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The Use of High-purity Oxygen in the Activated Sludge Process

Volume I

Edited by
J. R. McWhirter

CRC Press
Taylor & Francis Group

The Use of High-purity Oxygen in the Activated Sludge Process

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Editor

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Water Pollution Control Technology Series

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Reissued 2019 by CRC Press

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ISBN 13: 978-0-367-25950-1 (hbk)
ISBN 13: 978-0-429-29071-8 (ebk)

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FOREWORD

This second volume in the Uniscience Series on Water Pollution Control Technology is a comprehensive state-of-the-art report on the use of purified oxygen in the activated sludge wastewater treatment process. Economically feasible technology for use of oxygen rather than air in the activated sludge process is probably the most significant single development in wastewater treatment within the last decade. Dr. McWhirter and his colleagues, pioneers in the development and leaders in the commercialization of this process, have culled and critically reviewed data from numerous technical reports, journal articles, and conference presentations. Their objective was to provide a comprehensive and self-contained reference manual covering the waste treatment process itself as well as the necessary auxiliaries.

This book and other volumes in the Uniscience Series on Water Pollution Control Technology are addressed to design engineers, planners, and managers in industry and government. Our objective is to provide reference manuals that can be used by these diverse groups in this present critical period for implementation of water pollution control.

Richard Prober
Editor-in-Chief

PREFACE

The use of oxygen in the activated sludge process has grown over the past decade from a position of relative obscurity and limited academic interest to a position today of occupying a prominant role as a secondary wastewater treatment process. The economical substitution of oxygen for air in the activated sludge process was referred to by former Secretary of the Interior, Walter G. Hickel, as "the most significant technological advance in the secondary treatment of wastewater since the development of the activated sludge process in the early 1900s." The process has, indeed, achieved rapid and widespread use throughout the U.S. and is now receiving considerable attention throughout the world. Oxygen-activated sludge systems are already in operation in Japan, Mexico, Canada, the U.K., and Western Europe, and are being designed for use in the Philippines, South Africa, Finland, and Eastern Europe.

The advent of oxygen use in secondary treatment has brought with it a wealth of new technological information concerning the design of biochemical oxidation processes and, in particular, the activated sludge process. The use of oxygen in the activated sludge process has enabled many basic and substantial changes to be made in the fundamental design parameters of the process. Oxygen use and operation at high mixed-liquor dissolved oxygen levels removes many of the traditional constraints and limitations that have long plagued the standard air activated sludge process. This has resulted in the practical attainment of a high-rate, high-efficiency process which, in most cases, proves to be more economically attractive than the conventional air-activated sludge process as well as other secondary treatment alternatives.

The purpose of this two-volume series is to present a consolidated and comprehensive reference on oxygen-activated sludge technology. The subject matter is treated in considerable breadth and depth. The fundamental advantages of oxygen use and operation of the activated sludge process at high mixed-liquor dissolved oxygen levels is covered in detail. Many basic concepts of activated sludge system process design, equally applicable to both air and oxygen systems, are also included. The series is primarily aimed at wastewater treatment experts and, in particular, the practicing design engineer. There is also a substantial amount of material, however, that should be of interest and use in advanced undergraduate or graduate courses in environmental engineering and chemical engineering.

The present status of the oxygen-activated sludge process is due in large measure to the development and commercialization of the UNOX® System by the Linde Division of the Union Carbide Corporation. Consequently, this series is devoted almost exclusively to the UNOX oxygen-activated sludge system. Volume I of the series is divided into two parts which includes, (1) historical and background material relating to the use of oxygen and the development of the UNOX system, and (2) the basic process design considerations involved in oxygen-activated sludge system design. Volume II of the series is also divided into two parts consisting of (3) overall oxygenation system design considerations and additional applications, and (4) oxygen supply. As such, the two volumes effectively complement each other and provide a logical sequence for the presentation of the material which flows quite naturally from Volume I into Volume II. The individual parts of both volumes as well as the individual chapters of each part, however, develop in detail a particular aspect of the subject matter which enables it to virtually stand alone. Consequently, the reader is able to quickly focus on a subject area of particular interest and delve into this topic in depth without making extensive reference to the other parts of the series.

My sincere gratitude and admiration are extended to all of my colleagues at Union Carbide too numerous to name who were involved in the formulation and implementation of this work, many of whom also contributed greatly to the development of the UNOX System from its very early days in the laboratory to its current status of extensive world-wide application. Special thanks in this regard are particularly extended to Dr. L. C. Matsch, Mr. E. H. Zander, Mr. J. L. Steele, Mr. J. C. LeFever, Mr. R. H. Harris, and to Marie Costanzo for her tireless efforts in coordinating the preparation of the manuscript material by the numerous authors. Special appreciation is extended to Dr. Richard Prober, Editor-in-Chief of the CRC Press Uniscience Series on Water Pollution Control Technology, for his many helpful comments and suggestions, to the editorial staff of CRC Press, to Terri Weintraub, Gerald A. Becker, and Margaret Saulino for their cooperation and patience in the preparation of this book.

