The "UNOX" System—Oxygen Aeration in the Activated Sludge Process[1]

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Abstract

The UNOX System has been developed to improve upon the conventional activated sludge process. The use of enriched oxygen in a simple and economical multistage gas liquid contacting device allows oxygen to be transferred to wastewater at increased rates with significant decreases in power requirements over those required when using air as the oxygen supply media. The elimination of the mass transfer restriction allows operation at solids levels of 4500–7000 mg/l while maintaining a dissolved oxygen level of 8–10 mg/l in the mixed liquor. Retention times for the process can be correspondingly decreased to 1–2 hr. A highly flocculant sludge is obtained which has excellent settling and dewatering characteristics and is produced in less quantities than normally produced by a conventional air activated sludge process. The process has been demonstrated in a 2.5 mgd activated sludge plant at Batavia, New York. During the Federal Water Quality Administration (FWQA) contract the UNOX process was able to demonstrate consistent BOD and suspended solids removals in excess of 90%. A number of pilot plant programs in municipal waste applications are continuing to verify and confirm the excellent treatment effectiveness and decreased power requirements achieved with the system. Field tests are also being conducted on the treatment of industrial wastes. A pilot plant program is successfully underway treating a mixed petrochemical waste in one of the Union Carbide large petrochemical plants. Plans are being made to pilot plant the UNOX System on a pulp and paper mill waste stream during 1971.

Introduction

General Background

The use of the conventional activated sludge process as a means of removing a high percentage of the biodegradable organic constituents in municipal and industrial waste streams is an established and well known process. When it was developed and until recently the most economical method of supplying oxygen to satisfy the metabolic requirements of the activated sludge was to compress air and inject it into the mixed liquor where a certain fraction of the contained oxygen was dissolved and thereby made available to the biomass. A number of different devices have been devised over the years to affect the oxygen dissolution process; however all such devices have been constrained by the dominant characteristic of the gas being dissolved. Oxygen is a sparingly soluble gas in water and oxygen exists in the atmosphere at a relatively low partial pressure. As a consequence of these constraints the unit power requirements for operating an activated sludge process have been characteristically high and in practice the operating conditions for activated sludge processes have been selected with prime consideration being given to the oxygen supply limitations.

Two technical developments have occurred which offer the possibility of alleviating the oxygen transfer constraint which exists for an air-operated activated sludge process. The development of commercial scale highly efficient air separation technology in the past two decades has resulted in achieving the ability to separate air into its two major constituents, oxygen and nitrogen for much less power consumption than is required to dissolve oxygen into water from air. The second significant technical achievement is the development of an adaptation of the activated sludge process whereby the oxygen produced from an air separation plant can be dissolved into the mixed liquor with very high utilization of the oxygen within the process and with low power requirements.

With the use of pure oxygen as the aerating gas, the mass transfer restriction which exists when using air is largely removed. Consequently it is possible to operate at increased dissolved oxygen levels and high oxygen dissolution flux rates. The designer is now free to consider increasing the biomass concentration in the mixed liquor and thereby can achieve a commensurate decrease in the required retention time to achieve biological purification and stabilization of the waste. As a consequence of maintaining the high dissolved oxygen environment at low turbulence levels, a highly flocculant sludge is produced so that the solids liquid separation required by the process clarifier can be as readily achieved at high mixed liquor suspended solids (MLSS) levels as is achieved by conventional aeration systems operating at lower MLSS levels.

Historical Aspects

The use of pure oxygen or oxygen-enriched air in the activated sludge waste treatment process has been the subject of a number of technical and economic studies published over a period of more than 20 years. Okun (1) first reported on laboratory tests using oxygen in a modification of the conventional activated sludge process in 1949. This process, termed the "bioprecipitation system," was developed from a method first suggested by Pirnie (2). Okun reported the bio-precipitation process to be an effective means of treating wastewater, at least equally efficient as present day completely mixed activated sludge systems.

This process arrangement was not consistent with achievement of an economically desirable high percentage oxygen absorption and utilization necessary to minimize oxygen production costs. Consequently the bioprecipitation process has certain inherently undesirable features which tend to increase the cost of supplying oxygen to the reactor relative to the cost of direct aeration or oxygenation of the mixed liquor itself.

Carver (3) has reported data indicating that the rate of oxygen transfer with pure oxygen aeration was essentially independent of dissolved oxygen content of the liquid between 0 and 12 mg/l. He suggested that for systems exerting a high oxygen demand additional oxygen might be furnished as pure oxygen and some air aeration might be used for providing adequate mixing only.

