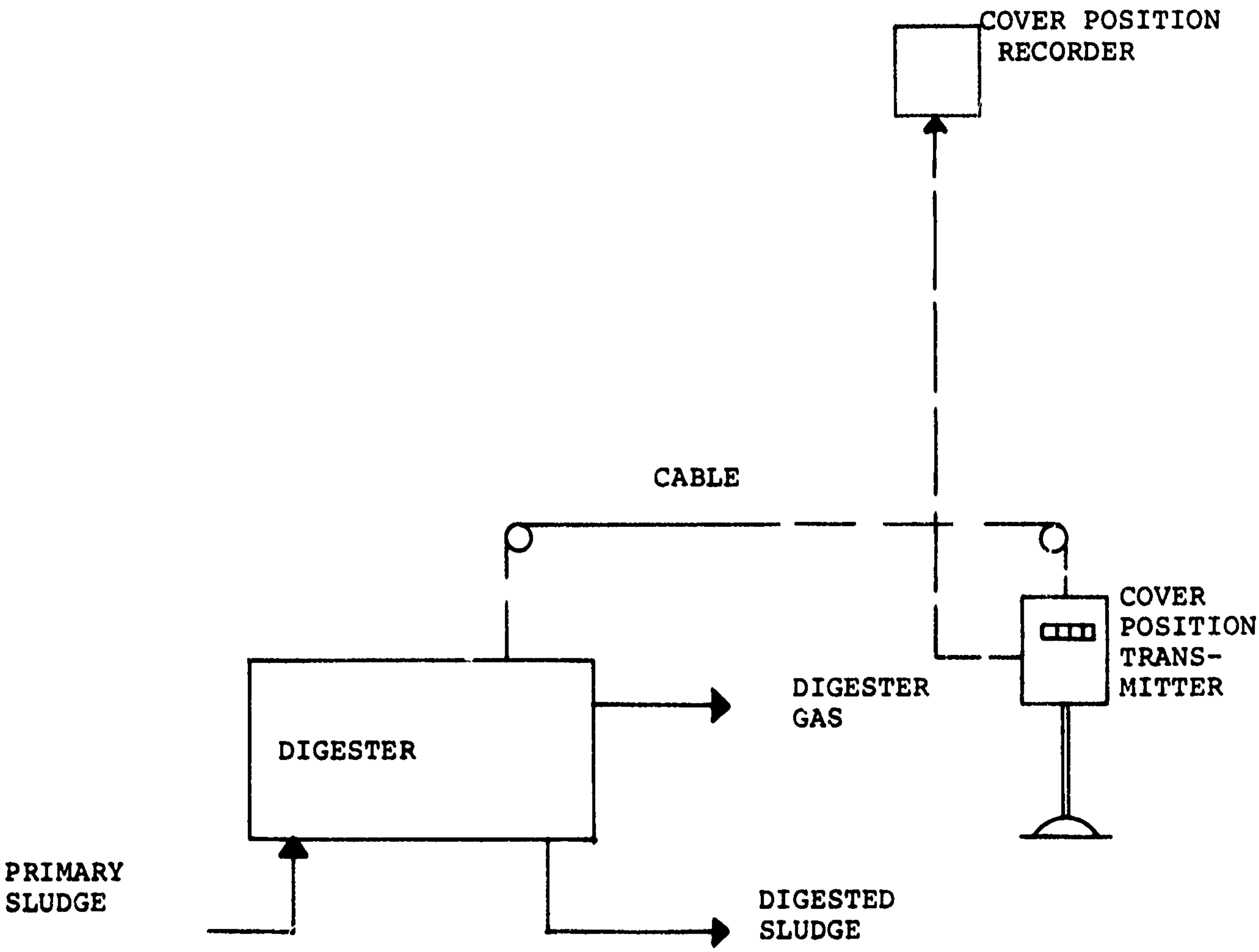



FIGURE 6-3

DIGESTER COVER POSITION

COURTESY OF FISCHER & PORTER CO.

pipe diameters upstream from the meter, and the adjacent section four pipe diameters upstream should be provided with straightening vanes. The major maintenance advantage of this turbine meter is the ease with which the turbine section may be replaced without removing the meter body.

6.3.E pH Measurement

While pH is one of the most important operating parameters for a digester, it is also the hardest to measure. At many installations attempts have been made to adjust the pH of the incoming sludge through addition of chemicals. Unfortunately, the automatic control of pH at the present time is for all practical purposes impossible. The sludge coats the electrodes making accurate measurment impossible.

6.3.F New Control Parameters

Work has been done on the oxidation-reduction potential of digesters, and their conductivity. Trends in redox potential are reproducible, and there exists a direct relationship between ORP and cummulative gas production. Also, there is a correlation between conductivity and total solids, as well as between conductivity and the degree of decompositon of a sludge mixture. A correlation between conductivity and dissolved solids is doubtful. Perhaps eventually these experimental correlations may be reduced to the level of operational parameters.

# CHAPTER 7

## POST CHLORINATION

### 7.1 PROCESS DESCRIPTION

The disinfection of water and wastewater in municipal and industrial applications is accomplished almost exclusively by chlorination. Chlorination has been successful in the killing of pathogenic bacteria. Chlorination also produces secondary benefits such as odor control, slime control, and the doubtful effect of BOD reduction.

The oxidizing agents produced by the dissolution of chlorine in water are important because as these compounds are killing bacteria and viruses, they are also oxidizing many other materials in the wastewater. Therefore, oxidation is usually considered to waste chlorine and make it unavailable for disinfection. A greater percent of the chlorine is used in oxidizing wastewater than in disinfection. As the degree of treatment of wastewater is increased, the amount of chlorine required to oxidize materials in it is decreased. Therefore, chlorine can be economized on by applying it to the most highly purified wastewater in the treatment plant.

Generally, the typical chlorination installation consists of a storage area for liquified chlorine, evaporators to convert the chlorine to the gaseous state, and a chlorinator which dissolves the gaseous chlorine in water (at varying rates) for eventual application to the plant effluent. After a sufficient contact period, the disinfected wastewater is sampled and residual chlorine and coliform concentrations are determined.

## 7.2 CONTROL OF CHLORINATION

Control of chlorination depends either upon chlorine demand, or upon chlorine residual. Chlorine demand is the amount of chlorine which will produce the desired chlorine residual after a stated contact time. At the present state of technology, this determination has not been automated. Chlorine residual is the only analytical method for chlorine which has been automated to produce a control signal for chlorination equipment. As discussed in Chapter 2, ORP has also been applied to the control of chlorination for the purpose of odor control.

### 7.2.A Amperometric Determination of Chlorine Residual

Whether the amperometric instrument being used for chlorine control is for laboratory use or as part of an automatic analyzer, the principle is the same: through a series of chemical reactions a specific molecular species is generated, the presence of which will allow current of a fixed voltage to pass through a solution. The amount of current (amperes) varies directly and exponentially with the concentration of the specific ion.

When automatic amperometric analyzers are used for wastewater, the effluent stream is constantly monitored. The sample is filtered and pumped to a constant head reservoir where most of the water flows to waste. At the reservoir a certain portion is diverted and mixed with dilution water. The dilution water keeps the reagent requirement to a minimum and helps prevent fouling in the analytical cell. Diluted samples leaving the dilution area of the reservoir have a phosphoric acid-detergent solution added by an electronic pump. Further along, another pump adds potassium iodide reagent, buffer, and detergent. The buffered sample (acid pH) then passes into the measuring cell. At the proper pH, the free chlorine converts the iodide to iodine which is the species actually measured. It is in this area that designs differ between the two principle manufacturers of chlorine analyzers. Wallace & Tiernan utilizes fixed electrodes, the anode (measuring electrode) being platinum, and the cathode (reference electrode) being copper. The electrode surfaces are kept clean by grit kept in suspension by the sample velocity.

The Fischer & Porter system utilizes a gold measuring electrode rotating inside a copper cylinder which is the reference electrode. Plastic pellets, which just fit between the two electrodes, are kept in constant motion by the rotating anode and are utilized to keep the electordes clean.

7.2.B Automatic Control of Chlorination

Figure 7-1 illustrates how a chlorine residual analyzer would be used to control chlorination via an automatic chlorinator. In the diagram the chlorination rate is governed similarly to the system explained in Chapter 2 for odor control. Briefly, an effluent flow signal is used to pace the chlorinator, with fine control coming from the chlorine analyzer. In some systems, chlorine residual alone is used to control the chlorinator because where the effluent has only small variations in oxidizable organic loading or, where the flow variation is small, flow pacing may not be required.

The effluent flow rate signal may be generated at the effluent weir of the chlorine contact chamber by using either a stilling well and float, or an in-stream flow transmitter similar to those discussed in Chapter 2.

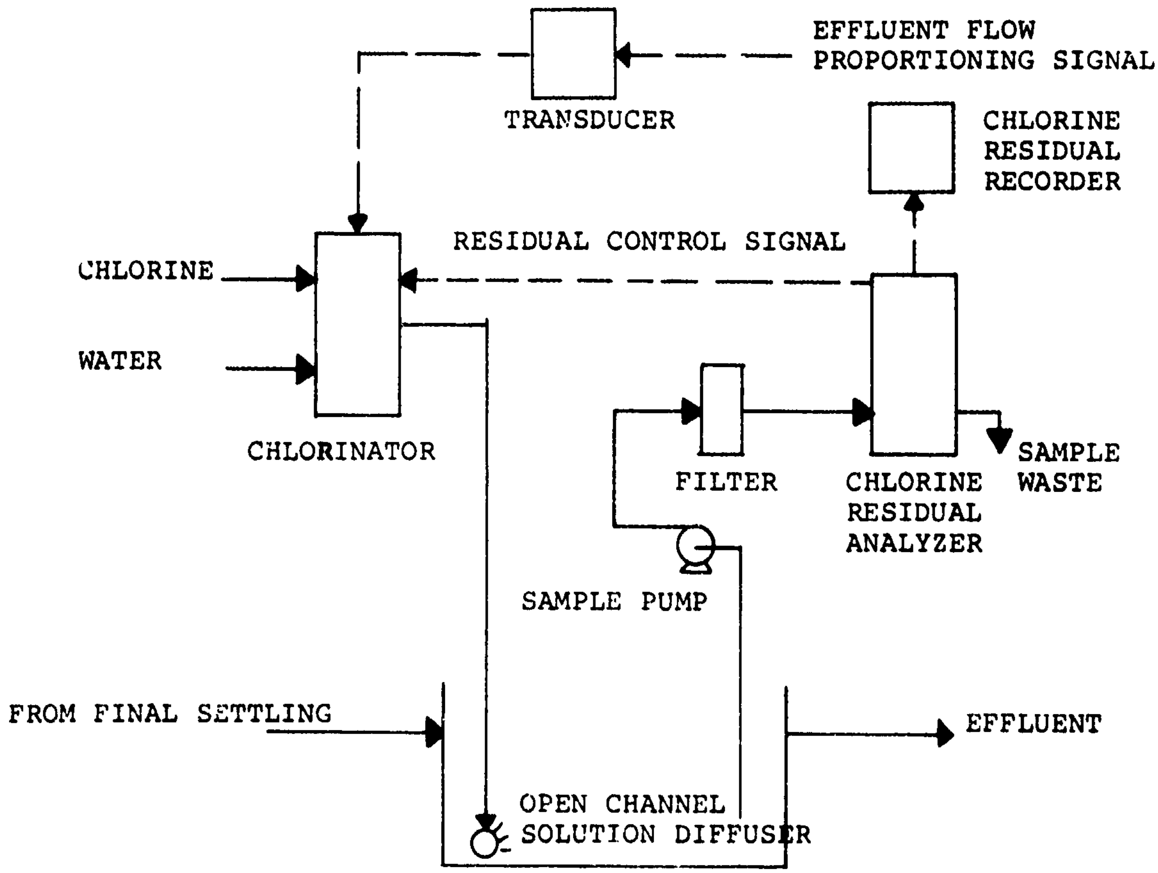



FIGURE 7-1

POST CHLORINATION FOR DISINFECTION
FLOW PROPORTIONING

COURTESY OF FISCHER & PORTER CO.

# CHAPTER 8

## AUTOMATIC SAMPLE COLLECTION

### 8.1 PROCESS DESCRIPTION

Chemical analysis of wastewater at various points in the treatment process is an essential function of plant operation. Only through analysis is it possible to determine the overall effect of a wastewater treatment plant, as well as monitoring the efficiency of the various process steps. The key to proper evaluation of analytical results is the assurance that the sampling technique has yielded a sample truly representative of the total plant flow. Since water quality and quantity vary independently of each other, it is necessary to sample a waste stream in proportion to its actual flow.

Generally, a significant difference exists between the data obtained by grab sampling and that obtained by the flow-weighted composite sampling technique. The significance of these differences has been found to be mainly dependent on the following factors: (a) the overall time period for which the wastewater is characterized; (b) the variability of both quality and quantity in the specific wastewater stream; and (c) whether concentration levels or materials transport rates are desired. Therefore, the flow-weighted composite sampler provides the sampling technique most suitable for universally obtaining representative samples of wastewater effluents.

### 8.2 METHODS FOR PROPORTIONAL SAMPLING

Figures 8-1 and 8-2 show two of the most common methods employed for composite sampling in sewage treatment plants. Figure 8-1 represents a Trebler sampler, designed by Dr. Trebler, and marketed by Lakeside Engineering Corporation. A curve can be drawn showing the upstream of a weir or Parshall Flume and the volume of liquid passing that point. From

