特 別 寄 稿

Advancements in the use of High Purity Oxygen in the Activated Sludge Process

*G. W. Kumke · *J. A. Sutton

Introduction

The use of the conventional activated sludge process as a means of removing a high percentage of the biodegradable constituents in municipal and industrial wastewater streams is an established and well known process. Until recently the most economical method of supplying oxygen to satisfy the metabolic requirements of the biomass was through the mass transfer of oxygen from air. Numerous air aeration devices have been developed over the years; however all have suffered from relatively high energy requirements per unit of oxygen utilized due to the relatively low partial pressure of oxygen in air and the low solubility of oxygen in water.

Early investigators (1, 2, 3) found significant process performance advantages when high purity oxygen was substituted as the aerating gas in the activated sludge process. These advantages included:

-possibility of obtaining a reduction in the power per unit of oxygen transferred;

-increased rate of stabilization of organic material;

-reduction in, or elimination of, periods of zero dissolved oxygen concentration;

-ability to operate systems at high rate (low retention time) at increased organic loadings.

Two major factors however delayed practical implimentation of these recognized process advantages. One factor was uneconomical oxygen utilization efficiency experienced in their attempts to adapt the use of high purity oxygen to the activated sludge process. The other was the lack of an economical supply of on-site generated oxygen gas.

Technical Considerations

The solution to these problems was a complex one calling for improvement in absorption efficiency, improvement in mass transfer rate and reduction in oxygen cost.

It was reasoned that an improvement in absorption efficiency or oxygen utilization could be achieved if the biological reaction were to occur in an enclosed reactor under dynamic conditions of continuous feeding of high purity oxygen and venting of spent

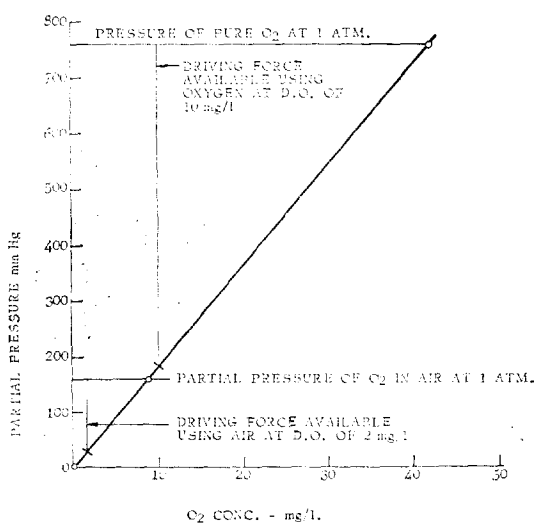

Fig. 1 Comparison of Oxygen System and Air System Oxygen Partial Pressure Driving Force

* Showa UNOX K. K.
Chuo Building No. 7
26-1, Hamamatsu-Cho, 1-Chome, Minato-Ku, Tokyo

gas. Since improved mass transfer would occur under conditions of maximum practical oxygen gas phase partial pressure, a multi-stage reactor was chosen to provide highest average gas phase partial pressure across the system.

With increased oxygen partial pressure it became possible to operate efficiently with increased dissolved oxygen (D. O.) concentrations. Figure 1 illustrates how this high D. O. level is 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 mg/l is compared with that of an oxygen aeration (oxygenation) system operating at a D. O. level of 10 mg/l. At a temperature of 20°C and one atmosphere total pressure the air aeration system has a 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 mg/l the oxygenation system has a driving force of about 4.7 times that of an air aeration system operating at 2 mg/l. Further, the high oxygen gas phase partial pressure provides interfacial transfer area containing relatively pure oxygen gas when compared to air. When combined with multistaged sewage flow, maximum driving force concentrations are achieved and mass transfer rate is significantly enhanced.

The combined results of the above is a system in which the aeration gas rates are significantly reduced through improved mass transfer. Oxygen utilization efficiency of 90 % is easily achieved. Oxygen feed gas rate is in the order of 5 % of that for an air aeration system. Homogeneous mixed-liquor suspension is optimally achieved through mechanical rather than gas agitation.

Even so, for practical implementation an inexpensive source of oxygen is required. Today this technology is available due to continuing advancements in cryogenic air separation plants over the last fifteen years and more recently, the development of ambient temperature oxygen generators employing pressure-swing adsorption technology.

