ACTIVATED SLUDGE PROCESS CONTROL SERIES

New Concepts and Practices In Activated Sludge Process Control

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PREFACE

This book is the result of my frustration with the operation of the activated sludge process. Early in my career I learned that activated sludge is a complicated, unpredictable, biophysical process, and that strange things happen for no apparent reason. After many years of study and experimentation, I am even more convinced that activated sludge is a complicated living system, but I have learned to believe that its actions can be predicted and, to a degree, controlled. The ideas and concepts presented in this book are based on the following observations:

1. To understand the activated sludge process, it must be recognized that activated sludge is a living system and, consequently, its performance is subject to environmental and physical conditions that affect the physiological systems of all forms of life.
2. Obtaining knowledge about the operation of a living system cannot be accomplished without continuous observation of biological and physical characteristics of the system.
3. Effective control of the process can only be accomplished when an operator can learn about the process by observing timely changes, by reacting to these observations according to some plan and, of most importance, "seeing" as soon as possible the results of his actions. This is the dose-response learning process so important to effective plant control.

The goal of my work has been to convince others that activated sludge is a living system; that we should monitor biological as well as physical parameters in a timely fashion; and that, if we accomplish this, the job of training plant operators will be much easier.

This book is a brief compilation of some of the above ideas. I hope that it serves to stimulate others to find new ways of eliminating the frustrations of activated sludge. There is much work yet to be done.

Robert M. Arthur

Robert M. Arthur is the founder and president of Arthur Technology, a consulting, research and development, testing, and training firm specializing in wastewater treatment plant operation and control. He has been involved with wastewater treatment plant operation and design as a professor of environmental engineering and as president of a municipal consulting engineering firm.

Dr. Arthur's education and training has emphasized control of biological systems associated with activated sludge wastewater treatment plants. He has been in charge of many funded research projects related to instrumentation and control of wastewater treatment plants.

A patentee in the field, Dr. Arthur is also a registered Professional Engineer and has written many technical papers. He is a member of several professional societies and was Chairman of the Instrumentation Subcommittee of the Water Pollution Control Federation and a contributing author to the WPCF Manual of Practice 21 "Instrumentation in Wastewater Treatment Plants." He is the 1981 winner of the Kermit Fischer Environmental award of the Instrument Society of America.

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CHAPTER 1

INTRODUCTION

THE NEED FOR PROCESS CONTROL

Modern wastewater treatment plants are required to produce high quality effluents. To accomplish this objective, design engineers, equipment manufacturers and contractors design and assemble concrete and steel into various forms and shapes to create a wastewater treatment plant. The plant components utilize various physical, chemical and biological methods to separate solids and liquids and convert the solids into easily disposed material. The separate and combined activities of all components of treatment make up the process of wastewater treatment.

Control of the process of wastewater treatment is the responsibility of the plant operator. The operator must use any means or devices at his disposal to determine how the process is operating and what might be done to make sure that the plant does, in fact, produce a high quality effluent. Control methods available to the operator include such simple means as visual operation or complicated methods such as the use of sophisticated analytical instrumentation. Whatever the method, the operator must interpret his observations in relation to his knowledge of the various processes and then with *judgment* determine the best procedures for plant control.

Unfortunately the combined efforts of engineers, manufacturers, contractors and operators have not led to adequate wastewater treatment plant performance. In studies supported by the U.S. Environmental Protection Agency (EPA) [1,2] it has been found that as many as fifty percent of the treatment plants funded by EPA do not meet effluent standards. In the same studies it was found that poor plant performance was related to both design and operation. Of some sixty commonly occurring factors, the first four were operation oriented and the next six were design oriented. The remainder were related to such factors as management policies, financial considerations, space limitations, equipment malfunction, etc. (see table 1).