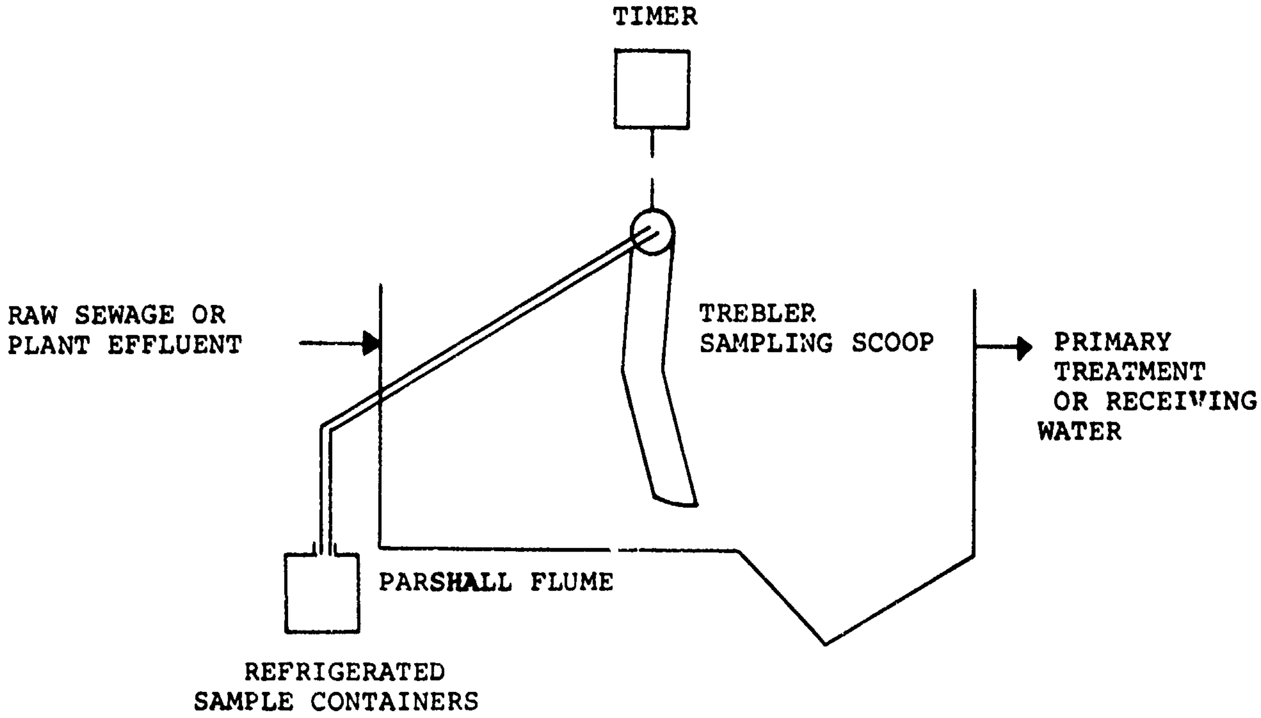



FIGURE 8-1

PROPORTIONAL SAMPLING
TREBLER SAMPLER IN PARSHALL FLUME

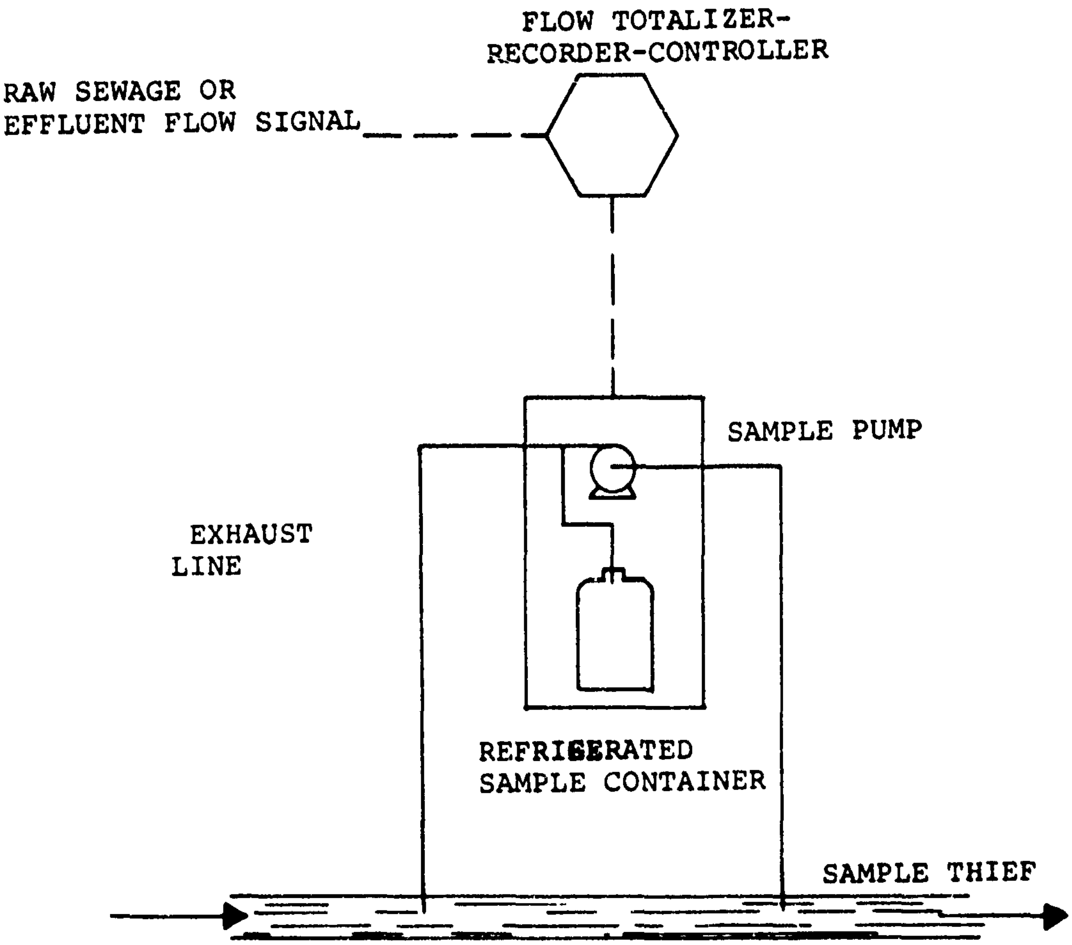



FIGURE 8-2

PROPORTIONAL SAMPLER
INTEGRATED FLOW ACTIVATED

these curves, a Trebler sampler scoop can be designed that will select a sample proportional to flow. For accurate sampling, the Trebler must operate in conjunction with a Parshall flume or weir. Since weirs are most generally used at plant effluents, where solids buildup is minimal, the Trebler sampler may be used at this point as well as in an influent flume. The Trebler sampler is activated strictly on a time basis, the sample proportioning coming solely from the varying sample size.

The Trebler sampler, while economical ($150 for a Pexiglass scoop), apparently has not met the need for proportional sampling. Figure 8-2 illustrates the technique that is being applied most often to proportional samplers, that is, totalized flow actuating the sampler to deliver a fixed volume. The most sophisticated of these devices receives a signal from a flow recorder-totalizer which is programmed to actuate the sampler every so many gallons, regardless of time interval. Nappe Corp., Protech Corp., Snyder Teague, Chicago Pump, and Union Carbide, all manufacture samplers based upon the above principle. Chicago Pump and Nappe samplers are designed for indoor remote operation; and those by Protech and Snyder Teaque are for on-site operation.

Brailsford samplers operate on a flow proportioned basis but do so using a head detection device. The head detector varies the frequency of fixed volume sampling in accordance with the position of a float on a variable resistance probe. The head probe consists of an array of magnetic switches connected to a series string of resistors. A float containing a magnet is arranged to slide up and down over the sealed resistors as the water level changes. In doing so, the switches are closed sequentially by the float magnet to alter the total amount of resistance in the circuit. The higher the level of the float, the faster the pumping rate and vice versa. While this instrument is the only truly portable proportional sampling device available, it still must be used in conjunction with a weir. Therefore, it may be used periodically at many points in a plant.

## 8.3 SEQUENTIAL SAMPLING

Many times it is desirable to monitor the hour-by-hour variation of a plant influent so that excessively high dosages of undesirable material occurring for short periods of time will not escape the attention of the analyst. In addition, analytical results on closely spaced samples give a much more precise characterization of the wastewater as it changes in respect to flow rate. Some of the suppliers of sequential samplers are Sonford Products Corp., and Instrumentation Specialties Company.

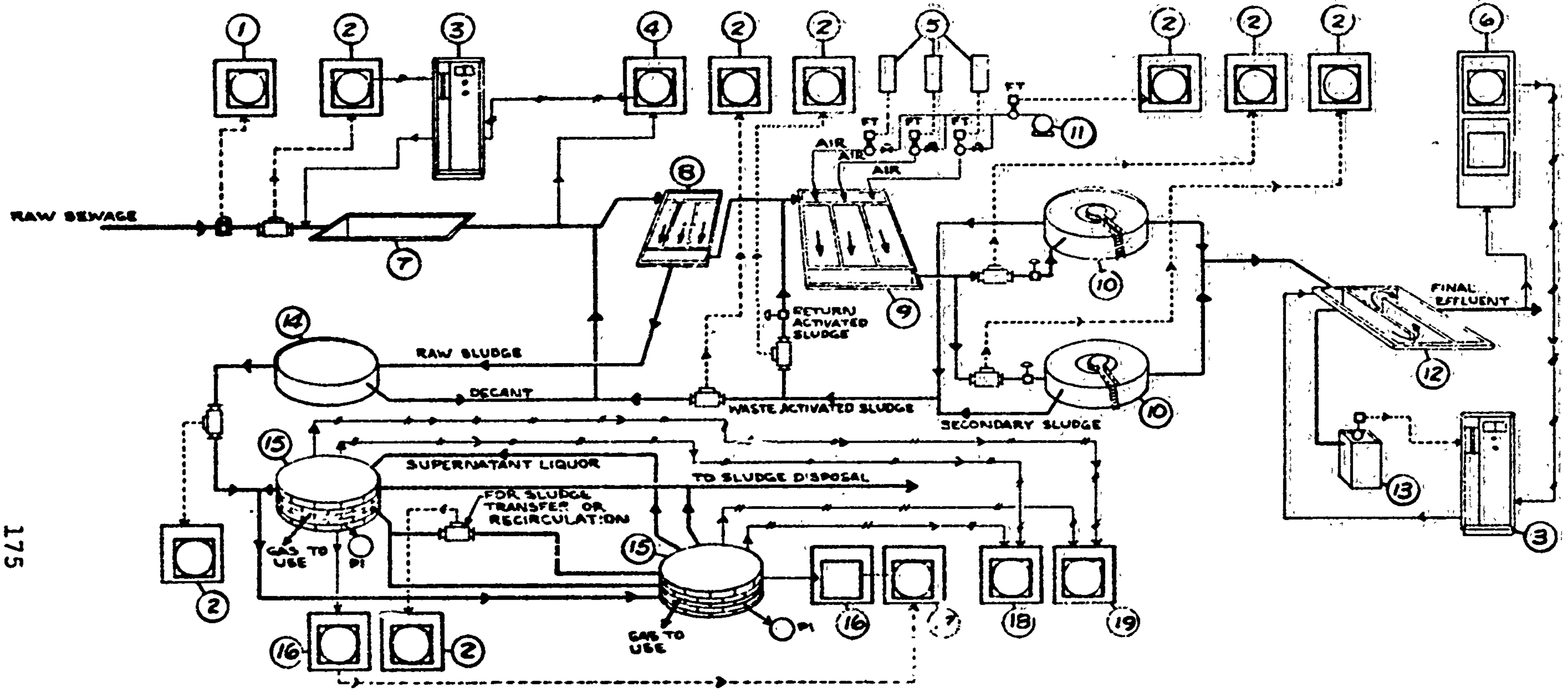
## CHAPTER 9

## AUTOMATION AND CONTROL OF TYPICAL WASTEWATER TREATMENT PLANTS

To provide an overview of the state of the art of wastewater treatment plant automation several typically controlled treatment systems will be presented to delineate cost estimates of automatic control equipment. Figure 9-1 depicts an activated sludge treatment facility incorporating automated control of prechlorination and post-chlorination with continuous monitoring of several other vital parameters. Prechlorination in this plant provides odor control and is automatically controlled through both influent wastewater flow and oxidation-reduction potential. A magnetic flowmeter (2) transmits a signal to the prechlorinator (3). Chlorine dosage is paced in proportion to raw wastewater flow and fine control is provided by oxidation-reduction potential. Continuous monitoring utilized throughout the plant includes flow recording of both return activated, waste activated, and total sludge flows. Such monitoring will provide an increase of the plant operator's potential for manual quality control. Automatic control of post chlroination is also shown in this plant. The final effluent is continuously monitored for residual chlorine (6) and this information is transmitted to the postchlorinator (3). Residual chlorine data together with float well data (13) provide adequate information by which the postchlorinator can pace its dosage.

The approximate costs of automation associated with a plant of this design, and a capacity of 1 MGD would be about $36,000.

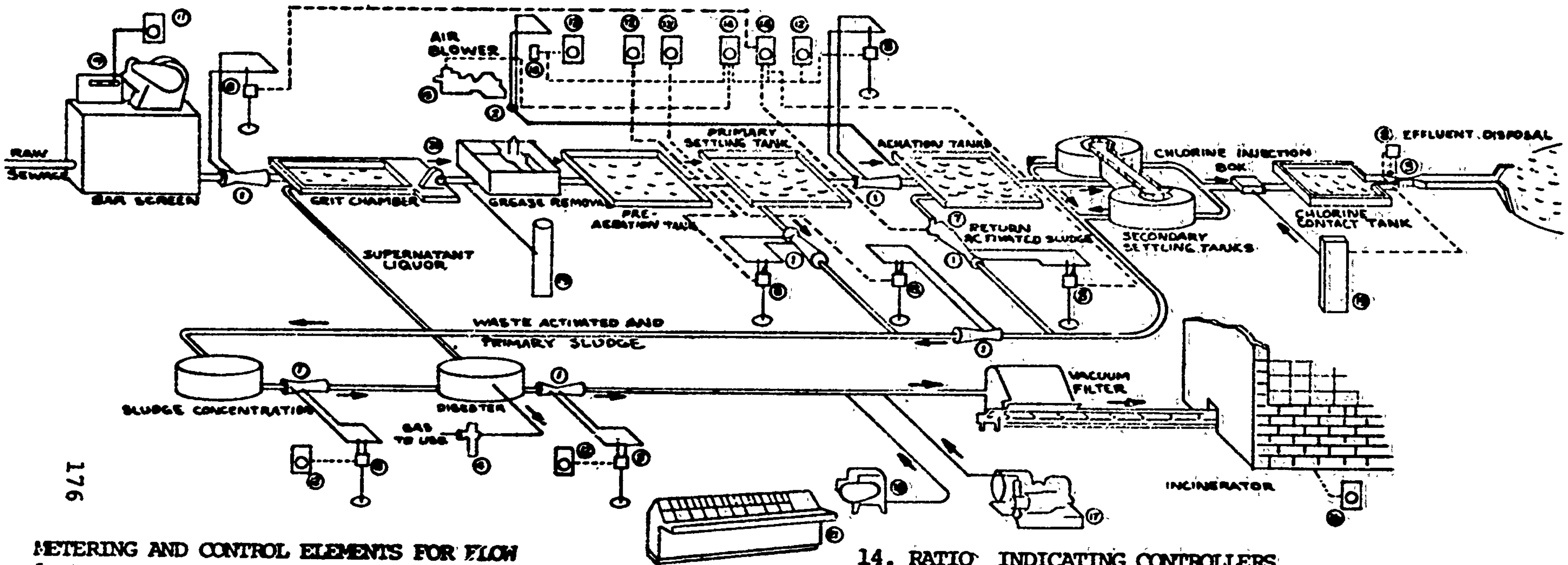
Activated sludge treatment plant B (shown in Figure 9-2) incorporates automatic control of barscreen




LEGEND
1. pH RECORDER
2. FLOW RECORDER TOTALIZER
3. CHLORINATOR
4. O-R-P RECORDER CONTROLLER
5. AIR FLOW INDICATORS
6. RESIDUAL CHLORINE RECORDER-CONTROLLER
7. GRIT CHAMBER
8. PRIMARY SETTLING TANKS
9. AERATION TANKS
10. SECONDARY SETTLING TANK
11. BLOWER
12. CHLORINE CONTACT TANK
13. FLOAT WELL
14. SLUDGE CONCENTRATION
15. DIGESTER
16. LEVEL INDICATOR-TRANSMITTER
17. DIGESTER LEVEL RECORDER
18. TEMPERATURE RECORDER
19. CARBON DIOXIDE RECORDER
FT-FLOW ELEMENT AND TRANSMITTER
PI-PRESSURE INDICATOR

FIGURE 9-1
ACTIVATED SLUDGE-TYPE SEWAGE PLANT, A

COURTESY OF FISCHER & PORTER CO.




METERING AND CONTROL ELEMENTS FOR FLOW
1. VENTURI FLOW TUBES
2. SHORT FORM VENTURI
3. PARSHALL FLUME
4. IN-LINE GAS METER
7. CONTROL VALVE

INSTRUMENTATION, TELEMETERING
8. FLOW TRANSMITTERS
9. LEVEL TRANSMITTERS
10. AIR TRANSMITTER
11. LEVEL INDICATOR-RECORDER-CONTROLLER
12. SLUDGE FLOW TOTALIZER-INDICATOR-RECORDERS.
13. AIR FLOW TOTALIZER-INDICATOR-RECORDER
14. RATIO INDICATING CONTROLLERS
15. SPEED CONTROLLER
16. TEMPERATURE INDICATOR-RECORDER

FEEDERS
17. FERRIC CHLORIDE SOLUTION PUMP
18. LIME SLURRY FEEDER
19. CHLORINIZERS
20. CIRCULATING PUMP

SUPERVISORY CONTROLS AND SYSTEMS
21. CENTRAL CONTROL CONSOLE

FIGURE 9-2

ACTIVATED SLUDGE-TYPE SEWAGE PLANT, B

COURTESY OF BIF CORP.

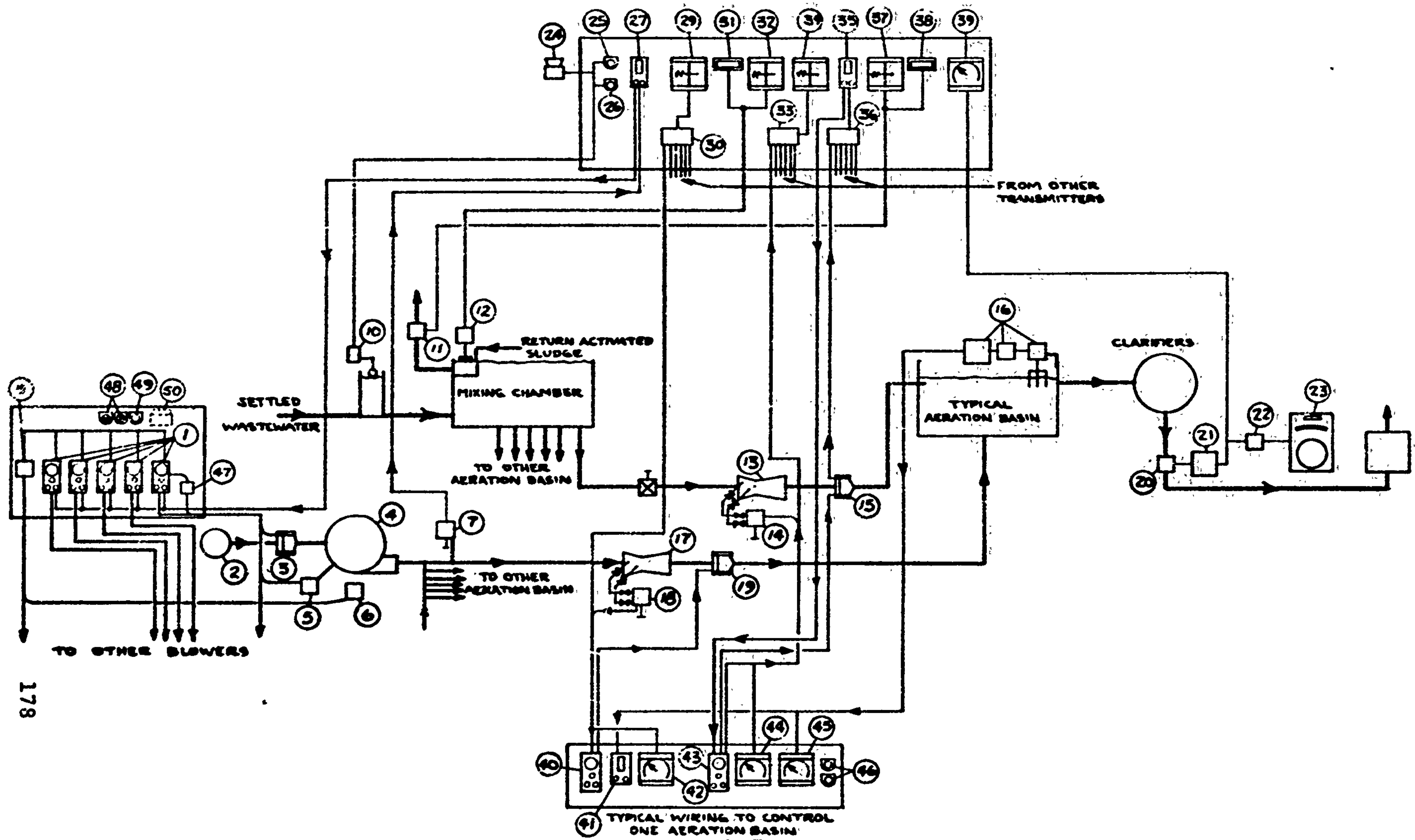
operation, aeration basin's organic loading to microorganism mass ratios (F/M) and postchlorination. An influent differential level indicator-recorder (11) and transmitter (9) signals the barscreen as to the head differential across the barscreen. When this differential exceeds a predetermined set point the barscreen is automatically activated. The aeration basin F/M ratio is also automatically controlled by means of indirectly monitoring F through a raw wastewater flow transmitter (8) and M through a return activated sludge flow transmitter (8). These two signals are relayed to a ratio controller (14) which controls the flow of return activated sludge flow and therefore the F/M ratio.