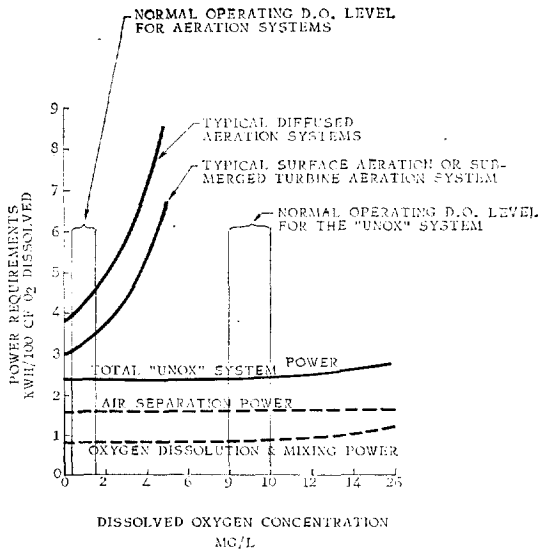

Fig. 2 Comparison of Total Power Requirements for Air and Oxygen Systems

In terms of energy consumption the economically viable use of oxygen is displayed in Figure 2. In this figure the total power requirements for dissolving oxygen into a waste stream using both an air and an oxygen system are shown. The total power for the oxygen system consists of the power 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 and lower in value than for an air system. The power requirements for typical diffused air, for surface aeration, or for submerged turbine aeration systems are greater than the total power for an oxygen system and are extremely sensitive to the design dissolved oxygen level.

The UNOX System

Through its research and development activities in the 1960's, Union Carbide determined these fundamental process concepts, then tested and designed the UNOX* system of wastewater treatment.

One simplified arrangement for the UNOX system

*UNOX and LINDOX are registered trademarks of UCC. Patents and patent applications in all Major countries.

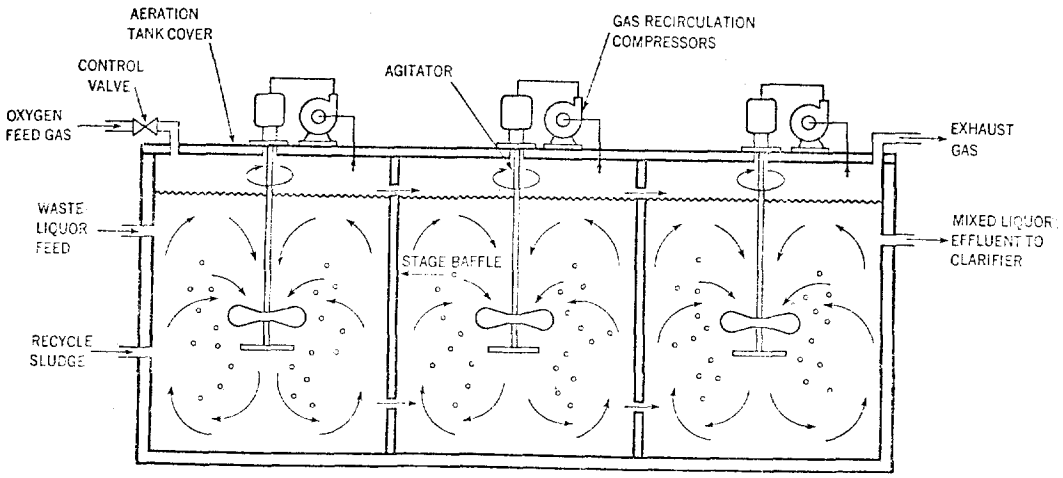

Fig. 3 Schematic Diagram of "UNOX" System with Rotating Sparger

is shown in Figure 3. The oxygen gas is fed into the first stage at a pressure of only about 20-80 millimeters 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 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 are connected to each other to allow gas to flow freely from stage with only a slight pressure drop, but yet sufficient to prevent gas back mixing. This is accomplished by appropriate sizing of the interstage gas passages. The mixed-liquor flow 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. Effluent mixed liquor from the reactor is settled in the conventional manner and the settled activated sludge is returned to the first stage.

The entire multistage activated sludge unit is fitted with a gas-tight cover to contain the oxygen enriched 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 of 20-80 millimeters of water is maintained by the feed gas flow controller. As the organic load and respiration of the biomass increase, the pressure tends to decrease and feed oxygen flow into the system increases to reestablish the pressure set point of the controller. Feed oxygen to the multistage system can be controlled on this pressurr demand basis by a simple regulator, or combination of differential pressure controller and automatic valve.

In general, the net flow rate of gas from stage to stage is largely determined by the rate of gas mass transfer to the liquid in each stage. Since the rate of oxygen transfer to the liquid is higher than the desorption rate of nitrogen and carbon dioxide from the mixed liquor, the gas flow rate will decrease from stage to stage. Cocurrently, however, the oxygen partial pressure of the gas phase in successive stages will gradually decrease as the carbon dioxide and nitorgen 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 per cent oxygen. Due to the overall 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 percent overall 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. In a plug flow or multiple liquid stage activated sludge 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 feed end of the aeration tank even in tapered aeration systems. The oxygen transfer capacity of a multistage cocurrent oxygenation system, however, varies from stage to stage with the inherent transfer capability of the gas contacting stage.

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 efficient energy utilization through judicious matching of efficient mixing and oxygen dissolution equipment to the requirements of each stage.

The exact method of gas-liquid contacting employed in the UNOX system can be varied without substantially altering the overall 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.