Both Okun (4) and McKinney (5) have reviewed the "state-of-the-art" in the use of high purity oxygen in secondary treatment and have recognized the inherent advantage of an aerating gas with a high oxygen partial pressure in increasing the rate of oxygen transfer. McKinney (5) concludes that the following advantages may be achieved if pure oxygen or oxygen-enriched air could be used in the activated sludge process: (a) possibility of avoiding excessively high aeration rates and hence obtaining a reduction in the power required per unit of oxygen transferred; (b) increased rate of stabilization of organic material; (c) reduction in, or elimination of periods of zero dissolved oxygen concentration; (d) ability to operate high rate systems by substantial increases in organic loading where oxygen is not limiting; (e) reduction in plant size and thus capital investment; (f) increased capacity of organically overloaded plants without need for additional aerator capacity. To this time the major problem in realizing these potential advantages has been the development of an efficient means of utilizing oxygen such that a high over-all utilization of gaseous

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[1] Presented at the AOCS Meeting, Houston, Texas, May 1971.

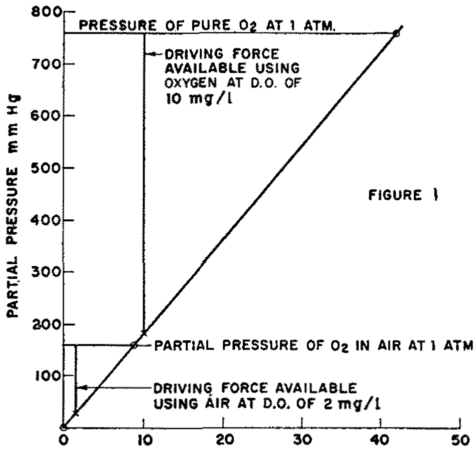

FIG. 1. Comparison of oxygen system and air system oxygen partial pressure driving forces.

oxygen might be achieved.

Union Carbide Involvement

In the mid-sixties the Linde Division of Union Carbide Corporation, recognizing that its air separation technology was highly advanced and could separate air into its constituents for lower power consumption than that required to dissolve oxygen into water from air, began development efforts to find a means for effectively and efficiently utilizing high purity oxygen in the activated sludge process. The problem was defined as a multicomponent mass transfer system in which oxygen must be dissolved into solution, dissolved nitrogen stripping must be accounted for, and finally carbon dioxide production must be considered. From such theoretical considerations a multi-staged system was devised in which oxygen is efficiently dissolved into the mixed liquor and effectively utilized in series flow through the multi-staged system. Pilot plant and laboratory tests confirmed the theoretical studies and provided valuable data pertinent to the highly flocculant nature of the biomass. In 1968 it was decided to approach the Federal Water Quality Administration with a full disclosure of the significant developments in oxygen aeration and to apply for a grant to demonstrate the process on a large scale. The grant was provided for demonstration of the process at an existing 2.5 mgd activated sludge treatment facility located in Batavia, New York. In 1969 Union Carbide modified half of the Batavia facility for oxygen service and conducted an extensive program of direct comparisons of oxygenation and conventionally aerated activated sludge processes. The report documenting this work was issued by the FWQA in the spring of 1970 (6).

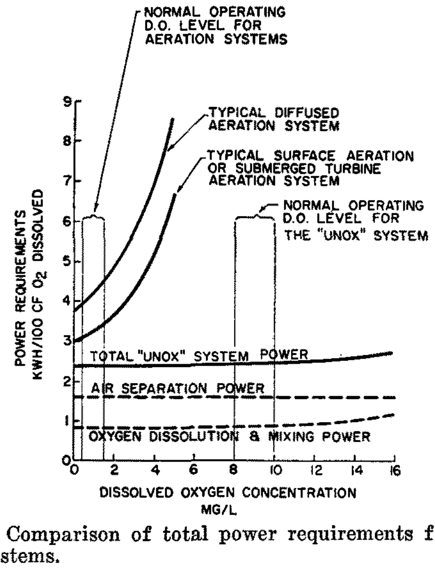

FIG. 2. Comparison of total power requirements for air and oxygen systems.

During 1970 Union Carbide applied for and received a follow-on contract to further investigate the oxygen process at Batavia. The specific objectives of this follow-on program were to further confirm the significantly decreased sludge production figures noted in the original contract work, to investigate the oxygen digestion of activated sludge, and to study the filtration characteristics of unthickened waste-activated sludge. Operation at Batavia was continued throughout the summer and fall of 1970. A final report is now being written for the FWQA and will be published in 1971.

As a result of the technical developments made and their successful demonstration at Batavia, Union Carbide is actively marketing the UNOX System. UNOX Systems are being installed in Detroit (300 mgd) and Newtown Creek in New York City (20 mgd, FWQA demonstration). Union Carbide has constructed a number of pilot plants demonstrating the UNOX process to municipalities throughout the country. Pilot plant programs are currently in operation at Middlesex County Sewer Authority, Blue Plains, D.C., Euclid, Ohio, New Orleans, La., Louisville, Ky., North Tonawanda, New York, and Town of Tonawanda, New York.

The use of oxygen is also applicable in industrial wastes where the activated sludge process can be applied. The process is currently being demonstrated at an integrated Union Carbide petrochemical plant and a UNOX pilot plant program is planned in the Pulp and Paper Industry during 1971.

The Union Carbide Oxygenation System

General Technical Considerations

The successful application of oxygen in the activated sludge process is by no means an obvious process achievement. To effectively and economically utilize oxygen the following significant factors must be recognized and incorporated into the system.