Postchlorination dosage (19) is paced according to effluent flow signals (8) thereby producing automatic control of this process.

The costs associated with instrumenting and controlling this plant, based on 1 MGD capacity, would be approximately $36,000.

Figure 9-3 illustrates and describes activated sludge treatment plant C. This diagram depicts the upgrading of a primary plant serving a city of approximately 140,000 (14 MGD), to a secondary system. This secondary treatment plant utilized the control of two aeration basin parameters: dissolved oxygen and organic loading to microorganism mass ratio (F/M). Aeration basin dissolved oxygen content is continuously monitored (16) and transmitted to a central control panel (41). This controller regulates throttling of the inlet blower valve (19) which in turn controls the amount of oxygen fed to the aeration basin. Aeration basin F/M ratio control is accomplished through indirect measurements of F and M. Influent wastewater flow monitoring signals for F and returned activated sludge monitoring signals (12) for M are forwarded to controllers which regulate the mixed liquor throttling valve and consequently aeration basin F/M ratio.

Activated sludge treatment plant D shown in Figure 9-4 illustrates a completely new secondary treatment system serving a population of




COURTESY OF BIF CORP.

FIGURE 9-3
ACTIVATED SLUDGE TREATMENT PLANT, C

See KEY on next page.

KEY TO INSTRUMENTATION AND CONTROL
ACTIVATED SLUDGE TREATMENT PLANT C

| Item | Description |
|---|---|
| 1 | Blower Control Module |
| 2 | Air Filter |
| 3 | Blower Inlet Throttling Valve |
| 4 | Multi-Stage Centrifugal Blower |
| 5 | Blower Motor Current Alarm |
| 6 | Blower Motor Contractors |
| 7 | Air Header Pressure Transmitter |
| 8 | Lockout Relay |
| 9 | Manual Sequence Selector |
| 10 | Float Switch for High Water Alarm |
| 11 | Waste Activated Sludge Flow Meter and Trans. |
| 12 | Return Activated Sludge Flow Trans. |
| 13 | Mixed Liquor Flow Tube |
| 14 | Mixed Liquor Flow Transmitter |
| 15 | Mixed Liquor Throttling Valve |
| 16 | Dissolved Oxygen Probe and Analyzer |
| 17 | Aeration Flow Tube |
| 18 | Aeration Flow Transmitter |
| 19 | Air Flow Throttling Valve |
| 20 | Plant Eff. Flow Meter and Trans. |
| 21 | Signal Converter - Pulse to Milliamp |
| 22 | Signal Converter - MA to Time Impusle |
| 23 | Plant Eff., Flow Totalizer-Indicator-Recorder |
| 24 | High Water Alarm Horn |
| 25 | High Water Alarm Light |
| 26 | Pushbutton - Alarm Silence |
| 27 | Blower Controller |
| 29 | Total Air Flow Indicator Recorder |
| 30 | Six Unit Summator |
| 31 | Return Activated Sludge Flow Totalizer |
| 32 | Return Activated Sludge Flow Ind/Rec |
| 33 | Six Unit Summator |
| 34 | Mixed Liquor Flow Ind/Rec |
| 35 | Mixed Liquor Flow Controller |
| 36 | Selector Relay |
| 37 | Waste Activated Sludge Flow Ind/Rec |
| 38 | Waste Activated Sludge Flow Totalizer |
| 39 | Plant Effluent Flow Indicator |
| 40 | Air Flow Auto-Man. Control Module |
| 41 | Dissolved Oxygen Controller |
| 42 | Air Flow Indicator |
| 43 | Basin Rate Set Station - Mixed Liquor Flow |
| 44 | Mixed Liquor Flow Indicator |
| 45 | Dissolved Oxygen Flow Indicator |
| 46 | High and Low Dissolved Oxygen Alarm Lights |
| 47 | Trimpot Assembly |
| 48 | High and Low Blower Discharge Alarm Lights |
| 49 | Alarm Silence Pushbutton |
| 50 | Blower Alarm Horn |

100,000 or about 10 MGD. This sewage treatment plant incorporates automatic control of aeration basin F/M ratio and flow proportioning throughout the system. Aeration basin organic loading (F) is indirectly monitored through influent wastewater flow data (P8). Return activated sludge flow data (P16) provides an indirect measure of microorganism mass (M). These two signals are transmitted to the return sludge ratio controller (P31) which regulates the return sludge flow (8) and consequently the aeration basin F/M ratio. Flow proportioning is practiced throughout this treatment facility including aeration basin flow control (PI) and secondary clarifier control (25). Other monitoring equipment directly related to quality control include phosphorus level recorders (P13), and ultrasonic level transmitters (19). The cost for the instrumentation alone in this plant is approximately $500,000.

Figure 9-5 illustrates current state of the art for automation of a trickling filter plant in which recirculation, return sludge flow, and post-chlorination are automatically controlled. Recirculation of secondary clarifier effluent is accomplished by proportioning recirculated flow to influent wastewater flow by means of ratio controller regulation of a recirculated flow valve. Likewise return sludge flow is automatically controlled by ratioing influent wastewater flow to return sludge flow. Both influent flow and return sludge flow data are transmitted to a ratio controller which in turn regulates the return sludge flow valve to achieve the desired ratio. Post-chlorination control is accomplished by ratio controller pacing of the chlorine feed rate in direct proportion with the effluent flow rate. The cost associated with this degree of automation for a trickling filter plant would be about $28,000.

While the prices of individual items have been presented to give a general idea of their relative worth, these prices cannot be taken as being indicative of the actual cummulative cost associated with instrumenting an entire plant. When plants go up for

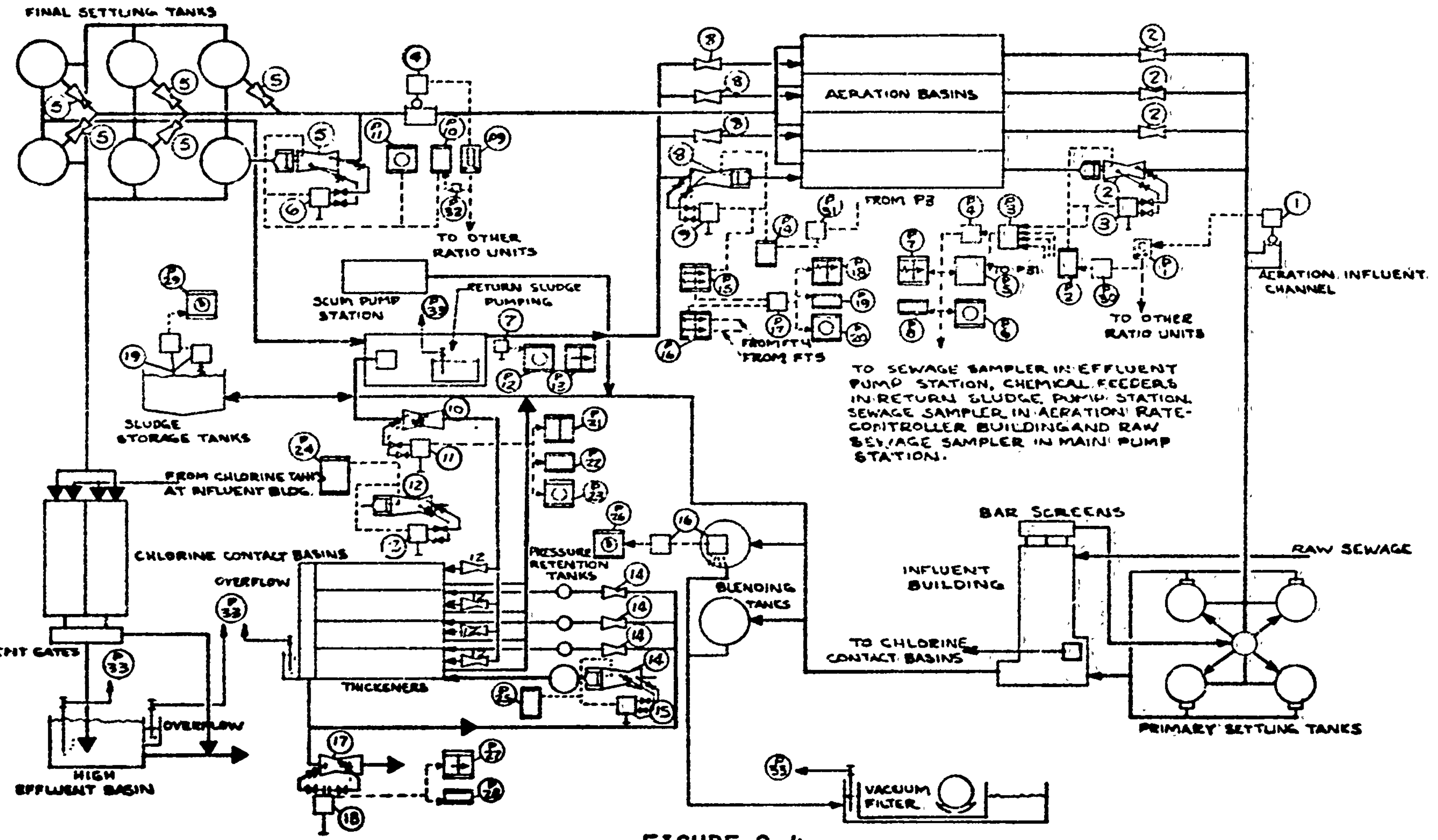



FIGURE 9-4
**ACTIVATED SLUDGE TREATMENT PLANT, D**

See KEYS on following pages

COURTESY OF BIF CORP.

KEY TO PANEL EQUIPMENT OF ACTIVATED SLUDGE TREATMENT PLANT D

| Item | Description |
|---|---|
| P1 | Aeration Influent Proportional Controller |
| P2 | Aeration Influent Flow Control Module |
| P3 | Total Plant Influent Summator |
| P4 | Total Plant Influent Signal Transducer |
| P5 | Total Plant Influent Indicator |
| P6 | Total Plant Influent Indicator |
| P7 | Total Plant Influent Indicator Recorder |
| P8 | Total Plant Influent Totalizer |
| P9 | Final Settling Tank Influent Proportional Controller |
| P10 | Final Settling Tank Influent Proportional Controller |
| P11 | Final Settling Tank Influent Flow Control Module |
| P12 | Effluent Flushing and Industrial Waters Indicators |
| P13 | Phosphorus Level Indicator Recorder |
| P14 | Return Sludge Flow Control Module |
| P15 | Return Sludge Flow Indicator Recorder |
| P16 | Return Sludge Flow Indicator Recorder |
| P17 | Total Return Sludge Summator |
| P18 | Total Return Sludge Indicator Recorder |
| P19 | Total Return Sludge Totalizer |
| P20 | Total Return Sludge Indicator |
| P21 | Waste Sludge Flow Indicator Recorder |
| P22 | Waste Sludge Flow Totalizer |
| P23 | Waste Sludge Flow Indicator |
| P24 | Waste Sludge Flow Control Module |
| P25 | Thickener Recirculation Flow Control Module |
| P26 | Sludge Blending Tanks Level Indicator |
| P27 | Thickener Overflow Flow Indicator Recorder |
| P28 | Thickener Overflow Flow Totalizer |
| P29 | Sludge Storage Tanks Level Indicator |
| P30 | Aeration Influent Ratio Unit |
| P31 | Return Sludge Ratio Unit |
| P32 | Final Settling Tank Ratio Unit |
| P33 | Bubbler Level Control System or Level Measurement |

Courtesy of BIF Corp.

KEY TO FLOW EQUIPMENT OF ACTIVATED
SLUDGE TREATMENT PLANT D

| Item | Description |
|---|---|
| 1 | Aeration Influent Channel Level Transmitter |
| 2 | Aeration Influent Flow Controller |
| 3 | Aeration Influent Flow Transmitter |
| 4 | Final Settling Tank Influent Channel Level Transmitter |
| 5 | Final Settling Tank Influent Flow Controller |
| 6 | Final Settling Tank Influent Flow Transmitter |
| 7 | Effluent Flushing and Industrial Waters Pressure Transmitter |
| 8 | Return Sludge to Aeration Flow Controller |
| 9 | Return Sludge to Aeration Flow Transmitter |
| 10 | Waste Sludge Flow Tube |
| 11 | Waste Sludge Flow Transmitter |
| 12 | Waste Sludge Flow Controller |
| 13 | Waste Sludge Flow Transmitter |
| 14 | Thickener Recirculation Flow Controller |
| 15 | Thickener Recirculation Flow Transmitter |
| 16 | Blending Tank Ultrasonic Level Transmitter |
| 17 | Thickener Overflow Tube |
| 18 | Thickener Overflow Flow Transmitter |
| 19 | Sludge Storage Tank Ultrasonic Level Transmitter |

Courtesy of BIF Corporation

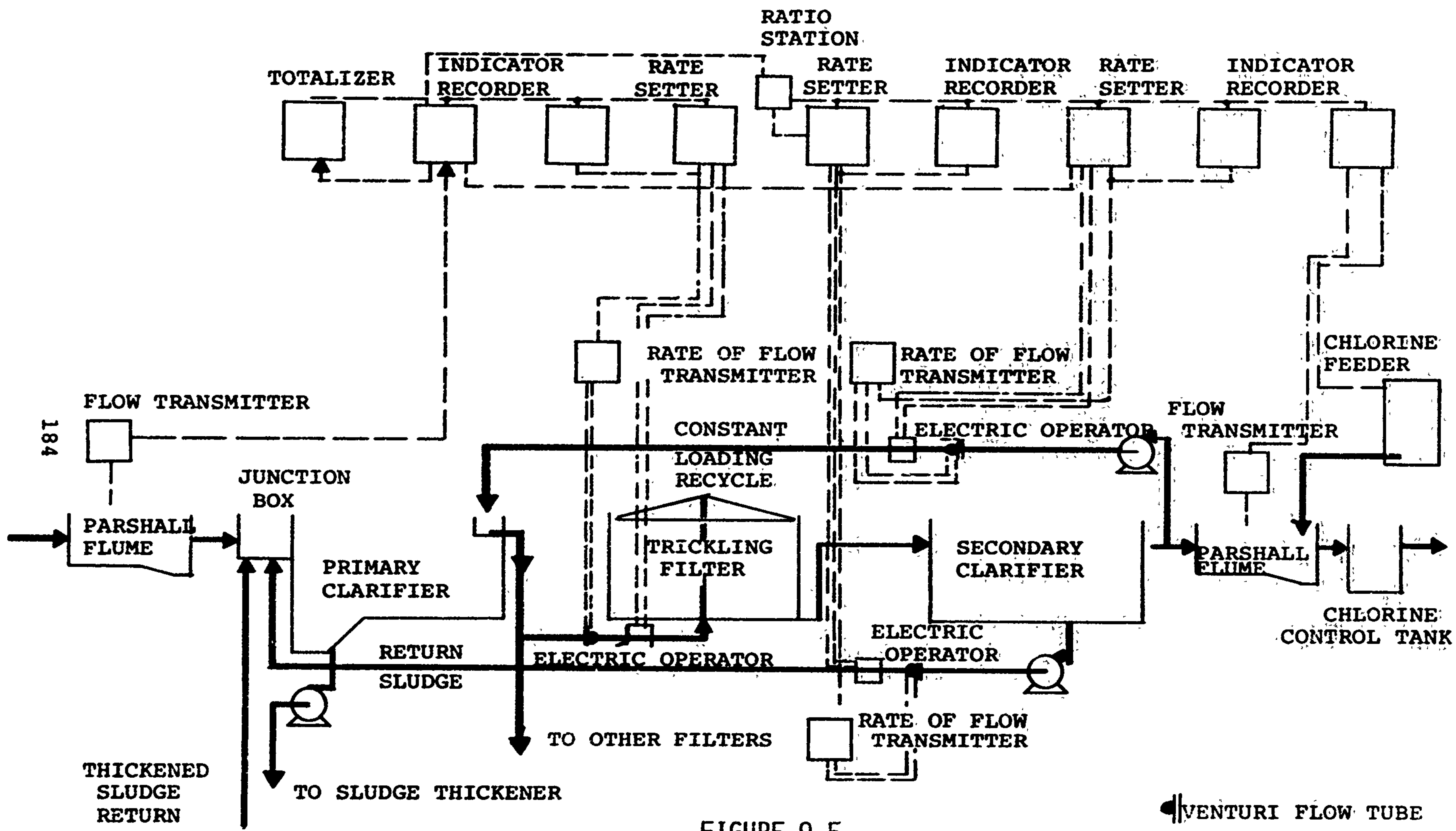



FIGURE 9-5
TRICKLING FILTER SEWAGE TREATMENT PLANT

COURTESY OF BIF CORP.

bid, the instrument manufacturers and systems suppliers will adjust their prices to remain competitive. Therefore, the costs associated with entire instrumentation and control systems, as just presented, would be more representative of actual costs, although they still represent just estimates and "ballpark" figures.