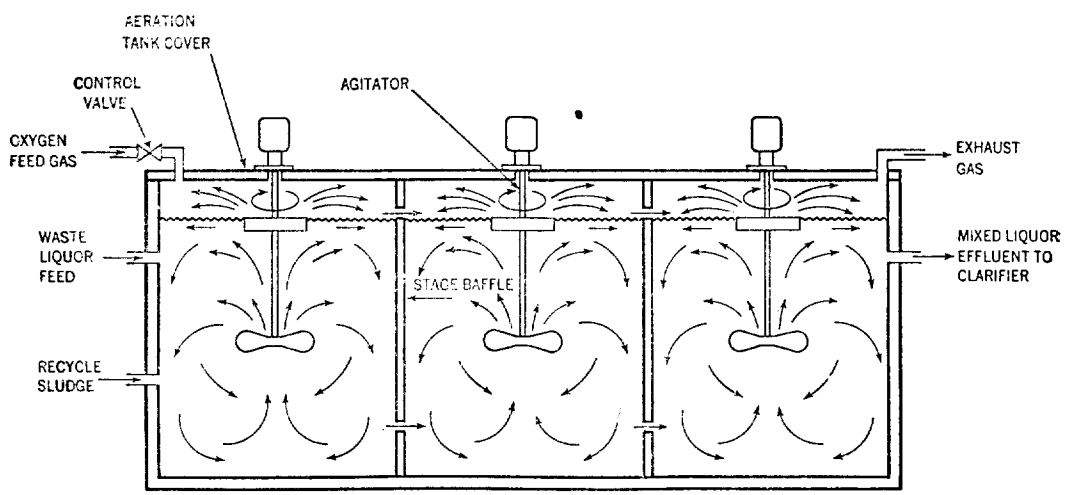

Fig. 4 Schematic Diagram of "UNOX" System with Surface Aerator

rate decreasing from the feed stage to the final stage due to the decreased gas phase oxygen composition. Thus, the use of cocurrent oxygen gas and mixed liquor flow through a multistage contacting system yields a tapered oxygenation system which matches the oxygen demand with the oxygen transfer

Oxygen Generation

On-site oxygen gas generaion plants are the most

economical and desirable form of oxygen supply for most applications of the UNOX system. Two basic oxygen generator designs are employed to satisfy the oxygen demands of waste water treatments plants ranging in size from about 2,000 M^3/D to 1,200,000 M^3/D or larger. These designs are the traditional cryogenic air separation process for the larger size applications and a pressure-swing adsorption (LINDOX*) system for the majority of plant sizes. The LINDOX system is a Union Carbide development in air separation technology which is uniquely suited to supply on-site oxygen gas for the smaller sizes of wastewater treatment plants.. Refer to Figure 5 for a simplified flow sheet. The process operates on a repeated cycle having two basic steps, adsorption and regeneration. During the adsorption step feed air flows through one of the adsorber vessels until the adsorbent is partially loaded with impurities(CO_2, N_2 and water vapor). At that time the feed air flow is switched to another adsorber and the first adsorber