An economical on-site oxygen gas generation system must be available. This technology has been developed over the last two decades and is readily available today. The power requirements for separation of air into its constituents, oxygen and nitrogen, are approximately 1.3–1.6 KWH per 100 cf of oxygen produced. This represents approximately one third to one half of the power required to dissolve oxygen into water from air using current aeration devices. Therefore if the energy expended to dissolve high purity oxygen into mixed liquor is equal to or less than the difference between the energy required to transfer oxygen directly from air and the energy required to produce high purity oxygen from air, then direct oxygenation with pure oxygen may be economically competitive with air aeration for secondary treatment biooxidation.

A high oxygen absorption and utilization efficiency must be achieved with the process since pure oxygen is a relatively expensive raw material. Even though power requirements to separate air are low, if the oxygen product is not utilized effectively the costs per unit of oxygen dissolved will be prohibitively high.

Efficient and ample liquid mixing must be provided to maintain the biomass in suspension and to maintain a uniform biomass concentration in the mixed liquor. One would expect that an oxygen process would operate with significantly less gas throughput since all of the nitrogen normally contained in air has been rejected by the air separation unit. Indeed gas throughput rates are significantly reduced since not only is the nitrogen eliminated but the over-all oxygen utilization achieved by the process is about 90% compared with the typical values of 10–20% commonly achieved by an aerated system. The net result is that the gas throughput rate for an oxygen system is 1–5% of that for an air system. Consequently auxiliary mixing is required to insure solids suspension and uniform mixed liquor concentrations. A convenient method of supplying this mixing is by the use of submerged mixing units.

Efficient oxygen dissolution as compared with air aeration systems is required. The standard activated sludge process

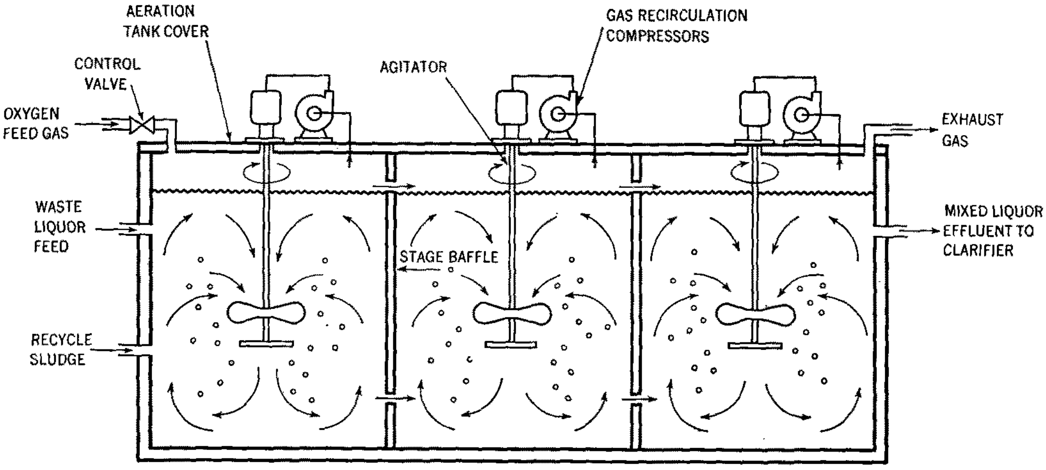

FIG. 3. Schematic diagram of UNOX system with rotating sparger (3 stages shown).

uses air as the source of oxygen to sustain the aerobic biological activity in the mixed liquor suspension. In order to be made available to the microorganisms, however, the oxygen must first be dissolved into the liquid phase. One of the characteristic aspects of air aeration is the relatively high energy requirements per unit of oxygen dissolved for oxygen dissolution from the atmosphere into the aqueous mixed liquor suspension. This is a consequence of the basic mass transfer process which in this instance is almost entirely liquid phase controlled, a feature which distinguishes all processes involving the dissolution of sparingly soluble gases in liquids. This is because both the solubility and diffusivity of oxygen in water are low. The presence of the large amount of nitrogen in air further aggravates the oxygen transfer problem by reducing the available oxygen partial pressure driving force for the interphase mass transfer process. As a result substantial amounts of energy must be expended in creating a large gas liquid surface area and a high degree of interfacial turbulence in order to enhance the interphase mass transfer rate. However in spite of considerable effort and many technological advances made over the years, the gas liquid contacting and oxygen dissolution step has remained a costly process in terms of the quantity of oxygen dissolved per unit of energy expended.

The UNOX system is normally operated at D.O. levels of 8–10 mg/l. Figure 1 illustrates how this apparently high D.O. level can be achieved economically when using high purity oxygen. The driving force available for oxygen transfer in an air aeration system operating at a D.O. level of 2 ppm is compared with that of an oxygenation system operating at a D.O. level of 10 ppm. At a temperature of 20 C and 1 atm total pressure, the air system has an available oxygen partial pressure driving force of about 125 mm Hg whereas the oxygen system has an available oxygen partial pressure driving force of about 585 mm Hg. Therefore, even at an elevated D.O. level as high as 10 ppm, the oxygenation system has a driving force of about 4.7 times that of an air aeration system operating at 2 ppm. In other words operation at a D.O. level of 10 ppm with oxygenation corresponds to operation at about the same percentage of equilibrium saturation as operation at 2 ppm with air aeration.