Appendix A presents a listing of the names and addresses of the various manufacturers mentioned in the course of this report.

Appendices B and C present as examples of present design considerations the instrumentation and control specifications of two activated sludge treatment plants.

## CHAPTER 10

## CONCLUSIONS AND RECOMMENDATIONS

### 10.1 CONCLUSIONS - MANUFACTURERS, INSTRUMENTATION, AND PROCESSES

#### 10.1.A Manufacturers

The various instrumentation manufacturers are an excellent source of process control information. The best advice and service can be provided by those companies with a histroy of involvement in the water-wastewater field.

#### 10.1.B Instrumentation

Those areas of the wastewater treatment process which have had the greatest success in being instrumented for control and/or information purposes are as follows:

1. Flow measurement: Venturi flow tubes, magnetic flow meters, and in-stream floats.
2. Chlorination: Residual chlorine for disinfection.
3. Sludge withdrawal: Timed, or flow totalized process initiation, and pumping duration by time.
4. Dissolved oxygen: Air-flow splitting in diffused air systems for activated sludge, using D.O. or ORP probes, and venturi flow tubes. Also record keeping of plant effluent D.O.
5. Return activated sludge: magnetic flow meter and ratio controller, or sludge depth control on final clarifier with turbidimeter.
6. Trickling filter recycle: Ratio controllers governing amount of recycle proportional to raw sewage flow.

7. Wet well level control: Capacitance rods, floats, or air bubblers to initiate pump sequencing.

8. Sludge bed depth: Turbidimeters, passive or active.

9. Anaerobic digester operation: Gas flow meters, temperature indicators, and level indicators.

10. Automatic sampling: Proportional and non-proportional samplers; proportional samplers operating according to totalized flow or sewage depth. Non-proportional operating at fixed time intervals.

Those areas of the wastewater treatment process which have only become instrumented and/or controlled, and offer excellent potential are as follows:

1. Computers: for logging purposes only, or for direct digital control of processes, with analog back-up.

2. Flow measurement: Bubbler systems for depth of flow at flumes or weirs.

3. Bar screen actuation: Bubbler system for measuring head differentials.

4. Chlorination: ORP for odor control.

5. Sludge withdrawal: Pumping duration by density measurement - nuclear, sonic, and specific gravity.

6. Dissolved oxygen: Surface aeration control by variable speed aerators, basin depth control by variable weir, and sliding spline shafts on aerators.

7. Sludge depth control: Infrared detection of sludge blanket.

8. Anaerobic digester operation: Analysis of gas production by hydrocarbon analyzer or specific gravity analyzer.

### 10.1.C Processes

There are many new and promising processes which have appeared in the field of wastewater treatment. Many of these processes require instrumentation for their successful operation and others will eliminate the need for instrumented control. For instance, the rotary-gravity screens should be able to operate in place of primary clarifiers without the need to precisely control sludge removal since the device dewaters the sludge in the process.

High purity oxygen aeration in conventional activated sludge appears to offer a large step forward in increasing treatment efficiency. In order to make this process perform well, it will be necessary to have close, automatic control of the dissolved oxygen levels in the aeration basins.

Anaerobic digesters cannot be automatically controlled, yet the more instrumented information that an operator has about the digester, the more precisely he can apply his "art" of digester control. On the other hand, aerobic digesters are much less complicated, are more easily controlled, and require a minimum of instrumentation, such as dissolved oxygen.

## 10.2 RECOMMENDATIONS

1. This study has shown that it is feasible to apply instrumentation to the automated control of wastewater treatment plants. A more in-depth evaluation should be carried out to determine how plant automation may be applied to specific Army needs.

2. A survey should be performed delineating the number of wastewater treatment plants at U.S. Army installations, as well as the degree and type of treatment performed. The degree of treatment would include primary or secondary, and type of treatment would include trickling filter, activated sludge, or oxidation ponds.

3. A collection of typical U.S. Army plant layouts, capacities, and process schemes should be compiled.

4. An inventory of process instrumentation at existing U.S. Army treatment facilities should be made.

5. The above information should be used to:

   a. Develop a picture of the present contribution of instrumentation to Army wastewater treatment plant operation.

   b. Develop several "typical" treatment plants to determine which areas of the treatment process would benefit most from instrumentation for manual or automatic control. This data would be used to initiate an in-depth study to determine the availability of control and automated equipment to fulfill the U.S. Army's long range treatment guidelines to include in-depth economic considerations, degree of operator training, and applicability of equipment.

6. Feasibility studies should be performed to determine the applicability of some of the newer, more promising treatment processes to U.S. Army installations. Examples of these process changes would include: oxygen aeration; surface aeration control by various methods; wet air oxidation of sludge; and multihearth sludge incineration.

7. An evaluation should be made to determine the most reliable type of proportional sewage sampling.

8. A study should be performed to investigate the possibility of controlling F/M ratios in U.S. Army sewage plants by the use of automated methods for determining organic loadings. Specifically, the study would involve performance evaluation of the three devices available

for this purpose (total oxygen demand analyzer, total organic carbon analyzer and automated COD), as well as the ability of this equipment to interface with control devices.

9. For those U.S. Army sewage plants treating combined industrial and domestic waste, instrumentation arrangements and control loops should be developed which would divert toxic amounts of industrial waste to storage lagoons. Subsequently, a programmed rate of return to the plant would effect the desired rate of treatment.

10. An economic and performance evaluation should be made of the various dissolved oxygen analyzers designed to be employed in activated sludge treatment plants for the purpose of automatic control of D.O. Once the best analyzer has been chosen, the optimum treatment scheme employing D.O. control should be determined. The treatment processes to be evaluated would be: variations on conventional activated sludge using diffused air; and the various methods for D.O. control using surface aeration.

11. Control system guidelines in hardbook form should be developed for U.S. Army personnel depicting automation and control alternatives available for various types of wastewater treatment plants at U.S. Army installations.

# APPENDICES

APPENDIX A

LIST OF MANUFACTURERS

## APPENDIX A

## LIST OF MANUFACTURERS

Autocon Industries, Inc.
995 University Avenue
St. Paul, Minnesota 55104

Automation Products, Inc.
3030 Max Roy Street
Houston, Texas 77008

Beckman Instruments, Inc.
2500 Harbor Blvd.
Fullerton, California 92634

BIF Division, General Signal Corporation
P.O. Box 276
Providence, Rhode Island 02901

Biospherics, Inc.
4928 Syaconda Road
Rockville, Maryland 20853

Brooks Instrument Division, Emerson Electric Co.
407 West Vine Street
Hatfield, Pennsylvania 19440

Chicago Pump
622 Diversey Parkway
Chicago, Illinois 60614

Cochrane Division
Crane Company
King of Prussia, Pennsylvania 19406

Clow Corporation
1999 North Ruby Street
Melrose Park, Illinois 60160

Dorr-Oliver, Inc.
77 Havemeyer Lane
Stamford, Connecticut

Eimco, Division of Envirotech
3000 Sandhill Road
Menlo Park, California 94025

LIST OF MANUFACTURERS (Cont.)

Fischer & Porter
County Line Road
Warminster, Pennsylvania 18974

Fisher Controls
Marshalltown,
Iowa

Foxboro Company
38 Neponset Street
Foxboro, Massachusetts 02035

Green Bay Foundry and Machine Works
P.O. Box 2328
Green Bay, Wisconsin 54306

Hach Chemical Company
P.O. Box 907
Ames, Iowa 50010

Infilco Products
P.O. Box 5033
Tucson, Arizona 85703

Instrumentation Specialties Company
4700 Superior
Lincoln, Nebraska 68504

Kay-Ray, Inc.
740 Northwest Highway
Palatine, Illinois 60067

Keene Corporation
1740 Molitor Road
Aurora, Illinois 60507

Kerotest Manufacturing Corp.
2525 Liberty Avenue
Pittsburgh, Pennsylvania 15222

Lakeside Engineering Corporation
222 West Adams Street
Chicago, Illinois 60606

LIST OF MANUFACTURERS (Cont.)

Leupold and Stevens Instruments, Inc.
P. O. Box 25347
Portland, Oregon 97225

Nappe Corporation
10 First Street
Pelham, New York 10803

National Sonics Corporation
43 Milbor Avenue
Farmingdale, New York 11735

Parkson Corporation
5601 Northeast 14th Avenue
Fort Lauderdale, Florida 33308

Permutit Company
East 49 Midland Avenue
Paramus, New Jersey 07653

Protech, Inc.
Roberts Lane
Malvern, Pennsylvania 19355

Robertshaw Controls
333 North Euclid Way
Anaheim, California 92803

Rockwell Manufacturing Company
Rockwell Building
Pittsburgh, Pennsylvania 15208

Snyder Teague, Division of BIF
P. O. Box 41
Largo, Florida 33540

Sonford Products Corporation
100 East Broadway
St. Paul Park, Minnesota 55071

Technicon Industrial Systems
Tarrytown
New York 10591

LIST OF MANUFACTURERS (Cont.)

Union Carbide Corporation
Instrument Department
5 New Street
White Plains, New York 10601

Universal Interloc, Inc.
17401 Armstrong Avenue
Santa Anna, California 92705

Wallace & Tiernan, Inc.
25 Main Street
Belleville, New Jersey 07109

Weston & Stack, Inc.
446 Lancaster Avenue
Malvern, Pennsylvania 19355

Worthington Pump International
Harrison Operation
Harrison, New Jersey 07029

CONSULTANT FIRMS

Charles J. Kupper, Inc.
15 Stelton Road
Piscataway, New Jersey 08854

Cook, Coggin, Kelly, and Cook
Engineers-Consultants
703 Crossover Road
Tupelo, Mississippi 38801

# COMMERCIAL REFERENCES


Autocon Industries, Inc., Product Catalog

BIF Product Catalog, Volume I

Bird Machine Company, South Walpole, Massachusetts 02071

Brooks Instrument Division, Emerson Electric Company,
Measurement and Control Instrumentation Catalog

Chicago Pump, Division, FMC Corporation
Sewage Equipment Data Catalog

Clow Engineering Manual, Vol. 1

Eimco Sanitary Binder, Vol. 1

Fischer & Porter, Water and Waste Equipment

Fisher Controls, Instrumentation Catalog 400

Foxboro Instrumentation Loops Catalog

Hinde Water Pollution Control Catalog

Keene Corporation Water Pollution Control Division - Catalog

Rockwell Manufacturing Company, Gas Meters - Instrument

Robertshaw Industrial Instrumentation Division Catalog

Wallace & Tiernan, Inc., Chlorination Catalog, Vol. 1

Worthington Water Pollution Control Equipment
2100 Series Catalog

# APPENDIX B

Instrumentation Specifications for a Secondary Wastewater Treatment Plant for the University of Mississippi, designed by Cook, Coggin, Kelly, and Cook, Engineers-Consultants, Inc., of Tupelo, Mississippi.

# INSTRUMENTATION AND CONTROL SYSTEM

1. GENERAL REQUIREMENT — Furnish and install a complete instrumentation and control system. The complete system shall be supplied by a single manufacturer with at least 5 years experience in the water and waste water control field.

To insure proper coordination, all equipment listed in this section shall be furnished by one supplier and complete hydraulic layouts, electrical schematic drawings, dimension drawings and functional descriptions shall be provided.

2. MAIN CONTROL CENTER — The main control center enclosure shall be formed, 14 gauge steel, bonderized and finished in two coats of enamel, in a color to be selected by the engineer. The enclosure shall be braced by 1-1/2" welded structural angles at top, sides and bottom. The enclosure shall meet NEMA I requirements and shall be constructed as illustrated on the drawings.

The following equipment shall be mounted within the control center:

a. All electrical devices as set out in the electrical specifications.

b. Four Variable Frequency-Adjustable Voltage Drives for Raw Sewage and Activated Sludge Recirculation Pumps.

c. One Time Clock for each of two Banks of Aerators.

d. Time Clock for Degritter Conveyor.

e. Time Clock for Control of Digester Aerator.

f. Raw Sewage Flow Indicator, Recorder & Totalizer.

g. Return Activated Sludge Flow Indicator.

h. Final Effluent Indicator, Totalizer & Recorder

i. Residual Chlorine Indicator and Recorder.

j. Two Independent Bubbler Control Systems with air purge, one for Raw Sewage Pumps and the other for Return Activated Sludge Pumps each with 4 1/2" Wet Well Level Gauge.

k. Autosensory Equipment necessary for proper operation of Control Systems.

l. Indication of Suspended Solids in each Aeration Basin.

m. Indication of Dissolved Oxygen in each Aeration Basin.

n. Alarm Indication of each of the following Conditions along with a Common Audible Alarm shall be provided:

   1. High and Low Raw Sewage Wet Well Level.

   2. High and Low Activated Sludge Wet Well Level.

o. Air purge controls for bubblers and flow tube.

Incoming power shall be 460 Volts, 3 Phase, 3 Wire, 60 Hz. Wiring shall be NEMA Class 2, Type C, with Master Terminal Strip.

All Variable Frequency Drive Output Leads and Constant Speed Starter Load Leads for the Raw Sewage Pumps shall be brought out to a Common Terminal Strip and provisions shall be made to connect any one of the three Raw Sewage Pump Motors to either Variable Speed Drive or the Constant Speed Starter.

The Return Activated Sludge Pump Motors shall also be connected in this fashion, so that each of these three Motors could be connected to either Variable Frequency Drive or the Constant Speed Starter.

The Enclosure Assembly shall consist of the necessary number of vertical sections required to accomodate the control devices. Each such vertical section shall be rigid, freestanding and be designed for multiple alignment with continuous main bus. Multiple vertical sections shall be securely fastened together and be sufficiently rigid to withstand usual handling during shipments and installation without frame distortion. Power equipment shall be isolated from the integral Autosensory equipment by sheet steel barriers. The Main Control Center shall be Autocon PlanPak I, as manufactured by Autocon Industries, Inc., Division of Control Data Corporation, St. Paul, Minnesota, or approved equal.

3. VARIABLE SPEED DRIVES — The Control System for both Raw Sewage and Return Activated Sludge Pumps shall be an integral part of the Main Control Center.

Two identical systems, each consisting of two Variable Frequency Drives and one Constant Speed Motor Control shall be provided. One system shall control the Raw Sewage Pumps and the second system shall control the Return Activated Sludge Pumps.

The Variable Frequency Drives shall be designed to power standard NEMA B Squirrel Cage Motors and shall vary both the Frequency and Voltage of the incoming power, thereby controlling speed without overheating the motor.

Wet well level shall be measured by self-purging Bubbletrols, one for each system, and air shall flow through an adjustable Air Flow Regulator, calibrated to permit visual setting of Bubbler rate. Raw Sewage Bubbler Tube shall be 1/4" outside diameter, hard copper from Control Panel to point of vertical run directly above the Wet Well and shall be 1/2" O.D. Stainless Steel Tubing from this point to termination. Recirculated Sludge Bubbler Tube shall be 1/2" O.D. hard copper tubing, from Control Panel to Wet Well located between the Clarifiers and shall be 1/2" O.D. Stainless Steel Tubing from directly above Wet Well to point of termination. A Stainless Steel Bubbler Tube Guard shall be installed on the end of each Bubbler Tube in the Wet Wells. Each Bubbler shall be equipped with a manual, high pressure purge system with a pushbutton for hold to purge operation.

Solid-State Signal Conditioners, one for each system, shall be employed to sense wet well level and provide electrical intelligence to the Variable Speed Drives, to control the speed of the pumps at desired wet well level.

The control shall start the Lead Pump at minimum speed and as the level rises, the control shall increase speed uniformly up to maximum speed. If the level continues to rise, the second pump shall start at a reduced speed.

After a predetermined time delay, the Lead Pump and the second pump shall share the pumping load equally and as the level rises, the control will increase the speed of both pumps to meet inflow requirements.

If, for any reason, the wet well level continues to rise with both Variable Speed Pumps running at maximum speed, or if one of the Variable Speed Pumps fails, the Constant Speed Pump will automatically start at a pre-determined level. Elevations for pump control shall be set as directed by the Engineer.

The Variable Speed Pump sequence shall be alternated once every 24 Hours. In the event of power failure, the Lead Pump will start at minimum speed upon restoration of power. Provision shall be made to remove pumps from automatic control and operator shall then be able to manually adjust speed of motor at control panel and motor speed shall be indicated at panel.