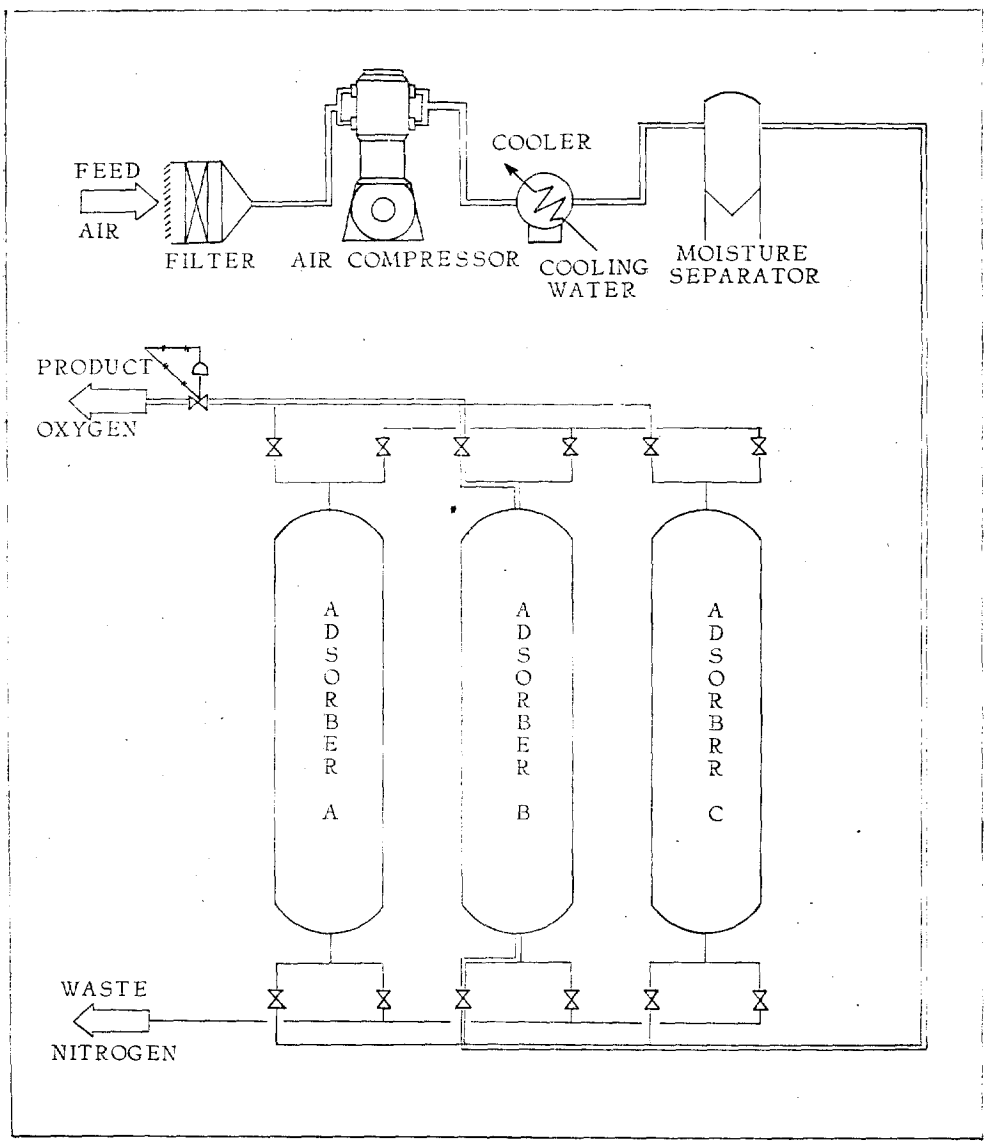

Fig. 5 "LINDOX" System Flow sheet

is regenerated. During the regeneration step, the impurities in the feed air are cleaned from the adsorbent so that the cycle of adsorption and regenration can be repeated.

Regeneration of the adsortbent is accomplished by:

- -The adsorber is depressurized to atomospheric pressure to remove the impurities.
- -The adsorber is briefly purged with oxygen to pre-load the bed prior to feed re-entry.
- -The adsorber is repressurized to adsorption pressure and is again ready to separate air.

The cycle changes are accomplished automatically with cycle changes initiated by a pressure sensing switch.

Process Characteristics

Through the use of high-purity oxygen the UNOX system optimizes the activated sludge process. Typical design parameters for both the UNOX system and the conventional air aeration system for an average municipal wastewater are shown in Table 1. As noted the UNOX system typically operates at biomass concentrations several times greater than an air system with a mixed-liquor D.O. concentration of greater than 6 mg/l. The combination of high volumetric oxygenation capacity and high biomass concentrations in the UNOX system allows for substantial decreases in the reactor hydraulic detention time. With an air system an increase in the biomass concentration with an associated increase in oxygen uptake demand would result in either an oxygen deficiency or would require significant increases in aeration rate to support the biological activity. The latter is not only uneconomical but causes increased turbulance and shear that adversely effects the flocculating characteristics of the biomass.

As noted in Table 1 typical reactor detention times for the UNOX system are 1.5 to 2.0 hours. At these low detention times, high biomass and organic loadings are achieved with levels of about 0.7 kg BOD_5/kg MLVSS-D and 3.0 kg BOD_5/M^3-D being typical. With these average loadings the feed stage of the multistage UNOX system is operating with an organic loading of about 12 kg BOD_5/M^3-D and a biomass loading of about 3 kg BOD_5/kg MLVSS-D. The hydraulic detention time in the first stage would be about 25 minutes. These conditions generate an oxygen demand that can only be satisfied through the use of high purity oxygen without destructive high energy inputs to the mixed-liquor. However, even at these high loadings the UNOX system is still capable of effectively treating both the hydraulic and organic load changes that generally are imposed on an operating waste treatment facility.

With the use of either air or oxygen in the activated sludge process, successful operation depends to a large extent upon the effective performance of the final clarifier. The clarifier must serve the dual function of clarifying the liquid overflow and thic-

Table 1. Comparison of Design Data

	UNOX System	Conventional Air System
Dissolved Oxygen, mg/l	6~10	1~2
Detention Time Based on Flow, hrs	1~2	3~6
MLSS, mg/l	6,000~10,000	1,500~4,000
MLVSS, mg/l	3,900~6,500	900~2,600
Organic Loading, Kgm BOD_5/M^3-D	2.4~3.2	0.5~1.0
Biomass Loading, Kgm BOD_5/MLVSS-D	0.4~0.8	0.3~0.6
Recycle Sludge Concentration, %	2~4	0.5~1.5
Recycle Flow, % of Feed Flow	20~40	25~100
SVI, ml/gm	30~50	100~150
Waste Biomass Accumulation, kg VSS/kg BOD_R	0.3~0.45	0.5~0.75

kening the biomass underflow. The clarification capacity of the unit is related to the initial settling velocity of the biomass whereas the thickening operation is related to mass loading imposed on the clarifier. Operation at both low shear and low power levels produces a compact, rapidly settling biomass, even at high organic loadings. Considerable data collected on many different wastewaters has shown the rapid settleability of the UNOX biomass at various mixed-liquor concentrations as compared to air systems. These data are shown in Figure 6. As noted, where the initial settling velocity is correlated with the mixed-liquor concentration for both air and oxygen, the UNOX biomass has higher settling velocities over the entire range of mixed-liquor suspended solid concentrations.