J.R. McWhirter
Westport, Connecticut
1977
November

EDITOR-IN-CHIEF

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Dr. Prober received his B.S. in chemical engineering in 1957 from the Illinois Institute of Technology. In 1958 he received his M.S. degree and in 1962 his Ph.D. degree in chemical engineering from University of Wisconsin.

Dr. Prober's accomplishments include curriculum development for wastewater treatment plant operator training; development of low-flow dissolved oxygen models for the Cuyahoga River and Tinkers Creek, including direction of stream surveys to calibrate the models; development of process-design oriented B.S. and graduate level programs in wastewater engineering; and extensive research into process development of activated carbon treatment and treatment for industrial wastes containing cyanides.

His professional associations include the Water Pollution Control Federation, American Institute of Chemical Engineers, and the American Chemical Society. Dr. Prober has also served as Symposium Chairman for national meetings of the U.S. Environmental Protection Agency, American Institute of Chemical Engineers, and Wastewater equipment Manufacturer's Association.

THE EDITOR

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Dr. McWhirter was graduated from the University of Illinois in 1959 with a B.S. in chemical engineering. In 1961 he received his M.S. degree and in 1962 his Ph.D. in chemical engineering from The Pennsylvania State University.

Dr. McWhirter is the inventor of Union Carbides UNOX® System and has been issued a number of patents related to the use of oxygen and ozone in the field of wastewater treatment. Among the recent citations Dr. McWhirter has received is the 1970 National Chemical Engineering Personal Achievement Award for his pioneering efforts in the development of the UNOX System for wastewater treatment. The UNOX development also led directly to the 1971 Kirkpatrick Award for Chemical Engineering Achievement given to the Union Carbide Corporation. Dr. McWhirter is also the recipient of the 1976 Jacob F. Schoellkopf Award of the Western New York Section of the American Chemical Society.

Dr. McWhirter is a member of the American Institute of Chemical Engineers, American Chemical Society, Water Pollution Control Federation, and Water and Wastewater Equipment Manufacturers Association. He has also authored numerous articles and given many presentations before technical society meetings over the past 10 years in the area of wastewater treatment.

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DEDICATION

This book is dedicated to my colleagues at Union Carbide whose skill, energy, and devotion to the UNOX effort over the past decade has resulted in the many technical advancements embodied in, and the commercial success of, the Unox system.

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Background and Introduction

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Chapter 1
INTRODUCTION

J. R. McWhirter

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The use of relatively high-purity oxygen gas in the activated sludge process has evolved since the mid-1960s from a position of primarily academic interest to a point today where it enjoys broad commercial application. A large and rapidly increasing number of oxygen-activated sludge wastewater treatment plants are already in operation and under construction, and the process continues to realize vigorous growth in the U.S., Japan, Europe, and Canada. As of July 1977, 90 oxygen-activated sludge plants were in operation worldwide with a total combined treatment capacity of approximately 1.5 billion gallons per day. An additional 61 plants were under construction throughout the world, with a cumulative capacity of over 2.8 billion gallons per day. Furthermore, another 97 oxygen plants are in various stages of design which represent an additional 3.1 billion gallons per day of total treatment plant capacity. Collectively, these 248 plants represent an overall combined treatment capacity in excess of 7.4 billion gallons per day which is committed to the use of the oxygen-activated sludge process. By 1985, it is projected that the total secondary treatment capacity which will be using or committed to the oxygen process will exceed 11 billion gallons per day. This represents a highly significant portion of the anticipated total secondary treatment capacity and is ample testimony to the importance and widespread application of the oxygen-activated sludge process. It is also evidence of the fact that the development, commercialization, and utilization of the oxygen-activated sludge process has been considerably more rapid and extensive than normally associated with new wastewater treatment processes.

I. BRIEF HISTORY OF OXYGEN USE IN WASTEWATER TREATMENT

A. Early Studies

Perhaps the earliest known reference regarding commercial consideration of the use of pure oxygen in wastewater treatment occurred in 1934 in an internal memorandum of the Linde Division of Union Carbide Corporation.[1] This was long before the development of the modern industrial gas industry as we know it today, and concerned the desirable market characteristics of potential oxygen use in wastewater treatment. It was thought that this application would provide a steady, base-load oxygen requirement which would stimulate the use and supply of industrial gases. In his December 4, 1934 letter to Dr. L. I. Dana, then Director of the Linde Research Laboratory, Mr. J. J. Murphy wrote:

During a conversation on one of your recent visits to New York we both agreed that new and larger uses for oxygen would be well worth finding. In addition, I personally believe that we could find uses which would be steady and not greatly affected by the normal depression in business cycles. With a very steady load we could probably be in a position to sell oxygen rather cheaply. The two uses I have in mind are water purification and sewage treatment.

The subject was again revived after World War II when the work of Pirnie[2] and Okun[3–5] on the bio-precipitation process was stimulated by the development of "Cheap Tonnage Oxygen" through the use of relatively low-cost, simple oxygen plants for the production of "low-purity" (95%) oxygen. The bio-precipitation process was further studied in the early 1950s by Budd and Lambeth,[6] but little subsequent interest developed. This process, as discussed in Chapters 2 and 3, Volume I, involved not only the use of oxygen but also a new activated sludge process configuration employing a combined reactor-clarifier concept which received preoxygenated feed.