Another very important advantage of the high available oxygen driving force is the ability to achieve a relatively high volumetric oxygen transfer rate per unit of power input. As shown in Figure 1, an oxygenation system can transfer approximately five times the oxygen per unit of interfacial area as a comparable air system. Hence an oxygenation system can operate with about one fifth the power input of an air system at comparable over-all oxygen transfer rates. This characteristic is particularly important in high rate activated sludge systems in order to minimize the volumetric power input and therefore the turbulence and shear levels to which the biomass is exposed while maintaining high mixed liquor D.O. levels. High turbulence levels tend to reduce the floc size and retard the flocculating tendence of the sludge and hence adversely affect its settling characteristics.

The net result of the ability to achieve a high oxygen transfer rate per unit of power input is shown in Figure 2. In this figure the total power requirements for dissolving oxygen into a waste stream from air and with a UNOX system are shown. The total power for the UNOX System consists of the powers for air separation plus the power required for oxygen dissolution and auxiliary mixing. It can be seen that at any D.O. level below about 12 mg/l the total power requirements are essentially constant. The power requirements for typical diffused air, for surface aeration, or for submerged turbine aeration systems are greater than the total power for a UNOX System and are extremely sensitive to the design dissolved oxygen level.

Increased biomass concentration can be carried in the aeration tanks because of the high oxygen transfer efficiency obtained when oxygen is used efficiently. With an air

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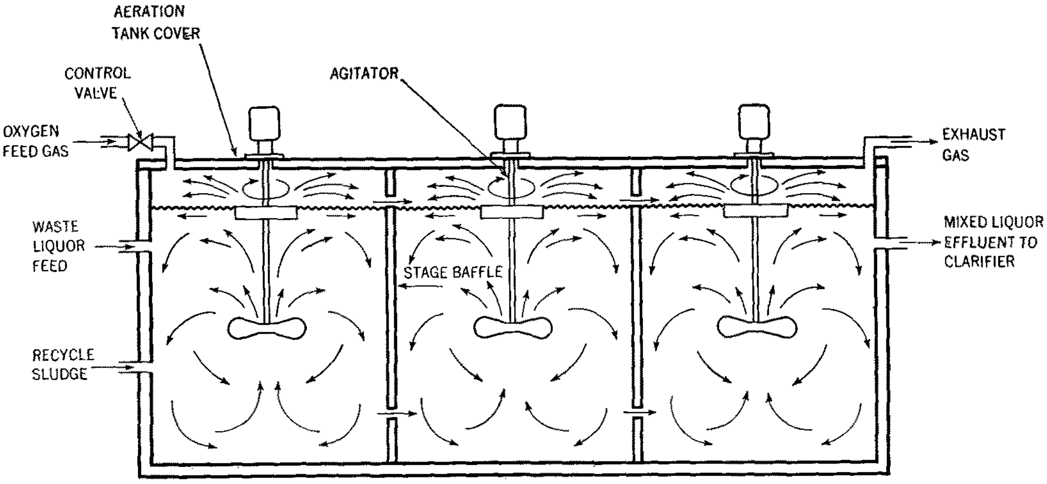

Fig. 4. Schematic diagram of UNOX system with surface aerator (3 stages shown).

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system an increase in the concentration of biomass with the consequent increase in oxygen uptake demand would result in either an oxygen deficiency and consequently a loss in process efficiency, or would require significant increases in aeration rate to support the biological activity. The latter is uneconomical due to the inherent high power requirements for dissolution of oxygen into water from air. Furthermore the increased aeration rate will increase the turbulence and shear which tends to reduce the flocculating characteristics of the sludge and adversely affect its settling characteristics.

The principal advantage of increased concentration of biomass in the aeration tanks are well-documented. The designer can utilize the increased concentration to decrease the hydraulic retention time for the process to save in aeration tank investment. This advantage has been long recognized but has been unattainable because of the economic considerations inherent in very high aeration rates to support high biomass levels. Of equal importance in preventing operation at high MLSS levels is the poor settling characteristics achieved at high turbulence levels. An oxygen system is able to operate at low unit power inputs, low turbulence, and low shear, at high D.O. levels, with a high MLSS level, and thus obtain a highly flocculant very settleable sludge which can be separated in conventional clarification equipment.

Oxygenation System Description

The above technical considerations have been incorporated by Union Carbide Corporation's Linde Division into an easy to operate yet highly efficient system. This system is a cost effective and reliable process which can be utilized for either new activated sludge design or can be adapted to existing activated sludge processes. One version of the process was demonstrated in a full scale activated sludge process at Batavia, New York under a FWQA-funded study (6). This process, shown schematically in Figure 3, is based on a series of enclosed and cocurrently operated gas liquid contacting stages. In this case only three contacting stages are shown, although in practice the exact method of contacting as well as the number of stages will vary with the specific application.