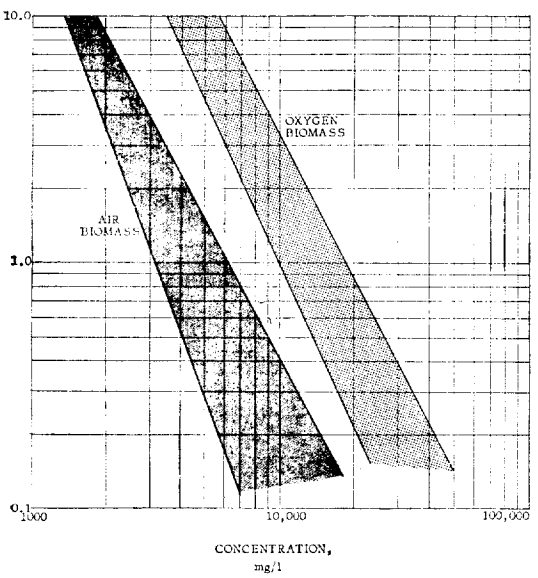

Fig. 6 Settling Characteristics for Air and Oxygen Biomass (ISR vs. Concentration)

Conventional air activated sludge systems normally use clarifiers with mass loadings of about 100 kg SS/M²-D in order to prevent interference with thickening of the biomass. The UNOX biomass, however, shows high thickening and compacting characteristics even at clarifier mass loadings greater than 300 kg SS/M²-D. This enables operation at high mixed-liquor concentrations while still maintaining high clarifier overflow rates and relatively low biomass recycle rates. The clarifier underflow is typically greater than 2 per cent, with up to 4 per cent solids not uncommon.

Another advantage of the UNOX system is its relatively low waste biomass accumulation, even at low oxygenation times and high organic loadings. During biological oxidation the degree of waste biomass accumulation is a function of the degree of endogenous respiration which in turn is dependent upon the biomass loading. With the staged UNOX biological reactor the biomass loading decreases rapidly in the initial stages and allows for a high degree of stabilization in the latter stages. This results in decreased waste biomass for disposal. The high mixed-liquor dissolved oxygen level also aids in producing a lower waste biomass accumulation since the biomass is maintained in a highly aerobic state. That is, more of the organisms within the biological floc are kept in a working mode.

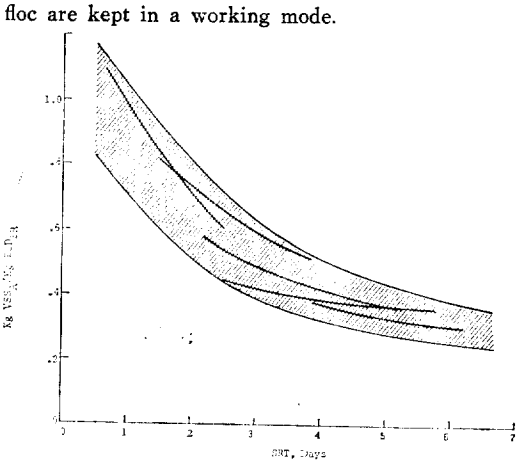

Fig. 7 "UNOX" System Solids Accumulation as a Function of Solids Retention Time

Figure 7 presents a relationship between waste biomass accumulation and cell retention time which has been obtained from many UNOX system studies. As indicated, the waste biomass accumulation increases as the cell retention time decreases. In most cases the UNOX system is designed to operation with cell retention times greater than four days. Where the UNOX system has been compared in parallel operation with air activated sludge the waste biomass accumulation from the UNOX system has

been significantly lower.

As is evident from the high clarifier underflow solids concentration attainable with the UNOX system, the mixedliquor biomass has good compacting characteristics. Gravity thickening studies on the clarifier underflow have shown that the solids thicken to a higher solids concentration at a higher mass loading than conventional biomass. However even though the UNOX biomass has good thickening characteristics its ability to be effectively dewatered by either vacuum filter or centrifuge directly from the clarifier underflow is believed to be unique.

Pilot-scale studies using both the solid-bowl basket and solid-bowl scroll type of centrifuge showed that with the direct feed of clarifier underflow containing 2 to 3 per cent solids a cake of 12 to 14 per cent could be attained without chemical addition. Solids capture during these studies was greater than 90 per cent. Pilot-scale vacuum filter studies with UNOX solids using the clarifier underflow directly, produced a cake that disengaged easily and had a solids content of 15 to 24 per cent. Filter yields as high as 22 kg/M²-H of filter area were obtained. During the vacuum filter tests ferric salts were determined to be the effective solids conditioner.

Performance Data

The unique process features of the UNOX system has been demonstrated in over 30 pilot-plant studies and with eight full-scale treatment facilities. Most of the pilot plant capacities were 100 M³ per day, whereas the largest operating full-fcale UNOX faclity is 75,000 M³ per day. Additional plants presently under construction range from about 4000 M³ to 1,200,000M³ per day flow with BOD_5 ranging from about 100 mg/*l* to 3000 mg/*l*.