In the late 1950s and early 1960s, interest in the use of oxygen diminished considerably as attention was primarily focused on the effects of the dissolved oxygen concentration on the rate of bio-oxidation or oxygen uptake rate for conventional activated sludge operation conditions.[7,8] These studies revealed that under the typical operating conditions employed in the conventional air-activated sludge process (low MLVSS levels and relatively low oxygen uptake rates), increased dissolved oxygen levels in the mixed-liquor did not increase the rate of biochemical oxidation or the rate of substrate removal. These apparently negative results regarding the potential benefits of higher dissolved oxygen concentrations in the conventional activated sludge process, when coupled with the assumed relative inefficiency and high cost of oxygen use, resulted in a general lack of interest in the concept. As will be discussed further in subsequent chapters, these studies did not reveal many of the advantages of oxygen use and operation at high dissolved oxygen levels for some very fundamental reasons. Earlier studies [9–11] that revealed little or no improvement in treatment efficiency with the use of oxygen were negative for essentially the same reasons.

McKinney and Pfeffer[12] reported on the use of oxygen-enriched air in biological wastewater treatment in 1965. They argued that it is not the level of dissolved oxygen concentration that can be obtained with the use of oxygen that is important, but rather the rate at which oxygen can be transferred to the mixed-liquor. They observed that at lower dissolved oxygen levels, the rate of transfer of oxygen would be significantly increased through the use of oxygen-enriched air. They reasoned that higher oxygen gas concentrations could only be advantageous under oxygen-limiting conditions. If higher oxygenation rates could be obtained, it would be possible to substantially increase the organic loading on the system. By simultaneously increasing the organic loading and the mixed-liquor volatile suspended solids levels, a high degree of treatment efficiency could be obtained at the higher loading and higher oxygen transfer rate conditions. Such, of course, is the case and represents one of the important process and economic benefits of oxygen use in the activated sludge process.

McKinney and Pfeffer[12] further pointed out that there must be some economic gain or process improvement associated with the use of oxygen in comparison to conventional air aeration techniques. They referred to the following areas where such improvements should be obtained:

1. The avoidance of excessively high aeration rates and a reduction in the power required per unit of oxygen transferred, particularly at high oxygen uptake rate conditions
2. Increased rate of stabilization of organic material through elimination of oxygen transfer limitations
3. Reduction in, or elimination of, periods of zero dissolved oxygen concentration to improve overall process operating conditions
4. Reduction in plant size and capital investment
5. Increased capacity of organically overloaded plants without the need for increasing the plant hydraulic capacity
6. Operation of high rate, high organically loaded systems at high removal efficiencies by removing oxygen transfer limitations

As will be amply illustrated and documented throughout these two volumes, these and other process and economic advantages can be practically and effectively realized through the efficient use of oxygen in the activated sludge process.

The problem remained, however, as to how to achieve the inherent potential process advantages of oxygen use while simultaneously obtaining

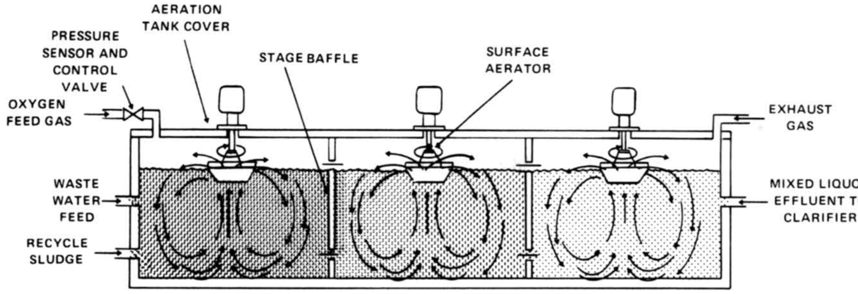

FIGURE 1. Simplified, schematic diagram of three-stage UNOX® System using surface aerators. (Courtesy of Union Carbide Corporation.)

efficient and economical oxygen utilization and retaining the desirable features of the conventional activated sludge process flow configuration.

II. THE UNOX® SYSTEM

The major impetus for the use of oxygen in wastewater treatment came with the development of the UNOX System by the Linde Division of Union Carbide Corporation. A study to evaluate the use of oxygen in the secondary treatment of wastewater was begun by Union Carbide in late 1966, followed by the invention of the UNOX System. The UNOX System is illustrated schematically in its usual form in Figure 1. The system uses a covered, multistage oxygenation and reaction system in which the wastewater and activated sludge are contacted in a series of cocurrent, gas-liquid mixing stages. The system is operated at essentially atmospheric pressure with relatively high-purity oxygen gas, wastewater, and recycle sludge being introduced into the first stage and flowing cocurrently through the successive contacting stages. The exhaust gas is vented from the last stage and the mixed-liquor is settled in a conventional gravity clarifier. The oxygen feed gas rate can be automatically controlled in direct proportion to the actual oxygen uptake rate in the system by means of a simple pressure controller in the first stage. As the oxygen uptake rate diminishes, the pressure in the first stage tends to increase and the oxygen feed rate is reduced. Alternatively, as the oxygen demand increases, the pressure in the first stage tends to decrease and the oxygen feed rate is increased. The number of stages employed, the overall reactor geometrical configuration, tank depth, and the specific type of gas-liquid contacting devices or aerators used in the stages can be economically optimized for each specific installation and process requirement. The system is extremely flexible in design and construction and employs standard mechanical equipment used in conventional air aeration practice. Standard surface aerators are typically used in most installations. The relatively simple construction features and the use of standard equipment components are two of the strong attributes of the system.