The Variable Frequency Drive shall be an all solid-state AC to AC Convertor, utilizing Silicon Semi-Conductors in the power switching circuits. The VFD shall vary both the AC voltage and frequency simultaneously to maintain a constant output volts/cycle relationship. The variable frequency drive shall be specifically designed for variable-torque pumping loads, fully capable of a 3:1 speed range with less than 3% slip at rated speed. The control shall vary the output frequency between 20 and 60 Hz, maintaining 5% regulation on volts per cycle. Control circuitry shall limit inrush current under both manual and automatic operating conditions.

The Variable Speed Controllers shall be Autocon Class 2000 Variable Frequency Drives as manufactured by Autocon Industries, Inc., Division of Control Data Corporation, St. Paul, Minnesota.

4. AIR COMPRESSORS

Air for the Bubbler Systems and air purges to bubblers and flow tube shall be supplied by two 1/4 H.P. Air Compressors, complete with one 10 Gallon Storage Tank, Air Intake Filter, Adjustable Pressure Switches, Pressure Reducing Valve and Discharge Pressure Gauge.

The sequence of the Compressors shall be automatically alternated and in the event of a failure of one Compressor, the second compressor will be immediately started. Shutoff Valves which isolate each compressor shall be provided.

The Compressor Systems shall be installed located as noted on the drawings.

5. ALARMS

A Twin Pressure Sensor shall be installed in each Bubbler System to sense Bubbler back pressure and shall be adjusted to close a contact at high wet well level. After actuation by a high level alarm condition, the contact shall remain closed until automatically restored at a safe level.

A second Twin Pressure Sensor shall also be installed in each Bubbler System to close Alarm Contacts at a low wet well level condition. The low wet well alarm shall be automatically restored at a safe level.

The audible alarm shall be a NEMA 4 Horn mounted on the control building exterior.

6. INSTRUMENTATION

The Contractor shall provide all labor, materials, equipment, tools and services required to furnish and install the instrumentation system described in this section of the specifications.

A 12" throat Parshall Flume Liner constructed of fiberglass shall be installed in raw waste water line as noted on drawings.

The flume shall be designed specifically for measurement of flow through partially filled lines where free-flowing conditions exist. The flume shall have a flat invert completely free from pockets and obstructions. The fiberglass shall be of such strength so as not to distort during concrete pouring.

For use with and mounted upon the Parshall Flume, there shall be an electric transmitter housed in a water and weather-proof case. The transmitter shall be actuated by a corrosion-resistant ski-type sensor which shall be located directly in the flume, riding on the surface of the fluid being measured. The sensor shall be directly connected to the transmitter by a corrosion-resistant rod and shaft without the use or presence of cables, pulleys, sheaves or rollers. The use of stilling wells, pressure pipe or flushing systems will not be acceptable. The transmitter shall include a visible indicator with a 0 to 100% scale.

The transmitter shall contain a scanning system based upon dual glass enclosed contacts in series which will initiate the signal when a data arm mounts and rides upon a characterized cam. The signal shall end when the data arm drops off the trailing edge of this cam. Four No. 14 Wires shall be installed to carry this signal from transmitter location to main control center and power from control center to transmitter.

A solid-state signal conditioner shall be installed at the main control center to accept flume transmitter signal and convert this signal to proper intelligence for indicating, totalizing and recording.

A 12" throat Parshall Flume Liner of fiberglass complete with transmitter and signal conditioner as described above, shall be furnished and installed as noted in the drawings in the final effluent line. The solid-state signal conditioner in the final effluent flow loop shall provide a 4 to 20 Milliamp Signal to pace the Chlorinator in addition to an indicating, totalizing and recording signal.

A 12" in diameter cast iron Flanged Type Flow Tube shall be installed in a concrete box with grating as indicated on the drawings in the recirculated, activated sludge flow line.

A differential pressure to current transmitter of the proper range shall be furnished to measure differential pressure created by the flow tube and the current signal developed shall be transmitted to the main control center for indicating the flow. Connect flow tube to transmitter to control center and to air purge system.

Electronic recorders of the 4-1/2" Strip Chart Type which have a 4 to 20 Milliamp input Signal shall be supplied. Chart travel shall be 7/8" per hour and continuous for 30 days. A one year's supply of charts and ink shall be furnished with each recorder.

One existing Infilco refrigerated sewage sampler shall be removed from the existing plant, cleaned up and reinstalled in the new building. The existing control panel shall be removed, cleaned up and reinstalled to serve the effluent sampler. Provide a manual transfer switch so that this sampler may be used for either raw or final samples.

A high pressure air purge with push-button and air valves shall bp installed to clean the pressure taps on the recirculating flow tube.

7. DISSOLVED OXYGEN MONITORING AND INDICATING SYSTEM

The contractor shall furnish and install a complete dissolved oxygen monitoring and indicating system. This system shall provide continuous indication of the dissolved oxygen level in each of the 2 aeration basins. The complete system shall be as manufactured by Weston and Stack, Inc., Malvern, Pennsylvania.

The primary sensing device for the oxygen level shall be a galvanic, membrane type oxygen probe mounted in the aeration tank and operated in conjunction with a dissolved oxygen analyzer installed in the control building.

The major components of the D.O. monitoring system shall include the following. The quantities listed are the total required for 2 aeration basins, including spares.

(2) Dissolved Oxygen Probe, Weston and Stack Model A-40.

(2) Sampler, Agitator Unit, Weston and Stack Model A-25.

(2) Dissolved Oxygen Analyzer, Weston and Stack Model 3000-1-B with indicator.

(2) Mounting Brackets for Probe/Sampler Units.

(2) "Y" Type cable assemblies probe to remote calibration unit.

(2) Remote Calibration Units, Weston and Stack Model RC-1.

(1) Maintenance Kit for Probe and Sampler Unit.

The Individual components of the dissolved oxygen system shall comply with the detailed specifications as hereinafter set forth.

Model A-40 Probe - The dissolved oxygen sensing probe shall be model A-40 as manufactured by Weston and Stack, Inc. It shall be of a galvanic cell type having a platinum cathode and lead anode. The probe shall be of the membrane type, utilizing a 2 mil teflon membrane and shall be equipped with a thermistor circuit providing continuous, automatic, active temperature compensation in the range from 0-50°C. For long-term, drift free performance, the lead anode shall be at least 438 sq. centimeters in the area exposed to the electrolyte and the net electrolyte volume shall be at least 326 cc's. The probe shall have zero output, repeatable at zero D.O.

Model A-25 Cleaner, Sampler, Agitator Assembly - The Model A-25 cleaner-sampler-agitator assembly shall be specifically designed to prevent fouling of the teflon membrane by means of a gentle wiping action near the face of the membrane. This near-wiping action shall also cause a liquid movement in the area of the probe tip which will ensure an even intensity of agitation at the membrane surface. The agitation or flow in the area of the membrane shall be such that the liquid sample is drawn in from the area surrounding the probe tip and discharged away from the membrane surface. The impellor-wiper assembly shall be made of silicone rubber and designed to minimize fouling from rags or stringy material. Its construction shall be such that it creates an area of reduced pressure or suction surrounding the probe tip with the discharge being outward and away from the membrane surface. The sampler unit shall be driven by a continuous duty 110 volt 60 Hz motor. The motor shall be mounted in a sealed, waterproof, molded, epoxy housing. The sampler drive unit shall be of the magnetic twin-disc type, eliminating the need for stuffing boxes or mechanical seals around the motor shaft.

Remote Calibration Unit - Each aeration tank shall be provided with a remote calibration unit, Weston and Stack Model RC-1. This unit shall be furnished in a weatherproof, brushed stainless steel enclosure and shall include a readout meter such that D.O. level can be read near the probe. The Model RC-1 shall also include a calibration knob such that the probe may be calibrated at the aeration tank without need for going to the analyzer. The unit shall include an on/off switch for the 110 VAC supply to the motor of the A-25 Sampler.

Dissolved Oxygen Analyzer and Consoles - The dissolved oxygen analyzers shall be installed in the control center panels with the strip chart recorder. Each analyzer channel shall be equipped with a high-low set-point type readout meter. The set points shall be of the optical or electronic type and the movement shall be a taut band type with 1% accuracy and tracking. The analyzer shall have solid state circuitry mounted on a single epoxy-glas, printed circuit board. The p.c. board shall be a plug-in type with edge card connector. The board shall be polyurethane coated on the foil side for protection against moisture. The maintenance and spare parts kit described elsewhere in these specifications shall include one spare complete p.c. board with all components pre-installed. The analyzer shall be equipped with dual readout scales such that the dissolved oxygen level may be read either in the range of 0-15 ppm or in the range 0-1.5 ppm. The temperature readout shall have a scale of 0-50°C and shall be accurate to plus-minus 1°C over the entire range. The temperature compensation circuit shall be of the active type.

Probe Mounting Bracket - A specially designed probe mounting bracket shall be furnished for each aeration tank. The bracket shall mount to the tank at location designated on the plans. The bracket shall serve to protect the probe from accidental damage and shall also permit easy inspection of the probe and sampler unit without cumbersome disassembly or risk to the safety of the plan operator.

Electrical Cables - Special, submersible type cables shall be furnished. These shall be molded "Y" type, 6 conductor cables for connections between the probe-sampler units and the railing mounted remote calibration units. These special 6 conductor cables shall be furnished by Weston and Stack, Inc. Additional 4 conductor cables of suitable length shall be furnished and installed between the remote calibration boxes and the dissolved oxygen analyzer-recorder consoles in the control building. These cables shall be furnished by the electrical contractor and shall be 18 gage, 4 conductor, non-shielded type SJO, installed in conduit as required and directed by the Engineer. The contractor shall also provide 120 Volt AC 60 cycle power to the remote calibration unit which will be mounted near the probe site.

8. MIXED LIQUOR SUSPENDED SOLIDS INDICATING SYSTEM — Furnish and install complete mixed liquor suspended solids indicating system providing continuous indication of the mixed liquor suspended solids level in each of the 2 aeration basins. The complete system shall be as manufactured by Keene Corporation, Aucora, Illinois.

a. Analyzer — The Model 8200 Suspended Solids Analyzer shall instantaneously and continuously measure the Suspended Solids concentration in aeration basins. The instrument shall consist of two parts interconnected with cables: The sensing probe, installed directly in the mixed liquor process basin, and the indicator assembly which shall be located in the control center. The instrument shall provide automatic, unattended operation, with indications reading directly in parts per million (PPM), over the range of 500-5000 PPM.

b. Probe — The probe shall be mounted directly in each aeration basin as shown on the plans. It shall be comprised of a sensing head, fixed to the end of a section of standard 1" PVC pipe. The sensing head itself shall be a metal cylinder which houses a light bulb and two photocells. Its exposed surface shall be covered by a thin sheath of heat-shrinkable Teflon and sealed against water by O-Rings near either end. The smooth surfaces shall be anit-fouling and debris which would accumulate, and affect the instrument's operation wash past the sensing area.

A cable inside the pipe shall connect the leads from the light bulb and photocells to terminals in the junction box. To facilitate removal of the sensing head from the pipe, a six-pin cable connector is located in the lower end of the probe.

c. Indicator Assembly — The indicator assembly shall house the power supplies and the electronic computing and indicating components of the instrument. The components shall be enclosed in a metal dust cover which shall be panel-mounted in the control center. On the front panel of the indicator shall be the power switch and indicating light, and a 4-1/2" meter which provides a single range, linear indication of Suspended Solids in the range of 500 to 5000 PPM. The instrument assembly shall be accurate to a tolerance of $\pm$ 5% of actual conditions.

# APPENDIX C

Instrumentation Specifications for a Secondary Wastewater Treatment Plant for the City of Middletown, N.J., designed by Charles J. Kupper, Inc., Piscataway, N.J.

## CONTROL EQUIPMENT

## SECTION 426



Section 466.1 General. There shall be furnished and installed at the locations indicated on Contract drawings, a plant control and indication system. This system shall consist of Units "A", "B1", "B2", "C1", "C2", "D" & "E" and shall be located as shown on the plans.

This equipment shall operate as an integrated motor control system, including variable speed control of the raw sewage and activated sludge pumps, an operations indication and control center for all shown process motors, an instrumentation display center, and a remote telemeter alarm and display center for pumping station alarms.

All units shall be the product of a single manufacturer, who shall assume responsibility for operation of the entire system. The Instruments, which are described in detail in "METERS AND INSTRUMENTS" and located in control units, shall be supplied, mounted and wired, by this control system manufacturer who shall assume responsibility for their coordination with the various controllers associated with them, and shall arrange for the supervised start-up of this equipment in the field.

Meters and instruments which are located remote from control centers shall be furnished and received by the Electrical Contractor, supplied to and mounted by the General Contractor.

Section 426.2 Unit Construction shall be equivalent to Autocon Plan Pak IA, being motor control center type construction equal to NEMA Type C Class II.

Equipment shall be housed in free-standing sheet metal enclosures for front access or as shown on plans, NEMA I welded #14 gauge steel, of number and dimensions as shown on plans. Top and bottom frames shall be 1-1/2" welded structural steel. Top plates shall be one piece #14 gauge sheet.

Structures shall have horizontal wireways at top and bottom, and vertical wireway with cable supports in each section. Doors shall be individually flanged and gasketed, mounted on semi-concealed, full length piano type hinges, for each motor starter compartment, and secured by 1/4 turn, slotted-head speed fasteners.

Main bus shall extend across top of all motor control sections with provisions made for shipping splits as shown, or required. Main bus shall be rated 600A. Bus shall be rectangular with rounded corners, of electrolytically pure copper, adequately supported on low tracking, high impact strength bus supports. All points of electrical connection shall be silver plated. Vertical bus shall be set for stab connection, where required, and rated 300A.

Size 4 starters, or smaller, or other control units, shall be mounted on a steel draw-out chassis of proper dimension for 4½" module design and shall so house components as to isolate them from adjoining circuits. Bus connection shall be by silver plated high conductivity stabs spring steel loaded for positive contact pressure. Test and fully disconnected positions shall be provided with provisions for padlocking in disconnected position.

Control shall be suitable for operation on 480 volts, 3 phase, 3 wire, 60 Hz AC power supply. Bus shall be braced to withstand 25,000 RMS ampere fault current. Centers shall be designed, manufactured and tested in accordance with latest applicable standards of NEMA, AIEE, and ASA.

Provide Standard 3" levelling channels. Master Terminal blocks shall be mounted at bottom. Outgoing load wires shall be from botton. Incoming supply feeder shall be from botton with lugs provided on main bus size as indicated or for load.

Motor starters, contactors, and circuit breakers shall be Westinghouse, Square D. Company, or approved equal as set forth in the proposal.

Units shall be prepared for painting by cleaning to bare metal and "bonderizing". Prime coat shall be Dupont Acrylic Primer #810-072, 1 Mil thickness and flash bake for 5 minutes at 300°F; finish coat Dupont Dulux Alkyd Enamel sprayed 1½ mil thickness baked 30 minutes at 300°F. Color to be selected by Engineer from manufacturer's color chart.

Section 426.3 Variable Speed Drives. Variable speed drives shall be suitable for use as secondary controllers for wound rotor motors. They shall be combination, reactor-resistance, all electric, units for the speed control of Wound-Rotor Motors by means of varying impedance in the motor secondary circuit. Manufacturer shall review proposed characteristic curves of proposed pumps, system curves and hydraulic conditions, and certify in his submittal that the drive was designed for these specific pumps, motors and hydraulic systems. Secondary characteristics of the motors shall be as shown on contract drawings.

Speed variation shall be means of variable reactance controlled by DC current from a Solid-State amplifier paced by a Program Controller. Drives shall hold power factor within 5% of pure resistance value, and each shall employ not less than 2 intermediate speed zone contactors which shall provide multi-speed, standby operation of pumps in event of stepless drive failure. Furnish drive transfer contactors and full speed contactors as shown on contract drawings. By-product speed control heat shall be dissipated directly to the air by drives.

Range of speed control shall be from 98% of motor full load speed down to a speed producing zero flow against the static head. Full automatic and manual control of drives, local and remote, shall be furnished as shown on plans.

Start of pumps, by any means, shall be with all resistance in secondary circuit of Wound-Rotor Motor, and current shall be limited to 125% of motor full load nameplate value.

Drives shall be equal, in opinion of Engineer, to Autcon Reactospeed Class 1901, and shall be programmed by the autosensory sections of Units "B" & "C" as described under individual units.

Section 426.4 Program for Power Failure Re-start

1. All variable speed pump controls, specified with wound-rotor motor drives, shall have integral power failure recycle feature, which, after power failure and restoration shall automatically restart motors, in adjustable sequence, at low speed - low voltage.