Full-scale performance data obtained from a UNOX system during a United States Federal Government sponsored program (4) at the 9500 M³ per day Batavia, New York waste treatment facility is shown in Table 2. During one phase the fullscale facility consisted of a three-stage sparged-impeller oxygenation system with each of the three stages having a 6 M × 6.5 M cross section and a 5.2 M liquid depth. The Batavia treatment facility contains no primary clarifiers, thus the UNOX system was operated on raw sewage. The data shown in Table 2 give average values, however the effluent quality did not vary significantly from these values even though the

Table 2. Summary of Batavia Test Results

Flow, M³/D	9,500
Detention Time Based on Flow, hrs	1.6
Dissolved Oxygen, mg/*l*	9.0
MLSS, mg/*l* MLSS, mg/*l*	7,000
MLVSS, mg/*l*	4,500
Organic Loading, Kgm BOD_5/M³-D	3.4
Biomass Loading, Kgm BOD_5/MLVSS-D	0.8
Recycle Sludge Concentration, %	3
Recycle Flow, % of Feed Flow	34
SVI, m*l*/gm	36
Waste Biomass Accumulation, Kg VSS/Kg BOD_R	0.41
Clarifier Overflow Rate, M³/M²/D	40

	Influent mg/*l*	Effluent mg/*l*	Removal %
COD_{CR}	325	97	71
BOD_5	220	23	90
SS	174	19	89

system was operated on the diurnal flow cycle which varied by a factor of two. As noted, the UNOX system was operated at a detention time based on raw sewage flow of 1.6 hours, with a biomass concentration of 7000 mg/l, a biomass loading of 0.8 Kg BOD_5/Kg MLVSS-D and an organic loading of 3.4 Kg BOD_5/M^3-D. At these conditions the BOD_5 was reduced from 220 mg/l to 23 mg/l and the effluent suspended solids was 19 mg/l.

The superior settling and compacting characteristics of the oxygenation system biomass is shown by the 3.0 per cent average recycle solids concentration, the 36 ml/gm sludge volume index, and the high quality of the effluent at the 40 M^3/M^2-D clarifier overflow rate maintained. The waste biomass accumulation during this study averaged 0.4 Kg/Kg BOD_5 removed while operating on raw sewage. This was about 40 per cent less than the biomass obtained at Batavia with the diffused air system when operating in a conventional manner during the same period on the same wastewater.

Performance data from a few of the muncipal pilot-plant studies conducted in the U. S. A. and Japan are shown in Table 3. The average operating time for each of these studies was about four months and in each case the pilot unit was operated on-line with the sewage plants daily variations imposed. Although the data presented in Table 3 is only from a few of the many pilot studies conducted it is representative of the data obtained in other UNOX system demonstrations.

The New Orleans (5) and Southeastern City, U. S. A., pilot operations were conducted on degritted raw sewage whereas the Midwestern Cities, U. S. A., and Iriezaki (Kawasaki City, Japan) pilot operations were carried out on primary clarifier effluent. However, the effluent quality from both applications was similar with no detrimental effects resulting from elimination of the primary clarifier. The oxygenation times between 1.3 and 2.0 hours shown in Table 3 are typical of what the UNOX system is generally designed for when treating municipal wastes. The biomass loadings for these examples range between 0.5 and 1.4 Kg BOD_5/Kg MLVSS-D. Even though average design biomass loadings of 0.5 to 0.8 Kg BOD_5/Kg MLVSS-D are normally applied, high quality effluents were attained at the average biomass loading of about 1.4 Kg BOD_5/Kg MLVSS-D indicating that the process will perform well during peak organic load periods when biomass loadings will exceed the design range. As shown by the data it is typical to produce an effluent containing less than about 15 mg/l BOD_5 and less than 25 mg/l suspended solids. As shown by the Iriezaki and Southeastern City data the toatal effluent BOD_5 has been reduced to about 5 mg/l for some wastewaters.

The data of Table 3 show clarifier underflow solids ranging between 1.5 to 3.2 per cent. The waste biomass for these demonstrations ranged between 0.27 to 0.78 Kg/Kg BOD_5 removed, with most of the studies having been conducted showing less than 0.5 Kg VSS/Kg BOD_5 removed. As previously noted, whenever parallel air studies were conducted the UNOX system accumulated less biomass for disposal than the air system. In addition, these waste solids could normally be directly dewatered from the clarifier