Although quite simple and straightforward in its physical embodiment, the underlying mass transfer and reaction processes involved in the UNOX System are considerably more complex than those involved in a conventional air aeration system. The enclosed, multistage recycle oxygenation system enables a high oxygen utilization efficiency to be achieved and maintains a high average oxygen partial pressure in the aerating gas. This results in efficient and economical oxygen utilization while simultaneously achieving a substantial reduction in the oxygen dissolution energy requirement per unit of oxygen dissolved. Also, economical operation at relatively high dissolved oxygen levels (4 to 6 mg/l) relative to standard aeration practice (1 to 2 mg/l) can be achieved. As will be discussed in subsequent chapters, this results in significant additional process and economic advantages with respect to mixed-liquor settling rates, sludge dewatering characteristics, and sludge production rates. It is this unique combination of effects that results in the UNOX System's overall process advantages and the accompanying economic benefits.

The first experimental tests of the UNOX System were accomplished in late 1967 and early 1968 in a simulated bio-oxidation system pilot plant. This unit (shown in Figure 2) employed a surface aeration system with four gas stages and a 1500-gal aeration tank, 14 ft in length by 3 ft in

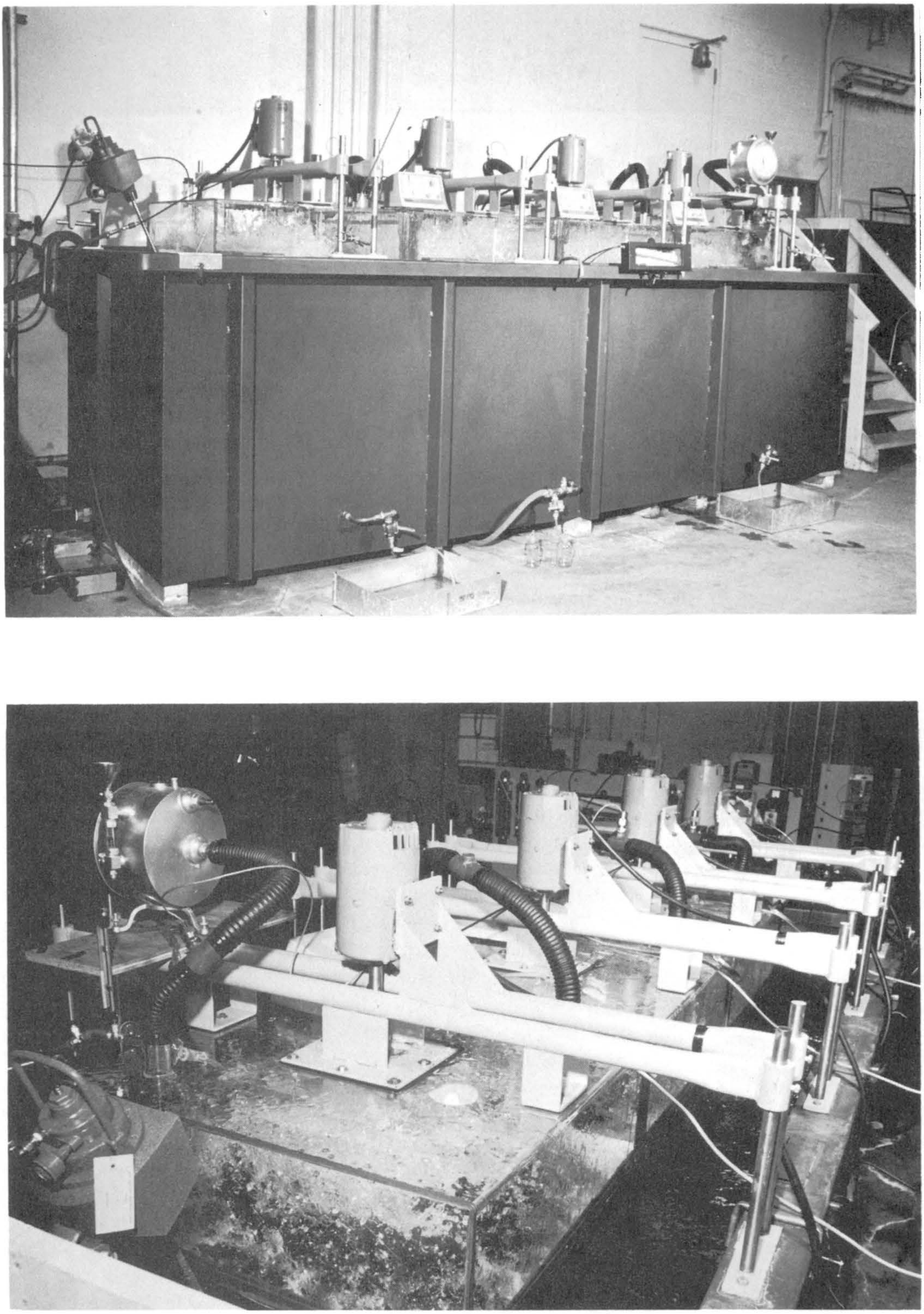

FIGURE 2. Simulated Bio-Oxidation system pilot plant unit used to conduct first experimental tests of the UNOX® System. (Courtesy of Union Carbide Corporation.)

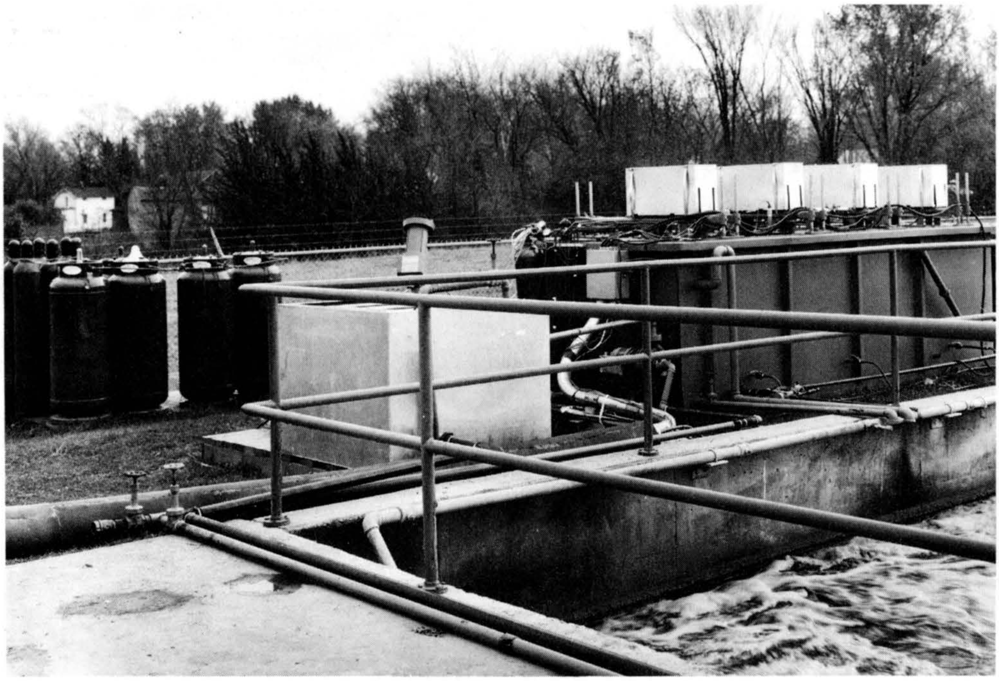

FIGURE 3. Pilot plant unit used to conduct the first activated sludge tests of the UNOX® System at Batavia, New York. (Courtesy of Union Carbide Corporation.)