2. All other motors controlled by Units "A" thru "E" shall have motor restart program timers which shall restart designated motors on the following schedule:
(Motors not listed do not restart automatically)

Section 426.4 Program for Power Failure Re-start (continued)

| | Motor | Seconds After Power Restoration |
|---|---|---|
| **UNIT "A"** | | |
| 1. | Plant Water Pump #1 | 15 |
| 2. | Plant Water Pump #2 | 30 |
| 3. | Plant Water Pump #3 | 45 |
| **UNIT "B"** | | |
| 1. | Aerator #1 | 60 |
| 2. | Aerator #2 | 65 |
| 3. | Aerator #3 | 70 |
| 4. | Aerator #4 | 75 |
| 5. | Aerator #5 | 80 |
| 6. | Aerator #6 | 85 |
| 7. | Aerator #7 | 90 |
| 8. | Aerator #8 | 95 |
| 9. | Aerator #9 | 100 |
| 10. | Aerator #10 | 105 |
| 11. | Aerator #11 | 110 |
| 12. | Aerator #12 | 115 |
| 13. | Blower #1 & #2 & 2 Final Settling Tank Drives | 120 |
| **UNIT "C"** | | |
| 1. | Screen Motors 1 & 2 Domestic Water Pump & Air Compressor | Instant |
| **UNIT "D"** | | |
| 1. | Raw Sludge Pumps | 10 |
| 2. | Horizontal Flight Drives 1 & 2 | 20 |
| 3. | Cross-Collector Drives 1 & 2 | 25 |
| 4. | Grit Remover Drive | 35 |
| **UNIT "E"** | | |
| 1. | Digester Heated Sludge Circulation Pump | 50 |
| 2. | Digester Gas Circulator | 55 |

Section 426.5 Unit "A" shall be contained in NEMA I cabinets equivalent to motor control center construction as described under "Unit Construction," below, and of number and dimensions as shown on plans, shall consist of motor controllers, sub-panel with transformer and disconnect circuit breaker to provide in-unit 120 VAC power, geographic panel with telemeter receivers, plant alarm section, plant status graphic panel and plant control bench, all as laid out in Contract Drawings.

Motor Controllers

For each sludge loading pump (SL-1,2) provide combination circuit breaker magnetic across-the-line motor starter, size 4 with 480V/120V control transformer 150 VA fused on secondary, 3 phase ambient compensated overload protection and low voltage release. Provide local control switch, and refer to contract drawings for circuit and component details, and to "Program for Power Failure Re-Start" section. Circuit Breaker Moulded Case 3P-FA Frame 150A Trip.

For each plant water pump (PW 1,2,3) provide motor starter as described above for sludge loading pump except NEMA Size 1 with 50 VA control transformer. Circuit Breaker 3P EH Frame, 25A Trip.

Sub-Panel #1

Moulded Case Circuit Breaker Disconnect, 2P EH Frame 15A Trip.

Dry type, single phase lighting transformer 3 KVA, 480V/120V.

Sub-panel NLAB Type 6 circuit SP with vault type door, directory key, under plastic, on reverse.

Control Bench shall be as shown on plans. All connections shall be brought down to master terminal boards in the base of each vertical section. Bench shall be constructed so as to provide for shipping splits. All operators not detailed on contract drawings shall be heavy duty oil tite.

Autosensory Section shall program re-start of controlled motors, and shall provide for the automatic control of plant water pumps as detailed below under "Motorol".

This section shall control speed of remote sludge return pumps (Unit "B") automatically and manually in conjunction with Autosensory Section of Unit "B" as described herein and under Unit "B". Provide ratio controller, ratio setter and bi-directional relay as described under "Instrumentation" together with means to switch sequence operation of pumps, select manual or automatic operation, and provide for increase and decrease of plant flow from 0 output of 1 pump to maximum output of 3 pumps, manually or automatically from this section or from Unit "B". Flow indication and status operation shall be as shown on contract drawings.

Section 426.5 Unit "A" (continued)

Geographic Panel shall be equivalent of Autocon Model B-1 Geographic Panel, with area map printed on transluscent plastic sandwiched between clear plastic sheets, aperture 23" W x 2?" H. The face of display panel shall be mounted flush with the cabinet. No symbols nor indicating lights shall be mounted on the face of the display panel and all indicating lights shall transmit 2 c... light through faceof panel. There shall be no nameplates or m... ing screws on face of panel, which shall be perfectly smooth to facilitate cleaning of the panel by the operating personnel.

Operating light locations shall be as shown on plans and shall be coded as follows:

| | | |
|---|---|---|
| STP Location | - | Steady White |
| Each Pump Station | - | Normal - Dim Green<br>Common Alarm - Flash Green<br>Power Failure - Flash Red<br>Acknowledge - Steady Bright Color |

Geographic Panel shall be operated by 8 Telemeter Receivers equivalent to Autocon Model 9204R, modified with 143-1D Power Unit, 146-1B Relay Unit, & 149-2B Protection Unit. Telemeter shall conform to allregulations of New Jersey Bell Telco for equipment used over a single pair of leased lines from each re... station. Equipment shall be properly fused and isolated.

Leased lines to be provided by the Authority.

Six (6) telemeter transmitters are part of this Contract ... will be installed by others.

Area map shall be developed from one clear, unfolded, area drawing to be provided by the Engineer. Map shall be printed in black, water in blue, and collection system details in red, as desired by Engineer.

Manufacturer shall convert Engineer's map to finished art ... supply print for approval. Changes will be included in final art and photostat submitted for final approval.

Manufacturer shall retain and protect original artwork for a period of five years to facilitate changes to accomodate future alterations in the system.

Provide for operation and silencing of common Unit "A" Alarm Horn, and common alarm signal to police station, and for reset alarm circuits. Provide test buttons for checking colored la... These operations shall be mounted under the sewage treatment ... alarm section.

Single alarm receiver shall be furnished under this contract and mounted and wired at Township Police Headquarters.

Plant Status Panel shall be constructed as described under "Geographic Panel" except aperture shall be 36" x 60" Plant Flow Diagram shall be as shown on plans and shall be printed in multi-colors as described by Engineers.

Operating light locations shall be as shown on plans and shall be coded as follows:

| | | | |
|---|---|---|---|
| Motor | Off | - | Out |
| | Run | - | Amber |
| | Fail | - | Red |

Two speed aerator motor locations shall display amber light for low speed and blue light for high speed.

Provide necessary contacts and circuits for all motor starters reporting to this unit. Panel shall be operated by direct wires from operating equipment at the Sewage Treatment Plant location.

This section includes the following instruments detailed under "Instrumentation":

1. Thicken Sludge - IRT
2. Chlorine Residual - IR
3. Digester #1 Cover Position Indicator
4. Digester #2 Cover Position Indicator
5. Return Sludge Flow - IRT
6. Plant Flow - IRT
7. Raw Sludge Flow - IRT
8. Raw Sludge Density - IR
9. Digester #1 - Level Indicator
10. Digester #2 - Level Indicator
11. Ratio Setter
12. Ratio Controller

Plant Alarms shall be equivalent to Autocon SP-L-6 Annunciator type with square transluscent white box covers and black lettering. Nameplates 3-3/8" W x 3-3/8" H. Provide oval transformer type lights and standard indication, as below:

| Condition | Visual | Audible |
|---|---|---|
| Normal | Off | Off |
| Alarm | Flashing | On |
| Acknowledge | Steady | Off |
| Clear Alarm | Off | Off |

Provide common test button and silence button. Audible alarm shall be 4" Modutone Horn. This specification applies to alarm stations in Units A & C.

Unit "A" Alarm Stations shall be as follows:

1. Main Pump Station
2. Chlorine Room
3. High Chlorine Residual
4. Low Chlorine Residual
5. Low Process Water Pressure
6. Digester #1 High Temperature
7. Digester #2 High Temperature
8. Digester #1 Low Water Level
9. Digester #2 Low Water Level
10. Generator #1 Run
11. Spare
12. Spare
13-18. Blank Spaces with Cover Plates (future stations)

Provide modified Model BP-3A Autocon Motorcl for con[illegible] of 3 plant water pumps. Unit shall have 4½ diameter pr[illegible] gauge calibrated 0-100 psi, brass shut-off valves for va[illegible] and system and brass control bleed valve. Provide ind[illegible] point-operated sensors without minimum differential, [illegible] to ½ of 1%, full range, restricted movement type, for [illegible] program operation below. Operator shall activate contr[illegible] "off-on" switch and system "on" lamp. Thereafter pump [illegible] position, as selected by manual transfer switch, shall [illegible] constantly to pressurize system. On sustained pressure [illegible] 60 psi, lag pump shall start. On subsequent sustai[illegible] drop to 55 psi, lag 2 pump shall start. A reverse [illegible] shall apply on sustained pressure increase to 70 psi. .2-90 second adjustable rotary timers for each of five [illegible] Provide automatic electric alternation of Lag 1 & Lag 2 [illegible] Control Manufacturer shall review proposed pump chara[illegible] curves and system curve and certify control for operat[illegible] these specific pumps. Transfers between pumps shall [illegible] without shock and surge in system. A maintained pres[illegible] to 50 psi shall actuate "Plant Water Low Pressure" a[illegible]

Section 426.6 Units "B1" and "B2". Unit "B1" shall [illegible] tained in NEMA 1 cabinets equivalent to Type "C" Cla[illegible] standards built as described under "Unit Constructio[illegible]" and of number and dimensions as shown on plans. Shall [illegible] of motor controllers, sub-panel with transformer and [illegible] circuit breaker to provide in-unit 120 VAC power, au[illegible] section, and 3 phase feeder circuit breaker.

Unit "B2" shall consist of 2 Reactospeed variable [illegible] controllers for 3 return sludge pumps.

For each 2 speed Aerator (A1-A12) provide com[illegible] breaker, magnetic across-the-line 2 speed-2 winding [illegible] Size 2 (High Size 2 (Low) (1800/1200 RPM), with [illegible] transformer, 100 VA, fused on secondary, 3 phase ambient compensated overload protection in each set of windings (total 6 relays) and low voltage release. Provide local control switch, and refer to contract drawings for circuit and component details, and to "program for power failure re-start" section. Circuit breaker moulded case, 3P, EH Frame, 50A Trip. Provide transformer Type 6 VAC "Hi Speed" & "Lo Speed" "Run" lamps.

For each final settling tank drive mechanism (FST.1,2) Combination circuit breaker, magnetic across-the-line motor starter, Size "0" with 480V/120V Control Transformer, 50 VA, fused on secondary, 3 phase ambient compensated overload protection, and low voltage release. Provide local control switch, and refer to contract drawings. For circuit and component details, and to "Program for Power Failure Re-start" section. Circuit Breaker Moulded Case, 3 P, EH Frame, JA Trip. Provide transformer Type 6 VAC "Run" lamps.

For each blower motor (BL-1,2) provide combination motor starter as described above, for final settling tank drive, except circuit breaker trip shall be 20A. Ammeters shall be furnished for each motor calibrated in cfm.

For each return sludge pump (RC-1,2,3) provide combination motor starter as described above, for final settling tank drive, except NEMA Size ~~2~~3 ~~100~~ VA control transformer and circuit breaker trip shall be ~~100A~~/125 These pumps shall be programmed automatically from "Autosensory" section and Unit "A", Autosensory Section, as described below. Furnish each starter with 120 VAC, 6 digit elapsed time meters.

Feeder Circuit Breaker shall be 3P EH Frame with 100A Trips.

Sub-Panel #3 as above, under Unit "A", for Sub-Panel #1, except transformer shall be 5 KVA and Panel 8 - SP circuits.

Manufacturer shall furnish, mount and wire following devices described in detail under "Instruments":

Plant Flow Indicator
Return Sludge Flow Summators (2)
Return Sludge Flow Indicator

Instruments shall display total flow rates and shall retransmit information to Indicator-Recorder-Totalizers at Unit "A". These instruments, and individual sludge flow indicators integral to magnetic transmitters (not part of this unit) will permit manual adjustments to speed of return sludge pumps and pump discharge valves. Unit "A" shall return a Bi-Directional Signal to provide manual remote and automatic control of pumps. Program control stack of pump variable speed drives shall be positioned by this unit. Rate of return sludge flow shall be determined automatically by the ratio setting at Unit "A", and manually by increase-decrease push buttons in this Unit "B" and at Unit "A". Control shall include automatic power failure re-cycle in any control mode and low voltage start shall be compelled. Provide speed indicators (3) for each motor calibrated in RPM.

See plans for details of control circuitry and control operators and indicators. It is intended that pumps may be controlled manually from this location or Unit "A", and automatically from Unit "A". Automatic speed control shall produce a pre-selected ratio of return sludge flow compared to plant flow measured at the Parshall Flume. Unit shall control operation of pump seal water solenoid valves, per contract drawings.

Provide automatic electric sequence alternator which may be "indexed" to change pumping order from this unit, or Unit "A".

Sludge Return Pump Reactospeed Drives (Unit "B2")

Units shall be as described under "Variable Speed Drives", and shall include transfer contactors so that either of the two (2) drives shall be capable of operating the three (3) pumps as manually selected at this unit. Units shall include contactors with fixed adjustable resistance so that the lead pump may be "locked-in" at 98% motor full load speed when drive is transferred from "Lead" to "Lag" pump and again when drive is transferred from "Lag" to "Standby" pump. It is the intent of these specifications that One(1) drive shall be "Active" and One (1) drive "Standby" at any given time. On installation, drives shall be adjusted so that flow rates shall be smooth during drive transfer.

Operation Signalling & Alarms

Shall signal to Unit "A" status of controlled motors appearing on plant status board. Consult Unit "A" and contract drawings for details.

## Section 426.7 Unit "C1" and "C2"

Shall be contained in NEMA I cabinets equivalent to Type "C" ... II NEMA standards built as described under "Unit Construction", ... and of number and dimensions as shown on plans. Shall con- ... of motor controllers, sub-panel with transformer and disconnect circuit breaker to provide in-unit 120 VAC power, autosensory section. ... "C2" shall consist of 2 Reactospeed variable speed controllers ... raw sewage pumps. water system control unit, and motor controllers

### Motor Controllers

For each raw sewage pump (RS-1,2,3) provide combination circuit breaker, magnetic across-the-line motor starter size 3½ with 480/120V control transformer, 150 VA, fused on secondary, 3 phase ambient-compensated overload protection, and low voltage release. Provide local control switch and refer to contract drawings, for circuit component details. Circuit breaker shall be moulded-case, ... frame with ~~150~~ 70 amp trips. These pumps shall be programmed automatically from "Autosensory" section, as described below. Furnish each starter with transformer Type 6 VAC "Run" lamp and 120 VAC elapsed time meter, 6 digit. Furnish each starter with watt hour meter Model D2A-2 as manufactured by Westinghouse.

For each Screen Drive (SCN-1,2), Domestic Water Booster Pump (DWP) and Hydropneumatic Air Compressor (AC) provide combination circuit breaker, magnetic across-the-line motor starter, Size "0" with .../120V control transformer, 50 VA, fused on secondary, 3 phase ambient compensated overload protection, and low voltage release. Provide local control switch and refer to drawings for circuit and component details, and to "Program for Power Failure Restart" section. Circuit Breakers Moulded Case, 3P, EH Frame, Trips as shown. Provide transformer Type 7 VAC "Run" lamps. For each grinder. Starters shall be as set forth above, except shall be size "1".

### Sub-Panel #4

As above, under Unit "B".

### Autosensory

Shall consist of components required for program operation for ... sewage pumps, raw sewage screens, domestic water booster ... and hydropneumatic air compressor, complete with all accessories required for operating system including an integral instrument air supply.

Air supply shall consist of 2 - ¼ hp non-lubricated air compressors with a capacity of 1CFM at 60 psi single stage, ... with a 10 gallon accumulator tank with 2 pressure switches, pressure gage 0-100 psi, 2 combination air filters and pressure regulating valves, 5 Schuttig air flow regulators 0-2.5 cfhr, and 2 Air Supply Gauges, 0-30 psi - Supply Lead - Lag Manual Xfer switch and wire per plans so that in event of failure of lead compressors, lag shall run, lead shall be locked out until manually reset, and alarm station shall be energized. Supply Bubbletrol Systems which shall meter air to bulkhead fittings for connection to ¼ OD Copper Bubbler Transmission Lines. Contractor shall run all pneumatic tubing to avoid condensation traps, pitched to bubbling end at least ¼" per foot. Bubble tubes shall be ½" OD with V-notches (facing downstream for screens) placed according to plans, and each supplied with 2 shut-off valves and hose fitting for use in manual purging of bubbler tubes. Wet well tube shall also be fitted with Hi Pressure Air Purge System and 3-way solenoid valve to allow remote-manual air purging of this line from Unit "C" without damage to control components or electric pump operation. After installation, bubbler lines shall be tested for leaks, at 75 psi, in presence of Engineer. Provide point operated sensors, Range .1-23', accurate to within plus or minus ½ of 1% full range, heavy-duty enclosed Mercury-Type, individually adjustable without minimum differential for program operations as described herein, and laid-out on plans. Provide pressure range sensor and motor-driven program controller with adjustable clutch and adjustable speed of response, with 4 position, "Forward", "Reverse", "Off", and "Automatic", Mode Selector Switch. Provide 10" diameter wet well gage, flush mounted in door, calibrated 0-160". Provide 2½" diameter internal gages for each of 4 screen bubblers. Provide brass shut-off valves for each gage and for each bubbler tube. Also provide brass bleed valves for each bubbler tube. It is intended that sensory section shall program 3 pumps from lead pressure range sensor and a second pressure range sensor and program controller shall act as standby. Pumps shall be controlled through a pump operating position transfer switch labelled "Pump Lead-Lag-Standby Selector Switch" with 3 positions designated 1-2-3, 2-3-1, 3-1-2, and a drive lead-lag selector switch which shall determine which pressure range sensor and program controller are operating pumps. Pumps shall operate as shown on plans, and in accordance with following program:

Wet Well Program
Rising Stage (Read Up)



| Elevation | |
|---|---|
| -11.00 | HWL Alarm (From separate Hi Level Safety Switch) |
| -11.00 | Lead, Lag at full speed (*) standby at 98% speed |
| -12.00 | Start Standby (High Alarm) |
| -13.60 | Lag Pump at full speed (*) |
| -14.35 | Start Lag Pump |
| -15.10 | Lead Pump at full speed (*) |
| -15.85 | Restore Lead Pump |

Falling Stage (Read Down) (*)

| | |
|---|---|
| -15.50 | Low Water Cut Out |
| -16.00 | LWL Alarm |

(*) Full speed means 100% full-load rated speed; maximum variable speed shall be 98% of this valve. Allow 1½" level increase at full speed before start of next variable speed pump.