Table 4. "UNOX" System Pulp and Paper Pilot Demonstration

Detention Time, hrs		1.8	1.33
Mixed Liquor Suspended Solids, mg/l		5330	6915
Organic Loading, Kg BOD_5/M^3-D		3.7	8.0
Biomass Loading, Kg BOD_5/Kg MLVSS-D		0.78	1.30
Clarifier Overflow Rate, M^3/M^2-D		25	34
Clarifier Mass Loading, Kg SS/M^2-D		172	295
Clarifier Underflow Solids, %		2.0	2.6
Sludge Volume Index, ml/gm		53	40
Waste Solids, Kg SS/Kg BOD_5 Removed		0.25	0.27
Oxygen Consumed, Kg O_2/Kg BOD_5 Removed		1.29	1.13
Influent Characteristics:	COD_{CR}, mg/l	874	1383
	BOD_5, mg/l	277	445
	SS, mg/l	91	66
Effluent Characteristics:	COD_{CR}, mg/l	414	669
	BOD_5, mg/l	20	39
	SS, mg/l	50	59
Removals:	COD_{CR}, %	53	52
	BOD_5, %	93	91

Table 3. "UNOX" System Pilot Plant Performance

Location	New Orleans	Southeastern City	Midwestern City	Midwestern City	Midwestern City	Iriczaki
Waste Component	Municipal with Brewery, Seafood Processing and Poultry Wastes	Municipal	Municipal, with Grain Processing and Meat Packing Wastes	Municipal, with Distilleries, Meat Slaughter, Dairy Products and Chemicals Wastes	Municipal, with Chemical, Dairy, Brewery, and Food Wastes	Municipal, with Chemical Wastes
Type Waste	Raw Degritted	Raw Degritted	Primary Effluent	Primary Effluent	Primary Effluent	Primary Effluent
Detention Time(Q), hrs	1.8	1.3	1.8	1.6	2.0	1.5
Mixed Liquor Suspended Solids, mg/l	7350	6000	4700	4000	7000	4000
Organic Loading, Kg BOD_5/M^3-D	3.1	3.15	5.6	3.0	2.75	1.2
Biomass Loading, Kg BOD_5/Kg MLVSS-D	0.56	0.64	1.4	1.02	0.5	0.54
Clarifier Overflow Rate, M^3/M^2-D	26	36	21	29	24	30
Clarifier Mass Loading, Kg SS/M^2-D	245	254	152	147	218	138
Clarifier Underflow Solids, %	3.2	2.3	1.5	1.7	3.1	1.6
Sludge Volume Index, ml/gm	48	55	82	61	42	60
Waste Solids, Kg VSS/kg BOD_5 Removed	0.27	0.36	0.64	0.52	0.27	0.78
Oxygen Consumed, Kg O_2/Kg BOD_5 Removed	1.03	1.07	0.85	0.94	1.35	1.46
Influent Characteristics: COD_{CR}, mg/l	377	398	826	365	467	208
BOD_5, mg/l	229	170	415	200	227	75
SS, mg/l	236	172	180	135	76	95
Effluent Characteristics: COD_{CR}, mg/l	66	63	99	72	81	34
BOD_5, mg/l	12	5	12	17	8	5
SS, mg/l	28	13	18	16	15	7
Removals: COD_{CR}, %	82	84	88	80	82	84
BOD_5, %	95	97	97	92	96	93
SS, %	88	92	90	88	80	93

thus elimniating the need for additional thickening.

In addition to the municipal waste studies the UNOX system has also been demonstrated on both a pilot and full scale basis for the treatment of industrial wastes. In Table 4 and 5 are shown pilot plant performance data from the treatment of pulp and paper and petrochemical wastewaters.

Table 5. "UNOX" System Petrochemical Waste Pilot Demonstration

Detention Time, hrs		15
Mixed Liquor Suspended Solids, mg/*l*		9340
Organic Loading, Kg BOD_5/M^3-D		4.3
Biomass Loading, Kg BOD_5/Kg MLVSS-D		0.5
Clarifier Underflow Solids, %		3.6
Sludge Volume Index, m*l*/gm		39
Waste Solids, Kg/Kg BOD_5 Removed		0.17
Oxygen Consumed, Kg/Kg BOD_5 Removed		1.6
Influent Characteristics:	COD_{CR}, mg/*l*	5730
	BOD_5, mg/*l*	2670
Removals:	COD_{CR}, %	68
	BOD_5, %	90

The Kraftmill pulp and paper waste study was conducted at the Cheasepeake Corporation of Virginia (6). The UNOX system was consistently operated at high MLSS ranging between 5000 to 7000 mg/*l*, at high overall oxygen utilizations of greater than 90 per cent, and at BOD_5 removals greater than 90 per cent. Data for operation at 1.33 and 1.8 hours of oxygenation are presented in Table 4. During the study the organic loading varied between 2.7 and 9.5 Kg BOD_5/M^3-D with a corresponding biomass loading range between 0.5 to 1.4 Kg BOD_5/Kg MLVSS-D. Over this entire range of loadings the UNOX system was able to maintain essentially a constant total BOD_5 removal of about 91 per cent. Normally the soluble BOD_5 associated with the clarified effluent was about 11 mg/*l*.