width with a water depth of approximately 3 ft. These tests provided basic verification of the capability of the multistage oxygenation system to achieve a high oxygen utilization efficiency while simultaneously maintaining a high average oxygen partial pressure in the aeration gas under the multicomponent mass transfer conditions encountered in the biochemical oxidation of wastewater. Following these simulated bio-oxidation tests, pilot plant tests involving actual activated sludge operation on municipal wastewater were conducted at Batavia, New York, during 1968 (Figure 3). These tests confirmed the activated sludge process advantages achievable with oxygen aeration as well as the economical utilization and dissolution of the oxygen gas.

The next phase of the UNOX program involved a full-scale plant test at the Batavia, New York municipal wastewater treatment plant under the sponsorship of the Federal Water Quality Administration (FWQA)[13,14] the predecessor of the current Environmental Protection Agency (EPA). This program was begun in late 1968 and spanned a period of approximately 2½ years. It involved a direct side-by-side comparison of the UNOX System with a conventional air-activated sludge system. Half of the Batavia treatment plant was converted to the use of the UNOX System while the other half was operated using the conventionally designed diffused air aeration system (Figure 4*). This comprehensive study provided full-scale verification of the process and economic advantages of oxygen vs. air aeration in the activated sludge process.

Following the successful conclusion of the Batavia demonstration program, Union Carbide announced its commercial entry into the wastewater treatment business in May of 1970. Shortly thereafter, the city of Detroit formally announced its decision to redesign one half of the first segment of its new secondary wastewater treatment plant for the use of the UNOX System. This marked the first commercial commitment to the use of the UNOX System. The half of the

* For Figure 4 see color insert, following page 50.