In such a system as shown in Figure 3, the oxygen gas is fed into the first stage at a pressure of only about 1–4 in. of water column above ambient. Small recirculating gas blowers in each stage pump the oxygen gas through the hollow agitator shaft to a rotating sparger device at a rate sufficient to maintain the required mixed liquor D.O. level. The indicated pumping action of the impeller located on the same shaft as the sparger promotes adequate liquid mixing and yields relatively long contact times for the effectively dispersed oxygen gas bubbles.

Gas is recirculated within a stage at a rate usually higher than the rate of gas flow from one stage to another. The successive aeration stages or chambers are connected to each other in a manner which will allow gas to flow freely from stage to stage with only a very slight pressure drop, but yet sufficient to prevent gas back mixing or interstage mixing of the aeration gas. This is accomplished by appropriate sizing of the interstage gas passages. The liquid flow (mixed liquor) through successive stages is cocurrent with the gas flow. Each successive stage is essentially identical to the preceding one except that as a higher proportion of the oxygen demand is met in the initial stages, the required volume of gas to be recirculated in subsequent stages will be less to maintain the desired dissolved oxygen level in the mixed liquor. Effluent mixed liquor from the system is settled in the conventional manner and the settled activated sludge is returned to the first stage for blending with the feed raw or settled sewage.

The entire multistage activated sludge unit is fitted with a gas tight cover to contain the oxygen aeration gas. A restricted exhaust gas line from the final stage vents the waste gas to the atmosphere. Oxygen gas is automatically fed to the system on demand with the entire unit operating in effect as a respirometer. A small positive pressure is maintained by the feed gas flow controller. As the organic load and respiration (oxygen demand) of the biomass increase, the pressure tends to decrease and feed oxygen flow into the system increases to re-establish the pressure set point of the controller. Feed oxygen to the multistage system can be controlled on this pressure demand basis by a simple regulator, or differential pressure controller, automatic valve combination.

In general the net flow rate of gas from stage to stage is largely determined by the net rate of gas mass transfer to the liquid in each stage. Since the rate of oxygen transfer to the liquid is usually higher than the desorption rate of nitrogen and carbon dioxide from the mixed liquor, the net gas flow rate will usually decrease from stage to stage. Concurrently, however, the oxygen partial pressure of the gas phase in successive stages will gradually decrease as the carbon dioxide and nitrogen content increases. Normally the system will operate most economically with a gas composition in the final stage, and in the vent gas from this stage, of about 50% oxygen. Due to the over-all net dissolution of gas, however, the vent gas rate will be only a small fraction, e.g., about 10–20% of the oxygen feed rate corresponding to a 90–95% over-all oxygen absorption efficiency. Such efficiency is well within the range of economic usage.

A very desirable feature of the multistage contacting system is that it lends itself very well to simultaneous staging of the mixed liquor as well. It is well known that in a plug flow or multiple liquid stage activated sludge

TABLE I

Comparison of Process Design Conditions for "UNOX" System and for Conventional Air Aeration Systems for Typical Municipal Wastewater

	UNOX oxygenation system	Conventional air aeration systems
Mixed liquor D.O. level, mg/l	8–10	1–2
Aeration detention time (raw flow only), hr	1–2	3–6
MLSS concentration, mg/l	6000–10,000	1500–4000
MLVSS concentration, mg/l	3900–6500	900–2600
Volumetric organic loading, lb. BOD/Day/1000 ft^3	150–250	30–60
Food biomass ratio, lb. BOD/lb. MLVSS	0.4–0.8	0.3–0.6
Recycle sludge ratio, lb. recycle/lb. feed	0.2–0.5	0.3–1.0
Recycle sludge concentration, mg/l	20,000–40,000	5000–15,000
Sludge production, lb. VSS/lb. BOD removed	0.30–0.45	0.5–0.75
Sludge volume index, Mohlman	30–50	100–150
Power requirements, KWH/100 cf O_2 dissolved oxygen		
dissolution and mixing	0.5–1.5	3–5
air separation	1.3–1.6	....

system the oxygen demand varies considerably from the feed end to the effluent end of the system. Staging increases the oxygen demand at the liquid feed end of the unit compared to the effluent end of the system. In conventional aeration systems this typically leads to a dissolved oxygen deficiency at the head end of the aeration tanks even in tapered aeration systems. The oxygen transfer capacity of a multistage cocurrent oxygenation system, however, naturally varies from stage to stage with the inherent transfer rate decreasing from the feed stage to the final or exhaust gas stage. This is a result of the decreased gas phase oxygen composition. Thus the use of cocurrent oxygen gas and mixed liquor flow through a multistage contacting system tends to yield a naturally tapered oxygenation system which matches the process oxygen demand requirement variation of the mixed liquor with the inherent oxygen transfer capacity variation of the gas contacting system.