Good settling biomass was obtained in the pilot studies on pulp and paper mill wastes. Initial settling velocities from 10 to 17 cm/hr were obtained with biomass concentrations of 5000 to 7500 mg/*l*. Good shickening characteristics of the biomass was also obtained with clarifier underflow solids ranging between 1.7 to 3.3 per cent maintained at overflow rates of 20 to 36 M^3/M^2-D. The ability to thicken the biomass to this degree was encouraging in view of the 90 per cent volatile content of the biomass. The biomass concentrations of 5000 to 7500 mg/l were maintained with a recycle rate of about 33 per cent.

The waste solids for disposal averaged 0.3 kg SS/Kg BOD_5 removed for the entire pilot plant study. Although no parallel air studies were conducted data from the literature indicate that the waste solids from a conventional air system operating on pulp and paper waste would be expected to be in the order of 0.5 Kg/Kg BOD_5 removed. Therefore, the available data do indicate that less biomass accumulation can be expected from the UNOX system. In addition the biomass has been successfully dewatered on a pilot-scale vacuum filter when mixed 1 to 1 with primary paper mill sludge without chemicals to obtain a cake consistency of about 16 per cent.

The oxygen utilization efficiency during the study averaged about 90 per cent. As shown by the data in Table 4 the oxygen requirements on an organic removed basis were about 1.2 Kg O_2/Kg BOD_5 removed. As expected the oxygen demand was higher at lower biomass loading conditions as a result of more endogenous respiration occuring.

Performance data presented in Table 5 represent pilot plant information obtained on a high strength petrochemical wastewater(7). Because of the 2700 mg/l BOD_5 of the wastewater and the presence of relatively difficult to biologically degrade organics the UNOX system was operated at about 15 hours of detention time based on raw wastewater flow. The biomass concentration during this study was maintained relatively high at about 9300 mg/l, with about 93 percent of the solids being volatile. The objective during this study was to obtain a 90 per cent BOD_5 removal which was accomplished at a biomass loading of about 0.5 Kg BOD_5/Kg MLVSS-D and an organic loading of 4.3 Kg BOD_5/M^3—D. Even with the high volatile content of the biomass the solids liquid separation was good with a clarifier underflow of about 3.6 per cent being obtained. This concentration of solids could be directly dewatered without additional thickening.

The influent solids associated with the wastewater were low with essentially all of the organics in a soluble state. Waste solids averaged about 0.17 Kg/Kg BOD_5 removed during the study and together with the high clarifier underflow concentration will allow relatively inexpensive ultimate disposal costs. The oxygen consumption for the treatment of the petrochemical wastes, approximately 1.6 Kg O_2/Kg BOD_5 removed, was relatively high as compared to biological oxidation of other waste types. However, experience with conventional air systems treating petrochemical wastes indicates that the oxygen consumption typically is higher than for other types of wastewater.

Conclusions

The use of high purity oxygen as the aerating gas in the activated sludge process is now a practical and economical process for biological wastewater treatment. High oxygen utilization and gas phase partial pressure are achieved by the use of high purity oxygen gas in a multistaged, enclosed biological reactor.

Unique performance advantages created by the use of high purity oxygen include:

-high dissolved oxygen levels in the mixed liquor,
-support of high mixed liquor biomass population,
-ability to effectively treat at hight organic loadings,
-significantly reduced retention times,
-reduced waste sludge quantity and increased clarifier solids concentration,
-significantly higher sludge compaction and settling rates at high mixed liquor concentrations,
-direct dewatering of waste activated sludge.

These advantages have been demonstrated in numerous pilot plant and full scale operations leading to geneal acceptance of the oxygenation process.

References Cited

1. Okun, D. A.; "System of Bio-Precipitation of Organic Matter from Sewage." Sewage Works Journal, 21, 1949.
2. Budd, W. E. and Lamaeth, G. F.; "High Purity Oxygen in Biological Sewage Treatment," Sewage and Industrial Wastes, **29**, 253, 1957.
3. Okun, D. A.; "Discussion of High Purity Oxygen in Biological Sewage Treatment," Sewage and Industrial Wastes, **29**, 253, 1957.
4. J. G. Albertsson, J. R. McWhirter, E. K. Robinson, N. P. Vahldieck; "Investigation of the Use of High Purity Oxygen Aeration in the Conventional Activated Sludge Process," FWQA Department of the Interior Program No. 17050 DNW, Contract No. 14-12-465, May 1970.
5. Grader, R. J., Dedeke, W. C., Powell, C. J. and Wiebelt, A. H.; "Pilot Plant Results Using Pure Oxygen for Treating New Orleans Wastewater", Presented at the American Society of Chemical Engineers, 71st National Meeting, Biological Treatment Symposium, Dallas, Texas, February 21, 1972.
6. Grader, R. J., South, D., and Djordjevie, B.; "The Activated Sludge Process Using High Purity Oxygen for Treating Kraftmill Wastewater", Presented at the TAPPI 1972 Environmental Conference, Houston, Texas, May 17, 1972.
7. Reimer, R. E., Conway, R. A., Wilcox, E. A., Kukura, J. F.; "UNOX System Activated Sludge Treatment of a Petrochemical Waste", Presented at the 27th Annual Purdue Industrial Waste Conference, Lafayette, Indiana, May 2-4, 1972.