FIGURE 5. Overall view of 300 MGD UNOX® System at Detroit, Michigan with 180 ton/day cryogenic oxygen plant and 900 ton liquid oxygen storage tank in the background. (Courtesy of Union Carbide Corporation.)

plant designed for UNOX had a treatment capacity of 300 MGD while using the same basic tank design as the other half of the plant which was designed for 150 MGD of capacity using a diffused air aeration system. The UNOX System was designed for a retention time of 1.14 hr and the air system was designed for a retention time of 2.28 hr (each design based on total flow through the aeration tanks including both influent waste and sludge recycle). Each system was designed to produce an effluent total BOD_5 of less than 25 mg/l from a total BOD_5 in the feed to the secondary system of 140 mg/l. The two systems were then to be tested and directly compared in performance and operation prior to a future decision regarding the design of the remainder of the facility. However, long before these first two plant segments were completed, the city of Detroit decided to base its remaining plant capacity on the oxygenation system design. In mid-1974, construction of an additional 600 MGD oxygen-activated sludge system was begun. The initial 300 MGD UNOX System in Detroit was placed into operation in 1975 and has more than confirmed its ability to meet or exceed the design performance requirements. Figure 5 shows an overall view of the 300 MGD UNOX System in Detroit with the 180 ton/day cryogenic oxygen plant and 900 ton liquid oxygen storage tank in the background.

In the early 1970s, Union Carbide initiated an extensive and comprehensive pilot plant program to demonstrate the advantages and capability of the UNOX System on a wide variety of wastewaters. Since that time, over 200 pilot plant or treatability studies have been conducted on virtually every type of municipal and industrial wastewater. Most of these tests were run using on-site mobile pilot plants mounted on trailer vans, such as the one shown in Figure 6. These

FIGURE 6. Typical mobile UNOX® pilot plant unit used for conducting on-site pilot plant tests. (Courtesy of Union Carbide Corporation.)

tests were conducted over an extended time period to enable evaluation of various climatic and wastewater conditions as well as operation over a wide range of process parameters. This pilot plant program is believed by many in the field to be the most exhaustive and comprehensive test program ever conducted on a new wastewater treatment process. The results of this program were aptly summarized in a news article that appeared in the November 1974 issue of the *Journal of the Water Pollution Control Federation:*[15]

> The oxygen activated sludge process is no longer an interesting concept of dubious practicality. Careful investigation and pilot plant testing have largely confirmed its publicized potential. As a process, oxygen activated sludge has come into its own.

III. CURRENT STATUS OF OXYGEN-ACTIVATED SLUDGE SYSTEM USE

During the last several years, numerous oxygen-activated sludge plants have come on-stream with an additional 20 to 25 plants going into operation every year. Tables 1 to 4 summarize the current status of oxygen-activated sludge system applications in the U.S. and world-wide and provide a breakdown into municipal and industrial wastewater usage. These tables are updated and slightly revised versions of those originally published by Brenner[16] in June 1976. As seen in these tables, application of the process is broadly based both geographically and by type of wastewater.

Brenner also published extensive operating and performance data case histories for 11 operating oxygen-activated sludge plants.[16] These plants cover a wide variety of process applications, system component configurations, and plant sizes. Figures 7 and 9 show pictures of several of the plants reviewed. With only one exception, these plants have met or substantially exceeded the design performance requirements. The lone case of subdesign performance resulted from excessive fat

TABLE 1

World-wide Oxygen-activated Sludge Plant Status, July 1977

Parameter	Operating plants	Plants under construction	Plants being designed	Totals
No. of plants				
Municipal	45	56	92	193
Industrial	45	5	5	55
Totals	90	61	97	248
Design flow (MGD)				
Municipal	1261.0	2615.7	2958.3	6835.0
Industrial	283.2	191.4	150.1	624.7
Totals	1544.2	2807.1	3108.4	7459.7
O_2 supply capacity (tons/day)				
Municipal	1749.4	4201.0	4257.0	10207.4
Industrial	982.7	204.5	340.3	1527.5
Totals	2732.1	4405.5	4597.3	11734.9

Modifed from Brenner, R. C., Updated Status of Oxygen Activated Sludge Wastewater Treatment, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, June 1976.

TABLE 2

U.S. Oxygen-activated Sludge Plant Status, July 1977

Parameter	Operating plants	Plants under construction	Plants being designed	Totals
No. of Plants				
Municipal	39	44	74	157
Industrial	24	4	2	30
Totals	63	48	76	187
Design flow (MGD)				
Municipal	1245.7	2326.4	2504.2	6076.3
Industrial	204.2	165.0	45.0	414.2
Totals	1449.9	2491.4	2549.2	6490.5
O_2 supply capacity (tons/day)				
Municipal	1734.4	3805.5	3602.0	9141.9
Industrial	709.7	188.0	180.0	1077.7
Totals	2444.1	3993.5	3782.0	10219.6

Modified from Brenner, R. C., Updated Status of Oxygen Activated Sludge Wastewater Treatment, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, June 1976.

and grease loadings in the influent (often in excess of 100 mg/l) from a local poultry processor. This excessive amount of grease, which escapes the secondary clarifiers as a consequence of inadequate skimming and grease removal capability, has prevented consistent attainment of the effluent quality objectives.