(*) Falling stage shall be reverse of rising stage with 2" adjustable drawdown.

After power failure, program controllers shall re-cycle to a zero position, and shall then proceed through program, re-starting raw sewage pumps, one-at-a-time - with adjustable intervals between until a program position, commensurate with wet well depth, is reached.

Controls shall be so arranged and interlocked so that when any raw sewage pump is called to operate the following sequence shall occur:

Start

1. Energize seal water solenoid valve, automatic discharge valve, motor starter, pump "Run" light, elapsed time meter, and timer.

2. When pump discharge valve limit switch closes (indicating normal operation of valve), drop out timer and lock in motor starter through limit switch.

3. If discharge valve limit switch opens, or remains open, after initiation of starting sequence, until timer completes (Adjustable .2-90 sec) cycle, initiate stop sequence.

Stop

1. De-energize automatic valve.

2. When valve limit switch opens, stop pump, turn off seal water solenoid, elapsed time meter and pump "Run" light.

Provide transformer Type 6 VAC, green pilot lamps which shall light when discharge valve limit switch indicates normal valve opening, and when seal water solenoid is energized.

Raw sewage control bubblers shall initiate the follow- alarms:

1. "Lag Air Compressor Active"
2. LWL Wet Well
3. HWL Wet Well (also from Hi Level Safety Sw...
4. HWL Dry Well

Provide Bubbletrol, from common air source described a... for operation of the 2 Approach Channel, Rotary, Motor-Driv... screens. In addition to Bubbler elements already described, furnish differential pressure sensors which shall monitor u... stream and downstream pressures and shall cause operation o... associated screen whenever the difference in water level exc... 6". Provide also for each screen a 24 hour program timer with 15 minute cam segments which shall operate the screens on a ti... bases, as set. Unit shall initiate high alarm when either ... level reaches elevation __-7.50__, which shall energize co... local alarm #6. Consult plans for circuit details. Control ... be equivalent of Autocon AP-2A Bubbler, modified.

Provide modified Model 1500A Autocon Duotrol for control of Domestic Water Pump and Hydropneumatic Air Compressor. Unit shall have 4½" diameter pressure gauge calibrated 0-100 psi, brass shut-off valves for gauge & system & brass control bleed valve. Provide individual point-operated sensors without mini... differential, sensitive to ½ of 1%, full range, restricted move- ment type, for each program operation below. Provide induction Probotrol and separate tank-mounted single probe, in bronze hous- ing, for level control. When pressure in tank drops to 30 psi, pump shall run until normal high level is restored. When pressure in tank drops below 35 psi, with tank at normal high level, air compressor shall run until normal pad is restored. Provide ... second adjustable rotary timer to provide zone for compressor operation. A maintained pressure drop to 25 psi shall actuate local "Domestic Water Low Pressure" Alarm #5.

Raw Sewage Pump Reactospeed Drives

Units shall be as described under "Variable Speed Drives" and shall include full speed and transfer contactors so that either of Two (2) drives shall be capable of operating the three (3) pumps as manually selected at this unit. Include manual pump sequence selector switch and control and indication operators as shown on plans. It is the intent of these specifi- cations that one (1) drive shall be active and one (1) drive shall be standby at any given time, and that either drive will operate all three pumps through minimum to 100% full load rated speed, including standby multi-speed operation in event of stepless drive failure.

Operation Signalling & Alarms

Shall signal to Unit "A" status of controlled motors appearing on Plant Status Board. Consult Unit "A" and contract drawings for details. Six local alarms shall be of type described under Unit "A" "Plant Alarms".

Section 426.8 Unit "D"

Shall be contained in NEMA I cabinets equivalent to Type "C" Class II NEMA standards built as described under "Unit Construction", below, and of number and dimensions as shown on plans. Shall consist of Motor Controllers, Sub-panel with transformer and disconnect circuit breaker to provide in-unit 120 VAC power, Autosensory Section, and 3 phase Feeder Circuit Breaker.

Motor Controllers

For each horizontal flight drive (HFD-1,2), cross collector drive (CCD-1,2), grit remover drive (GRD), grit pump (GP) and grit collector (GC) provide combination circuit breaker, magnetic across-the-line motor starter Size "O", with 480/120V control transformer, 50 VA, fused on secondary, 3 phase ambient. Compensat overload protection, and low voltage release. Provide local control switch and refer to contract drawings for circuit and component details. Circuit breaker shall be moulded-case, EH Frame with 15A trips. Consult "Program for Power Failure Restart" section. Provide transformer Type 6 VAC "Run" lights.

For each raw sludge pump (RSL-1,2) a combination starter as described above for horizontal flight drives, except NEMA Size 1. Circuit breaker trips shall be 25A.

Sub-Panel #2

As described above for Sub-Panel #1, Unit "A", transformer shall be KVA, and distribution panel 4 circuit.

Feeder Circuit Breaker

Shall be 3P, EH Frame with 100A trips.

Autosensory

Manufacturer shall furnish, mount and wire following devices described in detail under "Instruments":

Sludge Density Indicator-Controller
Sludge Density Amplifier

Instruments shall display sludge density and shall transmit information to Indicator-Recorder at Unit "A". These instruments and controls described herein with program automatic control of raw sludge pumps, suction sludge valves, and cross-collector drives, in the following manner:

1. Operator selects "Active" raw sludge pump and places motor controller selector switch in "Automatic" position.

2. Time Clock system 24 hour clock capable of giving momentary impulses at adjustable periods as frequent as each 15 minutes initiates program cycle.

3. "Lead" sludge valve opens associated cross-collector operates, and pump runs when valve "open" limit switch is closed.

4. If sludge density reaches pre-set value within adjustable time period (0-10 min), cycle continues. If not, all equipment shuts down until next time interval.

5. If cycle continues, equipment runs unit a sustained drop in density occurs, when pump is shut down, cross collector stops, and sludge valve is closed.

6. Alternator alternates operation between tank #1 and tank #2, and a switch provided permits either tank to be omitted from the program cycle.

7. Heated sludge pump operates when raw sludge pump operates.

Unit "D" shall include whatever components, such as relays, multi-circuit timers, multi-circuit electric alternators are required to perform the operations described. The intent of plans and specifications is to require equipment which shall allow the manual and automatic removal of raw sludge from the cross-collector hoppers, keeping the density of the material removed at an acceptable value as measured by the density detector.

<u>Operation Signalling & Alarms</u>

Shall signal to Unit "A" status of controlled motors appearing on plant status board. Consult Unit "A" and contract drawings for details.

Section 426.9 Unit "E"

Shall be contained in NEMA I cabinets equivalent to Type "C" Class II NEMA standards built as described under "Unit Construction", below, and of number and dimensions as shown on plans. Shall consist of motor controller, sub-panel with transformer and disconnect circuit breaker to provide in-unit 120 VAC power, instruments, maintained-contact start/stop push button, and externally powered 120 VAC "Run" lamp, for digester gas circulator pump starter (not part of this unit) and 3 phase feeder circuit breaker.

Motor Controller

For digester heated sludge circulation pump, provide combination circuit breaker, magnetic across-the-line motor starter, size "0", with 480/120V control transformer, 50 VA fused on secondary, and 3 phase ambient compensated overload protection. Refer to contract drawings for circuit and component details, and to "Program for Power Failure Restart" Section. Circuit breaker moulded-case, 3P, EH Frame 20A trip.

Feeder Circuit Breaker

Shall be 3P, EH Frame with 30A trips.

Sub-Panel #5

As above, for Unit "D", except .5 KVA transformer.

Instruments

This unit shall contain the following instruments detailed elsewhere in these specifications:

1. Digester #1 - Gas Flow
2. Digester #2 - Gas Flow
3. Waste - Gas Flow
4. Digester #1 - Temperature
5. Digester #2 - Temperature

The cabinet sections containing the gas flow instruments shall be isolated and vented over and under the instruments, as shown on plans. Provide removable and hinged backs, as shown.

Operation Signalling & Alarms

Shall transmit digester temperature alarms to plant alarm section in Unit "A". Consult Unit "A" and contract drawings for details.

## METERS AND INSTRUMENTS

## SECTION 427

Section 427.1 General. The Contractor shall furnish all meters, instruments and gauges, as indicated on the drawings and as herein specified. He shall install all such devices located remote from the Control Centers, complete with all essential piping. All meters, instruments, and gauges furnished by the Contractor that are required to be incorporated in the Control Centers, as indicated on the drawings or specified herein, shall be supplied, mounted and wired as a part of the Control Centers, described under CONTROL CENTERS by the Control Center manufacturer.

Certain meters and instruments to be incorporated in the Control Centers are specified under DIGESTER GAS SAFETY AND CONTROL EQUIPMENT.

The work covered herein includes all equipment, piping, appurtenances, and materials that are required for the complete installation of each meter, gauge, and instrument related to the operation of the Sewage Treatment Plant. External electrical wiring and conduit between items of equipment and/or Control Centers shall be done under the Electrical Contract.

The meters and instruments indicated on the drawings and herein specified are as manufactured by Fischer & Porter Company, Hatboro, Penna.; or as otherwise specified. Comparable equipment as manufactured by Foxboro Company, Foxboro, Mass., and Wallace & Tiernan Inc., Belleville, N.J. will be acceptable. However, any and all costs incurred under this contract or any other contract, as a result of a substitution of equipment, shall be borne entirely by this Contractor.

The Chlorine Residual Analyzer and Indicator shall be of the same manufacture as the chlorinators.

All of the instrumentation and related equipment shall be furnished by a single manufacturer, and shall be of the latest and most modern design, having the overall accuracies as guaranteed by the selected manufacturer. The selected manufacturer shall be responsible for the correct operation of the entire installation.

The instruments and meters specified under DIGESTER GAS SAFETY AND CONTROL EQUIPMENT need not be furnished by the above manufacturer.

The principal units under this item shall be as follows:

A. Raw Sludge Magnetic Flowmeter
B. Raw Sludge Magnetic Meter Converter
C. Raw Sludge Indicating Recording Totalizer
D. Thickened Sludge Magnetic Flowmeter.

E. Thickened Sludge Magnetic Flowmeter Converter
F. Thickened Sludge Indicating Recording Totalizer
G. Parshall Flume-Plant Flow
H. Plant Flow Transmitter
I. Plant Flow Indicating Recording Totalizer
J. Plant Flow Converter
K. Return Activated Sludge Magnetic Flowmeters
L. Return Activated Sludge Indicating Recording Totalizer
M. Plant Flow and Return Activated Sludge Flow Indicators
N. Plant Flow and Activated Sludge Flow Ratio Control System and Instrumentation
O. Digester Temperature Indicating Recorders
P. Digester Sludge Level Transmitters
Q. Digester Sludge Level Indicators
R. Chlorine Residual Analyzer-Controller
S. Effluent Sample Pump
T. Chlorine Residual Indicating-Recorder
U. Sludge Density Gage
V. Sludge Density Indicator-Recorder

Section 427.2 Raw Sludge Magnetic Flowmeter. The Contractor shall furnish and install in accordance with the plans and specifications, a sludge magnetic flowmeter of 4 inch size, fitted with 150# steel flanges to measure the flow raw sludge over the range from 0 to 300,000 GPD. Fisher & Porter Model 10D 1416C or approved equal.

The sludge magnetic flowmeter transmitter tube shall be constructed of non-magnetic aluminum with non-conductive liner of Teflon. The tube end shall be 150# ASA steel flanges. The tube shall be continuously heated by electro magnetic induction to a temperature preventing the build-up of sludge and grease on the tube walls, electro magnetic induction heating of the tube shall eliminate the requirements for either mechanical electrode cleaners or electrical electrode cleaners requiring interruption of either flow or the flow signal. The unit shall also be furnished with special electrodes that shall permit continuous cleaning without interruption of flow signal to the receiver. A 50 killocycle frequency shall be impressed upon the electrodes from a separately mounted ultra-sonic power supply.

Section 427.3 Raw Sludge Magnetic Flowmeter Converter. The Contractor shall furnish and install in accordance with the plans and specifications, a raw sludge magnetic flowmeter converter which shall be Fischer & Porter Model 50ED3411 or approved equal. The magnetic flowmeter signal converter shall be of the all solid state feedback type of modular plug-in chassis design. The instrument housing shall be of the weather proof design steel enclosure, suitable for wall mounting. An indicating meter shall be located on the front panel for rate adjustment. The unit shall also be furnished with initial zero adjustment.

The converter shall include automatic quadrature rejection and an adjustable dampening circuitry. There shall be complete interchangeability between signal converters and magnetic flowmeters. The input span shall be continuously adjustable 0-1 and 0-30 feet/second and shall be of the direct reading dial type. The system accuracy including the primary magnetic flowmeter shall be ±1% of full scale for maximum flow velocity between 3 to 30 feet/second. Repeatability shall be ±0.25% of full scale.

The converter shall also be furnished with a zero return unit which shall prevent the receiver from operating as a result of hydraulic serges when the pump shuts down. The zero return feature shall be connected between the converter and auxiliary contacts on the starter circuit for the pumps. Accessory equipment to be supplied by the manufacturer shall include the special shielded cable between the transmitter and receiving instrument.

The magnetic flowmeter, converter and indicating recording totalizer shall be a product of a single manufacturer.

Section 427.4 Raw Sludge Indicating Recording Totalizer. The raw sludge indicating recording totalizing receiver shall be furnished by the manufacturer of the panel located in the control building in Unit A and shall indicate, record and totalize the raw sludge flow rate. The unit shall receive a 4-20 milliamp dc signal from the converter and the unit shall be furnished with a Torque motor which shall incorporate the flux bridge contactless feedback element system. The unit shall be Fischer and Porter Model 1102DB20 or approved equal. The unit shall be furnished with necessary power supply system. The unit shall also be furnished with 24 hour electric chart drive with a range of from 0 to 300,000 GPD and an 8-digit totalizer and indicator scale. The unit shall also be furnished with one years supply of charts and ink.

Section 427.5 Thickened Sludge-Magnetic Flowmeter. The Contractor shall furnish and install in accordance with the plans and specifications a magnetic flowmeter for metering thickened sludge flow. The magnetic flowmeter shall be the same as specified for raw sludge except that the size shall be 2 inches with a range of from 0 to 100,000 GPD.

Section 427.6 Thickened Sludge-Magnetic Flowmeter Converter. The Contractor shall furnish and install in accordance with the plans and specifications a Fischer and Porter Model 50ED3411 4-20 milliamps dc converter the same as specified for the raw sludge system except that the range shall be from 0 to 100,000 GPD.

Section 427.7 Thickened Sludge-Indicating Recording Totalizer. The sludge meter receiver shall be furnished by the manufacturer of the panel located in the control building in Unit A and shall be indicating recording and totalizing and shall be the same as specified for the raw sludge system except that the unit shall have a range of from 0-100,000 GPD.

Section 427.8 Parshall Flume-Plant Flow. There shall be supplied for installation in the flume channel, a Fischer and Porter Model 10F1940 molded, fiberglass reinforced polyester Parshall flume with a throat width of 24 inches. The flume shall be molded in one piece with ample wall thickness and reinforcing ribs to prevent distoration during shipment, installation and operation. The flume shall be self-supporting and require no external supporting structure. Interior dimensions shall conform to those shown in the latest revision of U.S. Department of Agriculture Circular 843.

Section 427.9 Plant Flow Transmitter. The Contractor shall furnish and install a flowmeter which shall be of the float actuated type wherein the level measurement is a function of flow rate. The flowmeter shall have a range of 0 to 20 MGD. The float shall be a 12" stainless steel ball and shall be suspended on a cable. The instrument case shall be of die-cast aluminum mounted on 2" pipestand and shall be suitable for outdoor mounting. All linkages shall be of stainless steel. The flowmeter shall be Fischer & Porter Model 10F1272 or approved equal. The unit shall also be equipped with a 4-20 milliamp dc electronic 2-wire transmitter which shall not require power at the transmitter location.

Section 427.10 Plant Flow-Indicating Recording Totalizer. The plant flow indicating recording totalizing receiver shall be furnished by the manufacturer of the panel located in the control building in Unit A and shall indicate record and totalize the plant flow. The unit shall be a Fischer and Porter Model 1102DB20 and shall be the same as furnished for the raw sludge system except that the range shall be from 0 to 20 MGD.

Section 427.11 Plant Flow Indicator. The plant flow indicator shall be furnished by the manufacturer of the panel located in the sludge contol Unit B. The unit shall be a Fischer & Porter Model 55ME2400 which will accept a 4-20 milliamp dc input, scale length shall be 4½" long. The unit shal utilize a Taut-Band suspension system and shall make use of a permanent magnet moving coil mechanism. All components shall be mounted on a plastic draw which slides into a black thermo plastic case with a clear, curve window. The entire assembly shall be treated to be static free. The unit shall also be furnished with a direct reading scale to read from 0 to 20 MGD.