The oxygenation system as shown in Figure 3 depends upon separate mechanical components for liquid mixing and oxygen dissolution. The relative liquid mixing and oxygen dissolution energy requirements in the system will vary considerably from stage to stage. Therefore each stage is equipped with an independent mixer-compressor combination designed to provide only the required level of mixing and gas recirculation for that particular stage. This arrangement results in very efficient oxygen transfer energy utilization through judicious matching of efficient mixing and oxygen dissolution equipment to the requirements of each stage throughout the multistage contacting system. The over-all power required for liquid mixing and gas recirculation will vary with specific system configurations, but will generally be 0.08–0.14 hp/1000 gal mixed liquor under aeration.

As stated earlier the exact method of gas liquid contacting employed in the UNOX system can be varied without substantially altering the process efficiency. Depending upon specific process conditions, surface aerators can also be used to contact the oxygen gas with the mixed liquor. Figure 4 shows a schematic diagram of such a UNOX System. This design eliminates the need for gas recirculating compressors and the associated piping. The system operates exactly like that shown in Figure 3 in all other respects. The level of bulk fluid mixing required to maintain the sludge in suspension and insure a uniform liquid composition is provided by an efficient pumping, slow speed, low shear agitation impeller much like that used in the design shown in Figure 3. These units are designed to provide the necessary liquid mixing in the most efficient form possible.

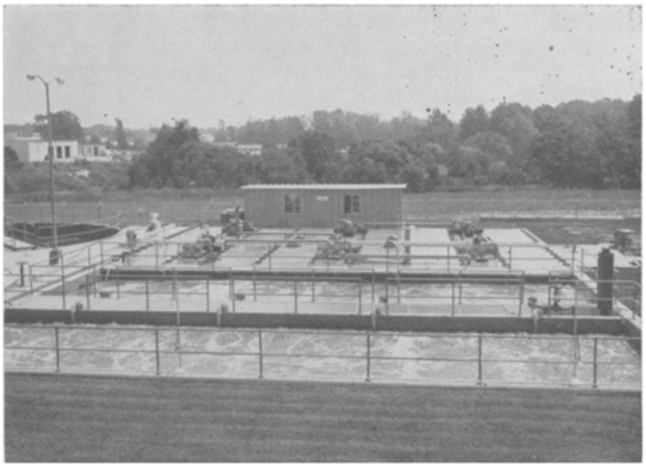

FIG. 5. View of oxygenation and air systems at Batavia.

Process Design and Operating Conditions

The economical substitution of oxygen for air in the activated sludge process enables practical operation under process conditions which have long been sought, but which are either impossible, impractical or uneconomical with air as a source of oxygen. These distinguishing process performance and operating conditions are: (a) economical operation at high mixed liquor D.O. levels (~10 ppm D.O.); (b) multistage or plug flow operation at high organic loadings and high MLSS levels without oxygen limitation; (c) high volumetric oxygenation capacity per unit of gas liquid contacting power input; (d) operation under high rate, high MLSS levels with good sludge settleability, compactability and low sludge recycle ratios; (e) low sludge production under low retention time, high organic loading conditions.

Table I compares typical design parameters for the UNOX Oxygenation System with conventional air aeration systems for nominal municipal wastewater treatment conditions. As shown the UNOX System can operate at MLSS levels several times greater and aeration detention periods several times less than those of air aeration systems while maintaining comparable or better levels of treatment.

The need for a high volumetric oxygenation capacity in the UNOX System can be best understood by consideration of the operating conditions in the first or feed stage of a typical four stage system operating under the over-all average conditions outlined in Table I. The feed stage is operating with an organic loading of 600–1000 lb. BOD/

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FIRST CALL FOR PAPERS

AOCS 63rd Annual Spring Meeting

Robert T. Conner, Technical Program Chairman, has issued a call for papers to be presented at the AOCS Spring Meeting, April 23-26, 1972, Los Angeles Hilton Hotel, Los Angeles, California.

Papers on lipids, fats and oils, and all related areas are welcome.

Submit two copies of a 100-300 word abstract with title, authors and speaker to Robert T. Conner, Director of Research, Max Factor & Co., 1655 N. McCadden Pl., Hollywood, California 90028.

The deadline for submitting papers is December 1, 1971.

FIG. 6. View of stage no. 1 oxygenation system aerator, blower and turbine drive.

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day/1000 ft^3 and a food-biomass ratio of 1.6–3.2 lb BOD/lb. MLVSS. The retention time in this stage would be 15–30 min. Obviously these conditions generate an extremely high oxygen demand which must be satisfied as well as high mixed liquor D.O. levels maintained in order to insure maximum process effectiveness. The UNOX system is able to operate at mixed liquor D.O. levels of 8–10 ppm in the first stage under these operating conditions.