The overall process and mechanical reliability of these plants has been excellent. A few minor mechanical problems with the equipment were encountered with some of the early Pressure Swing Adsorption (PSA) oxygen generators and with some of the aeration system components; however, these were readily corrected. The plants reported on by Brenner,[16] as well as all of the 90 oxygen-activated sludge plants in operation world-wide by July 1977 have confirmed the process and economic advantages of oxygen use.

TABLE 3

Breakdown of Oxygen-activated Sludge Plants by Country, July 1977

Country	Operating plants	Plants under construction	Plants being designed	Totals
U.S.	63	48	76	187
Japan	22	3	5	30
Canada	1	1	1	3
Mexico	1	–	–	1
United Kingdom	1	–	3	4
Germany	1	2	3	6
Denmark	–	1	–	1
Switzerland	–	1	–	1
Belgium	1	–	–	1
Italy	–	3	2	5
France	–	2	2	4
Poland	–	–	1	1
Austria	–	–	2	2
Finland	–	–	1	1
Taiwan	–	–	1	1
Totals	90	61	97	248

Modified from Brenner, R. C., Updated Status of Oxygen Activated Sludge Wastewater Treatment, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, June 1976.

TABLE 4

Breakdown of Oxygen-activated Sludge Plants by Industrial Application, July 1977

	Operating plants		Plants under construction		Totals	
Industrial application	No. of plants	Design flow (MGD)	No. of plants	Design flow (MGD)	No. of plants	Design flow (MGD)
Chemicals	10	38.9	0	0	10	38.9
Dyestuffs	1	3.1	0	0	1	3.1
Food processing	2	2.5	0	0	2	2.5
Petrochemical	9	27.4	0	0	9	27.4
Pharmaceutical	2	1.7	0	0	2	1.7
Pulp and paper	18	194.3	5	165.0	23	359.3
Steel	1	13.7	0	0	1	13.7
Synthetic rubber	1	0.8	0	0	1	0.8
Brewing	1	0.8	0	0	1	0.8
Totals	45	283.2	5	165.0	50	448.2

Modified from Brenner, R. C., Updated Status of Oxygen Activated Sludge Wastewater Treatment, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, June 1976.

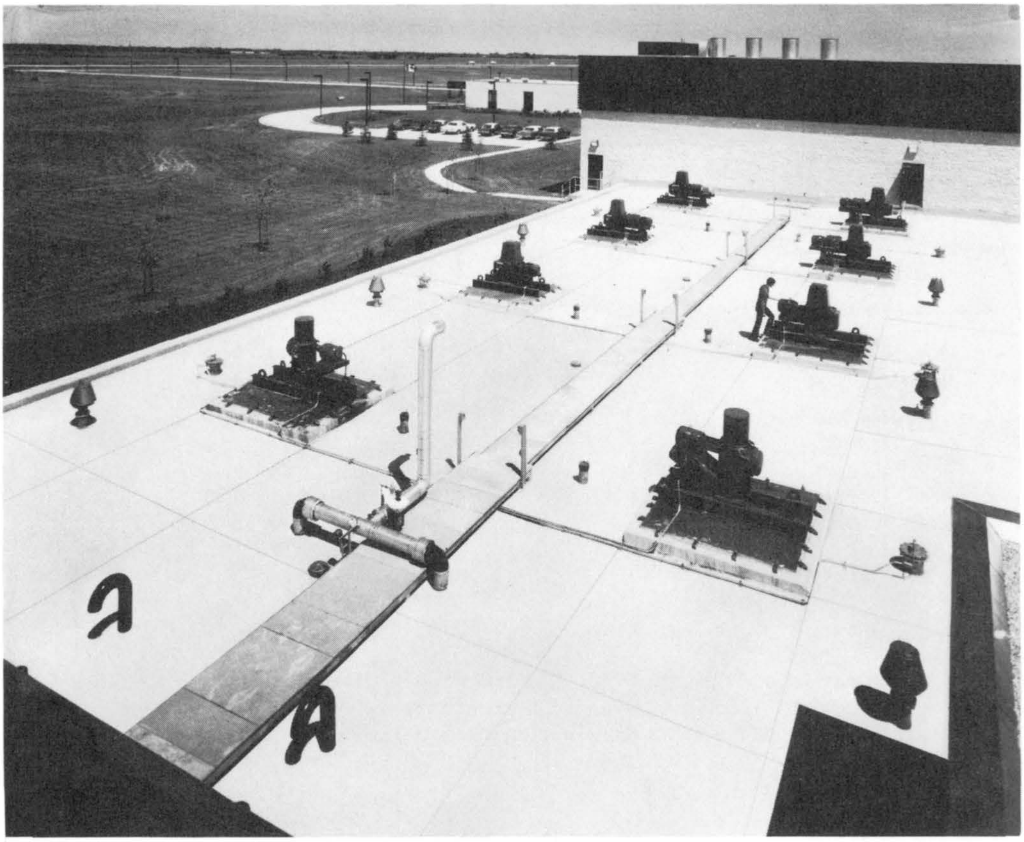

FIGURE 7. 12 MGD UNOX® System at Winnipeg, Canada. (Courtesy of Union Carbide Corporation.)