Table 1. Ranking of Performance Limiting Factors

Rank	Factor	Times Occurring	Times Ranked #1
1	Operator Application of Concpets and Testing to Process Control	28	6
2	Wastewater Treatment Understanding	20	4
3	Technical Guidance	17	5
4	Process Control Testing	21	0
5	Sludge Wasting Capability	18	3
6	Process Flexibility	16	2
7	Process Controllability	20	0
8	Clarifier (Secondary)	11	2
9	Sludge Treatment	15	0
9	Aerator	9	2
11	Performance Monitoring	15	0
12	Disinfection	10	0
12	Ultimate Sludge Disposal	12	0
14	Laboratory Space and Equipment	14	0
15	Alternate Power Source	13	0
15	Unit Process Layout	6	1
15	Policies (Administrators)	7	2
18	Infiltration/Inflow	11	0
18	Alarm Systems	12	0
20	Plant Coverage	10	0
21	Familiarity with Plant Needs (Administration)	7	0
22	Adequacy (O & M Manual)	8	0
22	Return Process Streams	6	1
22	Training (Operations)	8	0
22	Aptitude (Operations)	6	0
26	Number (Staff)	7	0
26	Scheduling & Recording (Maintenance)	8	0
28	Flow Proportion to Units	6	0
28	Working Conditions	7	0
28	Pay (Operators)	5	0
28	Preliminary (Design)	7	0
32	Plant Inoperability due to Weather	4	0
32	Supervision	4	0
32	Equipment Malfunction	4	1
32	Productivity (Operations)	5	0
32	Insufficient Time on the Job	5	0
32	Insufficient Funding	6	0
38	Motivation (Operators)	5	0
38	Flow Backup	3	0
38	Level of Certification	5	0
38	Housekeeping	4	0
38	Lack of Program (Maintenance)	4	0
38	Manpower (Maintenance)	4	0

Table 1, continued

Rank	Factor	Times Occurring	Times Ranked #1
44	Industrial (Loading)	2	1
44	Unnecessary Expenditures	4	0
44	Lack of Unity Bypass	4	0
44	Plant Location	3	0
48	Spare Parts Inventory	3	0
48	Equipment Age	3	0
50	Hydraulic (Loading)	2	0
50	Toxic (Loading)	2	0
50	Seasonal Variation (Loading)	2	0
50	Process Accessibility for Sampling	2	0
54	Lack of Stand-By Units for Key Equipment	1	0
54	Quality of Equipment	1	0
54	Level of Education	1	0
54	Organic (Loading)	1	0
54	Submerged Weirs	1	0
54	Process Automation Control	1	0
60	Personnel Turnover	1	0

The most common operator-oriented problem cited in the EPA survey was a lack of application of concepts and testing to process control. The second most frequent problem was a lack of understanding of wastewater treatment. The third was a lack of technical knowledge and the fourth was a lack of process control testing. Poor plant operation will obviously result if the operator does not understand process fundamentals and does not use analysis and observation as a means of achieving plant controls.

The most common design problem cited was a lack of process flexibility and process controllability. Lack of flexibility in control of aeration and return sludge rate limited the operator when he attempted to adjust the process to changing conditions of load. Also cited was a lack of means of performance monitoring.

This EPA study is of great value for it points out that plant operation is dependent on a combination of a knowledgeable informed operator and a well designed plant which is capable of being "operated." Without both factors present it is impossible to produce high quality effluents.

THE ROLE OF THE OPERATOR IN PROCESS CONTROL

The first requirement of a process control operator is to have a thorough understanding of the fundamentals of the biological, chemical, and physical systems which are basic to the operation of components of wastewater treatment. Too often operator training emphasizes the broad picture of the process and only briefly addresses fundamental concepts. Emphasis is placed on memorizing flow patterns of various types of treatment without describing why the type was developed and why it has advantages over other types of treatment because of basic biological or physical considerations. In process control emphasis is placed on the magnitude of the numbers which are derived, such as sludge volume index and sludge retention time instead of the fundamental meaning of the control method. In addition, little emphasis is placed on the limitations of each process control scheme and how all are related to fundamental principles.

The second requirement of an operator is to recognize the importance of the application of testing and process monitoring to plant control. He must first recognize that not all analytical tests performed on wastewater are useful in process control. Tests can be divided into two categories—those which are used to monitor performance and those used to control performance. Monitoring tests are used to determine the performance efficiency or to determine effluent quality. The results are usually reported to Government officials and all tests must be performed according to *Standard Methods*, ASTM, EPA or state regulatory requirements [3-5]. Control tests on the other hand are used to provide the operator with the most useful information available in a *timely* manner. It must be information which will tell him how to adjust controllable elements and it must be available automatically or with minimum effort as frequently as necessary to follow changes in plant operation. The tests need *not* be performed in accordance with a "standard" technique but can be any method, scheme or device which gives *reliable* and *consistent* results and *in which the operator has confidence*. Examples of monitoring and control tests are listed in table 2. Please note that to be effective all control tests should provide timely information and therefore require minimum laboratory analysis or must be obtained from on-line automatic instruments.

The third requirement of an operator is to combine a knowledge of treatment fundamentals with the results of control tests and apply the combination to process control. He must attempt to analyze changes in monitored data and relate them to basic phenomena and then develop a control strategy based on his analysis. He should thoroughly understand the *limitations* of the fundamental concepts as well as the means of testing the performance. He must be able to be flexible in determining a control strategy based on fundamentals and timely information about process variables.