The combination of operation at high D.O. levels and at relatively low shear and low power levels produces superior activated sludge settling characteristics. Operation under these conditions produces a flocculant, rapid settling sludge with excellent compacting and dewatering characteristics. This enables operation at high mixed liquor solids levels (6000–10,000 ppm), with high secondary clarifier overflow rates and relatively low activated sludge recycle rates (low sludge volume index). Numerous studies of air aeration systems under comparable high solids and low retention time conditions have shown poor sludge settling characteristics necessitating low clarifier overflow rates and high sludge recycle ratios. These factors tend to significantly offset the economic incentive for operation under high rate conditions in the aeration tanks.

In addition to the above-mentioned factors, operation at high mixed liquor D.O. levels has the added benefit of providing a substantial buffer against sudden or shock organic loads which quickly increase the oxygen demand on the system. The high D.O. level provides a "cushioning" effect to sustain peak process efficiency during such periods. Any subsequent lowering of the D.O. level then provides a greater oxygen partial pressure driving force, enabling a greater oxygenation capacity to be obtained almost instantaneously. The automatic pressure control system then immediately responds to this situation by increasing the oxygen supply rate to the first and later stages in the system to cope with the increased demand.

Another very important feature of the UNOX System, as stated above, is its relatively low excess sludge production even under low retention time, high organic loading conditions. One of the traditional drawbacks to the operation of high rate air aeration systems has been the significantly greater sludge production compared to the more conventional low rate operation. Since sludge disposal is a major cost factor in any secondary treatment biooxidation process, this is an important economic consideration. As can be seen in Table I, the UNOX System produces considerably less excess sludge per pound of BOD removed than comparable conventional processes operating under much lower organic loading conditions.

TABLE II

Oxygenation System Performance Data
Batavia Test Program

	Phase I	Phase II	Phase III
Average process conditions			
Number of stages	6	3	3
Aeration detention time, hr.	3.4	1.2	2.0
Recycle ratio	.24	.34	.43
MLSS, mg/l	3000	7000	6200
MLVSS, mg/l	2200	4500	4300
Wastewater temperature, F	59	66	70
Mixed liquor D.O., mg/l	8.7	9.0	8.0
Food biomass ratio, lb. BOD/day/lb. MLVSS	.41	.80	.55
Organic loading, lb. BOD/day/1000 ft^3	58	213	145
Secondary clarifier overflow rate, gal/day/ft^2	1500	1000	1150
Recycle sludge concentration, %	1.9	3.0	2.0
Process performance			
Feed BOD, mg/l	159	220	262
Effluent BOD, mg/l	11	23	14
BOD removal, %	92	90	94
Feed COD, mg/l	352	325	578
Effluent COD, mg/l	73	97	89
COD removal, %	80	71	84
Feed SS, mg/l	221	174	430
Effluent SS, mg/l	9	19	12
SS removal, %	96	89	97
Molmann SVI	64	36	49
Sludge production, lb. VSS/lb. BOD removed	.48	.41	....
Biomass oxygen requirement, lb. O_2 utilized/lb. BOD removed	.94	.96	.72
Exhaust gas composition, % oxygen	46	55	51
Oxygen utilization, %	96	93	91
Gas liquid contacting power consumption, hp/1000 gal under aeration	.09	.13	.14

Oxygenation System Performance Data

Batavia, New York

At this time the Union Carbide Oxygenation System is undergoing field evaluation at a number of municipal wastewater treatment sites including Cincinnati, Ohio, Washington, D.C., and Middlesex, New Jersey. The first of these, however, was a one-year full scale test program sponsored by the Federal Water Quality Administration during 1969 at the 2.5 mgd wastewater treatment plant in Batavia, New York (6). In this case two of four existing aeration tanks were converted for oxygenation as shown in Figure 5. Each of these tanks in turn was divided into three stages having a 21 × 23 ft cross section and a 17 ft liquid depth. A close up of the oxygenation equipment, which for this application consisted of a rotating sparger-mixer-compressor combination, is shown as Figure 6.

The Batavia project consisted of three phases. In the first mode of operation the two oxygenated tanks were connected in series, yielding a six stage gas and liquid contacting system. Operation during this phase was at process conditions more typical for an air system, inasmuch as the mixed liquor volatile solids levels and detention times were maintained at 2200 mg/l and 3.4 hr respectively. The oxygen system as such handled exactly one half of the total plant flow in one half of the existing aeration tankage. In contrast to this Phase II represented a high rate process condition. Here the entire plant flow was passed through only one of the oxygenation tanks comprising three stages. The final phase involved intermediate conditions where one half of the total plant flow was processed in these same three stages.