FIGURE 8. 7.5 MGD UNOX® System at Speedway, Indiana. (Courtesy of Union Carbide Corporation.)

FIGURE 9. 8 MGD UNOX® System at Morganton, North Carolina. (Courtesy of Union Carbide Corporation.)

IV. ALTERNATIVE OXYGENATION SYSTEM DESIGNS

The vast majority of the development and commercial application of the oxygen-activated sludge process to date has been with the UNOX System. The attention drawn to the use of pure oxygen has, however, stimulated other developments. Among these are the OASES® System by Air Products and Chemicals, Incorporated, Allentown, Pennsylvania; the MAROX® System by FMC, Chicago; and the F^3O System by Air Reduction Company, Murray Hill, New Jersey.

The OASES System for wastewater treatment was first introduced on the market in 1971 by Air Products and Chemicals, Incorporated. This system uses covered oxygenation basins that are typically divided into a number of gas and liquid contacting stages with gas and liquid flowing cocurrently through the reactor. Oxygen feed control is normally accomplished by means of reactor pressure control. Air Products also uses a design modification referred to as the Controlled Back Mix OASES System. This design employs a covered oxygenation basin with multi-stage gas contacting. The mixed-liquor is contacted cocurrently with the gas in an elongated, "serpentine," liquid flow circuit defined by partitions in the reactor.

The MAROX System, marketed by FMC Corporation, utilizes an uncovered oxygenation basin design in which the oxygen feed gas is directly diffused into the mixed-liquor. This sytem uses rotating active diffusers for oxygen dissolution. Oxygen feed gas is pressurized and fed through a hollow shaft mixer assembly to the diffusers which disperse the oxygen gas into small bubbles. Oxygen feed gas control is accomplished by the use of mixed-liquor D.O. probes that maintain a preset dissolved oxygen concentration in the mixed-liquor.

The most recent development in the design of oxygen-activated sludge systems is Airco, Incorporated's forced free-fall oxygenation (F^3O) system, oxygen dissolution is accomplished in the process. Physically, the F^3O System is a self-contained module of monolithic cast concrete construction designed to be fully submerged within an aeration basin. Mixed-liquor is pumped into the top center of the module by means of an axial flow impeller. The flow enters a central draft tube, is forced up an outer annular region and falls through an enclosed region where a high purity oxygen atmosphere is maintained. Oxygen transfer is effected in this region. The pumped mixed-liquor then leaves the module through exit ports in the base and returns to the external aeration basin. Mixed-liquor D.O. levels are used to control the height of the liquid fall and the oxygen feed rate.

This two-volume series is principally devoted to the technology and application of the UNOX System. The editor and many of the chapter authors have been intimately involved with, and responsible for, the development of the UNOX System since its very beginnings. The concentration on the UNOX System is due to its widespread commercial acceptance and their familiarity, experience, and access to the extensive body of design and performance information related to this method of oxygen-activated sludge wastewater treatment.

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Chapter 2

OXYGEN AND THE BIO-PRECIPITATION PROCESS

D. A. Okun

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I. INTRODUCTION

On October 26, 1946, the late Malcolm Pirnie, a consulting engineer of New York City, sent the late Gordon M. Fair, then Dean of the Graduate School of Engineering of Harvard University, an office memorandum entitled "Cheap Oxygen Possible New Tool in Sanitary Engineering."[1] Pirnie had been intrigued with the development of relatively low-cost and simpler plants for the production of oxygen by air liquefaction and rectification during World War II. The low cost was possible because the percent purity was somewhat lower than oxygen produced conventionally, and because it might be used directly without compression or liquefaction. Such "tonnage" oxygen appeared to have promise for industry, particularly in increasing the productivity of steel mills. It seemed to Mr. Pirnie that such oxygen might find a place in biological wastewater treatment, where increasing the availability of oxygen might increase the rate of treatment.

With his memorandum, Pirnie attached a proposed plant design that made use of an upflow precipitator that he had developed for the removal of coagulated floc particles in water treatment. The modification was that the influent to this upflow precipitator was oxygenated with pure oxygen, thereby carrying dissolved oxygen into the floc blanket (Figure 1).

This writer was at that time a Teaching Fellow and a doctoral candidate at Harvard University and Dean Fair suggested that he might undertake a study of the potential of pure oxygen for wastewater treatment. Fill-and-draw activated sludge treatment studies with pure oxygen were undertaken to establish whether or not the microbial life associated with biological wastewater treatment was benefited or deleteriously affected. A search of the literature revealed that others had earlier made studies of the use of pure oxygen in activated sludge and, if the results were not conclusive, they provided no evidence that high dissolved oxygen concentrations interfered with microbial activity.[2-5] It was noted that nitrification may be inhibited in wastewaters and diluted wastewater samples, particularly in biochemical oxygen demand (BOD) tests incubated at high dissolved oxygen concentrations.[6]

When the fill-and-draw activated sludge studies proved promising, parallel continuous-flow pilot plants were installed in the laboratory to demon-