Table 2. Examples of Monitoring and Control Tests

Monitoring Tests	Control Tests
BOD_5 Raw	Respiration Rates—Mixed Liquor Return Sludge
BOD_5 Final	Settling Rates
S.S. Raw	Settling Volume
S.S. Final	D.O. in Aeration Tank
D.O. Final	S.S. in Mixed Liquor
Fecal Cloriform—Final	S.S. in Return Sludge
Residual Cl_2—Final	ORP of Mixed Liquor
Nitrogen—Final	ORP of Return Sludge

THE ROLE OF THE ENGINEER IN PROCESS CONTROL

To be effective in wastewater treatment plant design an engineer must have a complete knowledge of the role of the operator in process control. He must also have the capability of designing a plant which allows the operator the opportunity to develop his role in process control. This knowledge and capability has not existed in the past, for most plants have been designed using "cook book" values based on average loadings. This, as evidenced by the EPA study, has led to inflexibility and lack of process control capability. Today's demand for high levels of treatment require new approaches to determining sizes and characteristics of plant components based on actual variations in loads on the system. If the engineer uses this approach, he will design a plant which has the flexibility and controllability needed to produce high quality effluents.

"Ten State Standards" has been widely used as a source of design criteria for wastewater treatment plants. The original standards were initiated in 1947 and there have been six editions. In many states these standards have become part of state statutes on wastewater treatment plant design. The "standards" provide design criteria for all components of plant and sewer design. For example, past standards indicated that aeration systems should be designed with a capacity of 1500 cubic feet of air per pound of BOD_5 removed. The engineer determines the BOD_5 load on the system (usually from "standard" values of pounds of BOD_5/capita and an estimate of the population to be served) and then sizes the aeration equipment in accordance with the design criteria. Unfortunately the 1500 cubic feet of air requirement bears little relationship to the actual hour to hour changes in respiratory requirements of the microorganisms. To establish the "standards" well operated plants were surveyed to determine average loadings for "best" treatment. It was expected that these values would become *minimum* standards but instead they have become design standards and have led to the design and construction of inflexible and in many cases poorly sized wastewater treatment plants [6].

The most recent Ten State Standards [7] has taken a new look at design criteria and strongly suggests that design be based on *actual* loading of organic matter and flow and that components be designed to accommodate *changes* in loadings on the system. This new emphasis on flexibility in component design will do much to eliminate present problems of process control. Use of pilot plants and actual analysis of wastewater characteristics will result in a much more realistic design technique than the existing reliance on "standard" criteria.

THE ROLE OF INSTRUMENTATION IN PROCESS CONTROL

If an operator is well grounded in the fundamentals of wastewater treatment and understands how to apply analytical data to process control and the engineer has designed the plant for flexibility and controllability, the system will still not perform satisfactorily unless *process information* is available to the operator. Only then can the operator take full advantage of the flexibility of the plant. On-line instrumentation, in effect, serves as the "tools" of process control. It must be selected to provide the operator with maximum timely information about the process so that the operator responds to the data, determines a course of action, and then observes the results of his action—again with instrumentation. This is the type of dose-response mechanism which is important in the learning process and results in conditioned responses to variations in doses (or loadings) on the system. It means that the operator truly *controls* the process and leads to stability and reliability in plant performance.

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CHAPTER 2

CONTROLLABLE ELEMENTS IN WASTEWATER TREATMENT

THE EVOLUTION OF ACTIVATED SLUDGE WASTEWATER TREATMENT PLANTS

The formation of cities and towns in the development of our civilization led to the problem of collection and disposal of wastewater. Collection was accomplished with the construction of sewer lines and disposal consisted of discharging the wastewater into the nearest body of water. Here nature was utilized to "treat" the waste matter. Natural processes of sedimentation and aeration purified the water as it flowed down a river or was retained in a pond or lake. As cities grew and the amount of wastewater increased, the receiving body of water could no longer assimilate the waste material and artificial treatment methods were developed.

The first wastewater treatment plants utilized only sedimentation (known as primary treatment) to remove those solids which could easily be settled out in one- to three-hour detention periods. The effluent, which contained suspended and dissolved solids, was then disposed of by discharging it to a lake or stream where natural biological action was used to stabilize the organic matter.

Secondary treatment processes, or those which purify the water discharged from primary sedimentation tanks, were developed to remove suspended and dissolved solids prior to discharge to a body of water. These processes utilized nature's processes of microorganism metabolism to break down the solids and convert them to stable compounds. It was soon recognized that large masses of microorganisms could be used to "treat" large amounts of waste material. The first application of this technique was in England where masses of microorganisms were developed in aerated batch reactors. After a period of time the aeration was stopped and the microorganisms were allowed to settle to the bottom of the reactor. The supernatant was discharged as plant effluent.