Table II summarizes the operating conditions and performance data for the Union Carbide Oxygenation System during these three phases. It is evident that BOD and suspended solid removals were consistently well above 90% while COD removals ranged from 71–84%. Although the conditions shown in Table II are based upon daily averages, it should be pointed out that these high treatment levels were maintained in spite of a typically twofold variation in flow between the daytime high and the night-

TABLE III

Typical Oxygenation System Performance Data
Cincinnati Pilot Plant Program

	Phase I	Phase II
Average process conditions		
Number of stages	0	4
Aeration detention time, hr.	2.2	2.8
Recycle ratio	.37	.44
MLSS, mg/l	6200	8790
MLVSS, mg/l	4150	4130
Wastewater temperature	72 F	80 F
Mixed-liquor D.O., mg/l	6.1	6.8
Food biomass ratio, lb. BOD/day/lb. MLVSS	.44	.25
Organic loading lb. BOD/day/1000 ft^3	115	87
Recycle sludge concentration, %	2.3	2.9
Process performance		
Feed BOD, mg/l	232	217
Effluent BOD, mg/l	20	8.4
BOD removal, %	91.4	96.1
Feed COD, mg/l	680	677
Effluent COD, mg/l	158	106
COD removal, %	76.8	84.3
Molmann SVI	43	36
Biomass oxygen requirement, lb. O_2 utilized/lb. BOD removed	1.37	1.59

time low values. The same behavior was observed with respect to mixed liquor dissolved oxygen levels which were readily maintained above 5 mg/l even at the highest organic loadings. During all three phases of operation a highly flocculant and readily settleable biomass was formed as evidenced by the high recycle sludge concentration (1.9–3%) and the low sludge volume indices (36–64) which were achieved. In this respect the results of phase I are particularly noteworthy inasmuch as the Oxygenation System sludge characteristics, even under operating conditions which are more typical for an air system, were far superior to those normally observed with air aeration. At the same time the secondary clarified overflow rate of 1500 gal/day/ft^2 was higher than dictated by conventional practice.

The highly flocculant nature of the sludge produced by the Oxygenation System was clearly visible to the naked eye during settling tests. Although the fundamental reasons for this characteristic are not totally understood, microscopic examination of the biomass reveals a very large concentration of higher life form organisms such as protozoa, rotifers and stalked ciliates. The high mixed liquor dissolved oxygen levels obtainable with this low shear oxygen transfer and agitation system are felt to be important factors in achieving such a microorganism population and sludge characteristics at high mixed liquor suspended solids levels. These factors are also felt to contribute to the low sludge production that has been observed with the Oxygenation System. As shown in Table II less than ½ lb. excess sludge was produced per pound of BOD removed during treatment of unsettled raw sewage. This represented only about one half of the sludge produced by the Batavia diffused air system when operated during the same period in a conventional fashion at lower organic loading conditions.

These results from the Batavia study also demonstrate the fact that high oxygen utilizations are indeed achieved with this system at relatively low dissolution power levels. As pointed out earlier the latter conditions is brought about by the existence of a high mass transfer driving force throughout the contacting stages. Gas phase composition profiles for the three stage Oxygenation System typically showed values of 83%, 72% and 50% from inlet to exit at a feed composition of 99.9% oxygen. Thus it is evident that the mass transfer driving force profile is closely matched to the oxygen demand profile, thereby yielding the maximum energy transfer efficiency for a given total oxygen absorption requirement.

Cincinnati, Ohio

Early in 1970 a further demonstration of the Union Carbide Oxygenation System was begun at the Mill Creek Wastewater Treatment Plant in Cincinnati, Ohio. Here an existing municipal pilot plant of a nominal feed wastewater capacity of 140,000 gal/day was converted to oxygen aeration. Primary effluent was used as feed to the Oxygenation System in this application and in contrast to the one at Batavia described earlier. In addition the municipal wastewater collection system at Cincinnati receives effluent from a large number of small and intermediate size industries including soap and detergent manufacturing, metal working and dye processing.

Some preliminary data for two operating periods at this plant site is shown in Table III. During each of these phases feed and recycle flows were maintained fairly steadily, for about eight weeks. Once again this data confirms that the oxygenation system is capable of reaching very high carbonaceous removal levels at low detention times. Average BOD removals of 91.4% and 96.1% were obtained during these phases at detention times of 2.2 hr and 2.8 hr respectively. COD removals ranged from 77–84%. Dissolved oxygen levels were again generally well above 5 mg/l even though the mixed liquor suspended solids concentrations frequently exceeded 10,000 mg/l. Very flocculant sludges were obtained throughout the operation as evidenced by the low sludge indices (SVI) of 43 and 36 and the high return sludge concentration which often exceed a value of 3% by weight.

New Consulting Company Formed

Announcement is made of the formation of a new consulting company: PETER KALUSTIAN ASSOCIATES, INC., Management Consultation and Engineering, 239 Reserve Street, Boonton, New Jersey 07005. This international organization, formerly Peter Kalustian, P.E., will be headed by him and will enlarge and expand service of its management consultation and engineering activities in the food, light chemical and related fields. Special emphasis will be given to refining, hydrogenation, winterizing, deodorizing, production of edible and specialty fats, fatty acids and chemical derivatives. Scope of activities will include expert testimony, feasibility studies, production, plant operations, formulations, product development, marketing and general management. Engineering, facilities improvement and expansion will also be covered.

Peter Kalustian

Prior to 1970, Mr. Kalustian did more than 36 years of service in many positions of responsibility in production, plant operations, product development and general management with Drew Chemical Corporation. He has an M.S. degree from the Massachusetts Institute of Technology, and is a registered professional engineer and a member of the American Oil Chemists' Society.

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