Section 427.12 Automatic Proportioning Chlorination Flow Converter. A Fischer & Porter Model 1101BQ44-65 or approved equal indicating converter shall be furnished and located in the chlorine room. The unit shall be furnished with a vaccum transmitter for automatically proportioning chlorine feed rate in proportion to plant effluent flow. The unit shall also contain a 4-20 milliamp dc 2-wire electronic transmission for transmission of flow rate signal to the instrument panel in Unit A. The 4 to 20 milliamp dc receiving unit shall be furnished with a Torque motor which shall incorporate the flux bridge contactless feedback element system. The unit shall also be furnished with necessary power supply system.

Section 427.13 Return Activated Sludge Magnetic Flowmeter. The Contractor shall furnish and install two Fischer & Porter Model 10D1430A or approved equal magnetic flowmeters. The units shall be 6" size with 150# ASA flange connections. The flowmeter shall have characterized electro-magnetic field with the field coil completely encapsulated in the metering lining material. Flange to flange laying length shall be approximately 1½ times the meter pipe diameter. The electrodes shall be field replaceable without effecting calibration in the Neoprene line meter. The magnetic flowmeters shall also be furnished with a Fischer & Porter Model 50SF1412A integrally mounted signal converters. The integrally mounted converter shall eliminate the need for special shielded signal cable between the magnetic flowmeter and converter. The unit shall be completely solid state and shall be provided with a direct reading range adjustment dial for setting the full scale values between 1 and 2 feet/second. The integrally mounted converter shall also be furnished with a local flow indicator. System accuracy shall be ±1% of full scale settings between 3 and 30 feet/second, repeatability shall be 0.25% of full scale. Output of the converter shall be 4-20 milliamps dc. Flow range 0 to 3.25 [illegible]

Section 427.14 Return Activated Sludge-Indicating Recording Totalizer. The return activated sludge receiver shall be furnished by the manufacturer of the panel located in the control building in Unit A and shall indicate, record and totalize the return activated sludge flow. The unit shall be a Fischer & Porter Model 1102DB20 and shall be the same as specified for the raw sludge [illegible] except the range shall be from 0 to 7.0 MGD.

Section 427.15 Return Activated Sludge Indicator. An activated sludge indicator shall also be furnished and shall be identical to the unit as specified for the plant flow system and shall also be located in Unit B. The indicator shall have a range of from 0-6.5 MGD.

Section 427.16 Ratio Control System. The plant flow and activated sludge ratio control system shall consist of an electronic controller, ratio control station, bi-directional controller [illegible] 125 ohm Potentiometer. The ratio control equipment shall be supplied by the manufacturer of Unit A located in the control [illegible]

The electronic controller shall be Fischer & Porter Series 53EL2000 or approved equal. The electronic controller shall be a completely self-contained indicating control station. The chassis shall be capable of withdrawal to a service position without disrupting controller operation. The controller shall be of modular plug-in design and transistor design circuits shall be used extensively. The entire mode adjustment modules shall be removeable as a unit. Interlock shall be provided to cut power to the mode module prior to its removal. The contoller shall contain a deviation type meter movement for indicating deviation of process from the setpoint.

The setpoint scale shall be 6" long and the deviation meter shall indicate directly on it. The setpoint scale shall be percentage. The output meter shall have a 2¼" scale indicating the 4-20 milliamp dc output signal. The front panel of the controller shall also contain adjusting means for bumpless transfer, an automatic setpoint generator, a manual control signal generator, and a "press to balance" switch for switching from automatic to manual or manual to automatic. The input signal shall be 4-20 milliamps dc. The range of the controller shall be changeable by changing the range calibration resistor on the input terminal board. The controller shall contain a power supply for the electronic transmitter.

An electronic ratio control station shall also be furnished including a bi-directional controller and a 125 ohm Potentiometer shall also be furnished by the manufacturer of Unit A located in the control building. The electronic ratio control station shall be Fischer & Porter Series 53ER2000 or approved equal. The ratio adjusting knobs and ratio setting indicator shall be on the front of the unit. The ratio station shall receive a 4-20 milliamp dc signal and transmit the output ratio signal to the controlling means. The output signal to the controller shall be biased from 0 to ±100% of span. The ratio station shall contain a power supply. The ratio ranges shall be o.1 to 1.0 linear. The accuracy shall be ½% with a ratio dial setting accuracy of 2%. Ambient temperature limits shall be 30 to 130°F.

<u>Section 427.17 Digester Gas Temperature Recording Indicators</u>. There shall be furnished and installed in Unit E in the Plant Control building by the manufacturer of the panel, two Fischer & Porter Model 1102TF03 temperature recording and indicating instruments.

The instrument case shall be of die-cast aluminum construction with a gasketed glass window. The linkages, pens, door latches, hinge pins and pivots shall be stainless steel.

The recording charts shall be 12" circular type with 50 to 150°F. range and 24 hour, 110 volt, 60 cycle chart drive. Each instrument shall also contain a high temperature alarm contact and each instrument shall also be furnished with one years supply of charts and ink.

The temperature sensing element shall be Class 1A liquid filled, fully compensated with a range of 50°F. to 150°F. The sensing element shall consist of Helix, required length of capillary, stailess steel bulb and ¾" bushing. Elements shall be installed in the gas piping where shown on the drawings.

Section 427.18 Storage-Digester Sludge Level. The Contractor shall furnish and install two Fischer & Porter Model 1451P65 or approved equal electronic level transmitters. The instrument case and door shall be of black fiberglass reinforced polyester resin. The door shall be gasketed and contain a glass window. The unit shall be suitable for wall mounting. The door latch, hinge, pivots and spindle gage assembly shall be stainless steel. The indicator shall be 5" segmental type, white, with black numerals and increments. The unit shall contain a 316 stainless steel type SD diaphragm seal unit with flushing connection and necessary capillary tubing. The unit shall also be furnished with a 4-20 milliamp dc electronic transmitter. The transmitter unit shall be composed of a Ferrite detector mechanism activated by the process senser within the instrument case, an encapsulated oscillator-amplifier and a feedback motion section consisting of an oil filled and damped force motor. The transmitting unit shall be of modular design. The transmitter shall be a 2-wire transmission system which shall not require power at the transmitter. The electronic transmitter shall be suitable for use in Class I, Group D, Division 2 atmosphere. Overall accuracy of the instrument shall be ±0.5%.

Section 427.19 Digester Sludge Level Indicators. Two digester sludge level indicators shall be furnished by the manufacturers of Unit A located in the control building. The unit shall be Fischer & Porter Model 1372 or approved equal miniature electronic indicator. Input to the unit shall be 4-20 milliamps dc, environmental and operational limits shall be 30 to 150°F. Chassis shall be aluminum with cast aluminum bezel and scale shall be 3¼" long by 1-11/32" wide. The unit shall also contain an integral power supply.

Section 427.20 Chlorine Residual Analyzer-Controller. The chlorine residual analyzer shall be of the amperometric type suitable for measurement of free residual chlorine in treated sewage effluent. The analyzer shall also indicate the chlorine residual in PPM. The indicator will have a uniformly spaced scale graduated from 0 to 5 PPM. The chlorine residual analyzer shall be located in the chlorinator room.

The sampling cell of the analyzer sahll contain two electrodes, which shall continuously detect the chlorine residual in the sample and generate an electrical signal proportional to the residual. The cell shall be provided with non-abrasive plastic pellets which are continually impelled against the electrodes to prevent the adherence of any foreign material to the electrode surfaces. The metal electrodes shall be rotated by a motor drive to provide the impelling force for cleaning the pellets. The analyzer shall not require a fresh water dilution supply.

A thermister immersed in the sample stream shall form a part of the electric signal circuit in order to automatically compensate for changes in water temperature. The analyzer shall be furnished with a sample flow rate meter to permit easy settling of the optimum flow for minimum buffer consumption. An adjustable solution feed system employing a positive displacement pump, motor drived, shall be employed to maintain the sample at a constant pH.

The chlorine residual analyzer shall be furnished with an indicating millivolt to 4-20 ma D.C. electronic converter which shall be housed on the analyzer cabinet.

The converter shall transmit to a chlorine residual recorder located on the instrument panel "A" in the building.

A chlorine residual controller shall also be housed on the analyzer cabinet. The controller shall be a completely self-contained indicating control station. Chlorine residual and its deviation from set point shall be indicated by deviation type meter movement. The output meter shall have a 2¼" vertical scale and shall indicate the output signal to the final control element. All miniature process instruments shall be transistorized and shall be of modular, plug-in type construction.

The chlorine residual analyzer-controller shall be Fischer & Porter Series 17S2010 with 53EL3000 controller, or approved equal.

The residual analyzer shall be furnished with a 6 months supply of buffer solution.

A motor driven Cuno type "G" auto-kleen filter shall also be provided for installation in the sample stream to the chlorine residual analyzer for filtering large particles.

An ampereometric titrator complete with case for calibrating the residual recorder shall also be supplied.

The unit shall be a Fischer & Porter Model 17T1010 or approved equal ampereometric type titrator, capable of determining the end point in titrations for chlorine residuals with accuracy to 1/100th PPM. The unit shall be completely portable with a self-contained rechargeable battery and also shall be capable of operating on 115 volt, 60 cycle current. The battery shall be recharged without use of special equipment.

A built-in micro displacement valve shall be mounted on the titrator for the positive accurate addition of titrant. The electrode cell shall consist of two noble electrodes, on which a D.C. potential shall be impressed. No salts shall be required for operation.

The titrator shall be equipped with standard accessories including the following chemicals:

480 ml Phenylarsene oxide solution
120 ml Potassium iodide solution
120 ml pH 4 buffer solution
120 ml pH 7 buffer solution
A carrying case
Back titration kit for total residual

Section 427.21 Effluent Sample Pump. There shall be furnished and installed, one effluent sample pump for pumping a sample of the treated effluent to the residual recorder. The pump shall be Goulds Fig. 3695-¾A close coupled self-priming centrifugal pump or approved equal. Pump capacity shall be 10 gpm, TDH-60 ft. with up to 20 feet suction lift. Motor to be ¾ HP, 3500 RPM, 115 v, 60 cycle.

Section 427.22 Chlorine Residual Indicating Recorder. A chlorine residual indicating recorder mounted in Control Center, Unit A in the Control Building shall be furnished by this Contractor, supplied, mounted and wired as part of the Center by the manufacturer of the Center.

The instrument shall be Fischer & Porter Company 1100 D B series electronic indicating recording receiver or equal. The receiver shall indicate and record chlorine residual over the range of 0_5 PPM on 12" evenly graduated charts, completing one revolution every 24 hours. Receiver case shall be constructed of die-cast aluminum with stainless steel door latch and internal linkages. The unit shall contain adjustable high and low alarm switches.

Section 427.23 Return Activated Sludge Totalizers. Two (2) Electronic Totalizers shall be furnished and installed in Unit B and shall be housed in a 3" x 6" metal case with metal slideout chassis. The units shall be transistorized and a modular design. The integrator shall be capable of operating an internal counter. The counter shall be 8-digit of the non-reset type. The output shall be displayed on a front panel counter calibrated to read directly in units of flow. The input signal shall be 4-20 milliamps DC liner. The unit shall contain a power supply for 2-wire transmitter. The power supply voltage shall be 39-53 volts, sufficient to power a 4-20 milliamp DC 2-wire transmitter. The accuracy shall be ± 0.5% of rate when operated above 10% of full scale and 1% when operating below 10% full scale. The unit shall be suitable for mounting on the panel. The integrator shall be Series 52ET2000 as manufactured by Fischer & Porter Co. or approved equal.

Section 427.24 Sludge Density Gage. The Contractor shall furnish and install one sludge density gage on the discharge of the raw sludge pumps. The gage shall measure the solids content of the sludge and, with related equipment, control the raw sludge pumps and sludge valves, to obtain a maximum solids content sludge.

The sludge density gage and applifier shall be as manufactured by the Ohmart Corporation, Cincinnati, Ohio, or approved equal.

The gamma radiation gage shall have a Cs-137 radioactive source contained in an AEC approved source holder. The measuring cell shall be an Ohmart cell, ionization chamber, or other suitable device. The stabilizer amplifier shall be a AC Feedback type with less than ±1% drift in 30 days. The amplifier shall have a meter calibrated 0-100 in evenly divided units. The amplifier output shall be 4-20 ma d.c.

A method of zero suppression shall be employed consisting of an electrical signal, or detector, or cell, of opposite polarity from the measuring cell or detector.

The unit shall have the following:

A. Range of measurement: 0% to 10% solids (1.00-1.03 sgu).
B. Measurement repeatability: Instantaneous: ±2% of full scale.
C. Pipe Size: 4" diameter, flanged
D. Radiation field intensity requirements: Not to exceed SMR/HR on any surface with pipe empty.

E. Equipment stability: Electrical zero drift not to exceed ±1% of full scale in thirty days. Calibration drift not to exceed ±2% of full scale in one month, exclusive of pipe wall build-up or erosion.

The density gage shall be a 4" model CS measuring unit and the amplifier a model WAE unit in a case suitable for panel mounting.

The amplifier shall be mounted and wired in control center by the control panel manufacturer.

The Contractor shall provide any and all license requirements for the installation and shall provide for four (4) days of operation instruction by a qualified representative of the manufacturer after the equipment has been adjusted, set up and tested.

Section 427.25 Sludge Density Indicator-Recorder. The sludge density indicator-recorder shall be furnished by the manufacturer of the panel located in the control building in Unit A and shall indicate, record the sludge density rate. The unit shall receive a 4-20 milliamp dc signal from the converter and the unit shall be furnsihed with a Torque motor which shall incorporate the flux bridge contactless feedback element system. The unit shall be Fischer & Porter Model 1102DB20 or approved equal. The unit shall be furnished with necessary power supply system. The unit shallalso be furnished with 24 hour electric chart drive with a range of from 0 to 10 percent and an indicator scale. The unit shall also be furnished with one years supply of charts and ink.

Section 427. 26 Shop Drawings. As required by the General Specifications, the manufacturer shall submit, for approval, completely detailed and certified wiring diagrams, shop and erection drawings of all primary elements, secondary elements, panels, wiring, and piping. He shall also submit sufficient data to ensure that all metering systems are complete and that all meters comple fully with the Specifications.

Section 427.27 Shop Painting. The transmitters, recorders, receivers, and panels shall be given a shop finish as customary with the manufacturer and/or herein specified.

Section 427.28 Adjusting and Testing. As required by the General Specifications, the Contractor shall arrange for the services of a qualified representative of the equipment manufacturer to inspect, test and place the metering and instrument systems in trouble free operation, and instruct the operating personnel in the proper care and operation of the equipment.

Section 427.29 Supplies and Tools. All special tools required shall be furnished. A supply of 400 charts, sufficient ink to last 1 yr. and a spare pen shall be furnished with each recording receiver.

Charts shall be printed on good quality paper unaffected by changes in humidity. A rubber stamp shall be provided for each chart. The stamp shall have inscribed the following: The Township of Middletown Sewerage Authority, (Name of Plant), name of the meter, unit of measurements for chart and space for dates, all as approved by the Engineer.

Section 427.30 Operating Instructions. The Contractor shall furnish three complete, bound, clear, and concise sets of instructions for the adjustment, operation, lubrication, and other maintenance of the meters and instruments, and three complete, bound sets of detailed drawings and parts lists.

## BIBLIOGRAPHY


Balakrishnan, S., Williamson, D.E., Okey, R.W. State of the Art Review on Sludge Incineration Practice, U.S. Dept. of the Interior, Fed. Water Quality Admin. Pub. No. 17070DIV 04/70, 1970

Burd, R.S., A Study of Sludge Handling and Disposal, U.S. Department of the Interior, Fed. Water Pollution Control. Admin., Pub. WP-20-4, 1968

Besselievre, E.B., The Treatment of Industrial Wastes, McGraw-Hill Book Company, St Louis, 1966

Fair, G.M., Geyer, I.C., Okum, D.A., Water and Wastewater Engineering, Vol. 2 Water Purification and Wastewater Treatment and Disposal, John Wiley & Sons, Inc. New York, 1968

Galetti, B.J., "Application of the Streaming Current Detector to the Continuous Measurement and Control of Colloidal Systems," Proceedings ISA Symposium, New Orleans, La., May 1969

Grune, W.M. "Automation of Sludge Digester Operation," Journal Water Pollution Control Federation, 37 (3), 353-380 (1965)

Hiser, L.L. "Selecting a Wastewater Treatment Process," Chemical Engineering, November 30, 1970, pp. 76-80

Jones, W.H. "Sizing and Application of Dissolved Air Flotation Thickeners," Water and Sewage Works, Ref. No. 1968

Lawrence, R.E., "Sludge Processing to Abate River Pollution," Water and Waste Engineering, 3, 66, 1966

Lee, A.C., "Simplify Terminal Treatment," Water and Waste Engineering, D-12-13, July 1971

Marks, R.H., "Waste Water Treatment," Power, June 1967

Millward, R.S., Walter, L.R.H., "Sludge Disposal by the FS System," Dorr-Oliver Technical Reprint No. 603P, 1966

Steel, E.W., Water Supply and Sewage, 4th ed., McGraw-Hill Book Company, New York, 1960

Tozart, D.W., Hiser, L.L., Childers, R.E., Boldt, C.A. "Comparison of Wastewater Sampling Techniques," Journal Water Pollution Control Federation, 42, (5), 708-732 (1970)