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ACTIVATED SLUDGE PROCESS USING PURE OXYGEN

BY

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ABSTRACT

An evaluation of the pure oxygen activated sludge system (UNOX) has been underway since May, 1970. During the first 16 months of test operation on the 100,000 gpd facility at the Blue Plains Wastewater Treatment Plant, over five different phases of operation were tested to demonstrate the performance of the system under varying conditions.

The oxygen activated sludge system (UNOX) consisted of a unique, four stage, gas tight biological reactor that employed cocurrent gas-liquid contacting. In less than 1.85 hours of oxygenation, the system removed 90 percent of the influent BOD_5 and utilized over 95 percent of the supplied oxygen. The effluent quality was as good or better than that obtained from a 3.6 hour step aeration system operating in parallel with the oxygenation system.

The microbial organisms visually were essentially the same as those found in a typical conventional system. Their rate of activity, however, was greater than those of the air system. The total solids production was significantly less than the similarly operating diffused air system. Solids production averaged between 0.2 and 0.5 lb. solids wasted per lb. BOD removed.

Satisfactory solid-liquid separation was achieved at clarifier overflow rates varying between 300 and 1940 gallons per day per square foot.

The clarifier underflow concentrations varied from 1.0 to 2.4 percent and mixed liquor suspended solids were maintained between 4000 and 7600 mg/l. The MLSS increased to over 8000 mg/l when operated with alum addition for phosphorus removal.

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SECTION I

SUMMARY AND CONCLUSIONS

Summary

In May 1970, an evaluation of the oxygen activated sludge system (UNOX) was begun at the Blue Plains Wastewater Treatment Facility to demonstrate the ability of the oxygen system to operate at high mixed liquor solids and short retention times and produce effluents of comparable quality with the conventional activated sludge of relatively lower solids and longer retention times.

Because the Potomac stream standards require about 98 percent phosphorus removal from the wastewater before discharge, an evaluation of phosphate removal by chemical addition to the pure oxygen system was conducted. Nitrification, though not of primary interest, was also studied.

During this program, the pilot plant was operated at relatively steady flow as well as with a diurnal flow pattern both with and without alum addition. In addition, the initial peripheral feed clarifier was modified to a center-feed clarifier on August 14, 1970. However, the clarifier overflow rates experienced were much higher than those in conventional practice. A description of the pilot plant facilities, characterization of the wastewater, mode of operation and process information are discussed in the report.

Conclusions

1. An oxygen aeration system (UNOX) employing a gas tight biological reactor has been in operation at the Blue Plains facility since May 1970. During this entire period a high quality effluent was produced while operating the system at high mixed-liquor solids levels and retention times of less than 2 hours.

2. Good quality effluent was produced with an average biomass loading of 0.30 lb. BOD per lb. MLVSS and a maximum value of 0.45 while the system was not stressed. Later operation showed effective treatment at loads as high as 1.3 lb. BOD/lb. MLVSS as reported by John B. Stamberg, et al (13).

3. The clarifier for the oxygen aeration system was operated for the majority of this program at average overflow rates of 1000 to 1300 GPDPSF with frequent periods of diurnal variations achieving 12 hour sustained

peak overflow rates of 1700 to 1900 GPDPSF. The oxygenation system demonstrated the ability to maintain MLSS levels of 4000 to 7000 mg/l even while operating at these high hydraulic loadings.

4. The oxygenation system demonstrated the ability to produce a concentrated recycle sludge. At these high overflow rates, the recycle sludge concentration was about 1.5 percent suspended solids. During this phase with alum addition, the concentration averaged about 2.3 percent suspended solids.

5. The addition of alum to the fourth stage of an oxygen activated sludge system was demonstrated to be a practical method of removing phosphorus. Average phosphorus residuals of 1.8 mg/l as P with alum dosage of 1.4 Al^{+++} to P by weight were achieved.

6. Nitrification was achieved by the oxygenation system during the summer and fall periods when process conditions and temperature were mutually established in the range where nitrification would be expected.

7. Based upon the influent and exhaust gas flow, over 95 percent of the oxygen was consistently utilized.

SECTION II

RECOMMENDATIONS

During the late winter and early springtime operation of the oxygenation system at Blue Plains it was noted that the settling characteristics of the mixed-liquor were not as good as had been observed in the previous summer and fall operation. During this period a filamentous culture was present at times in the mixed-liquor and waste temperature was of course lower than in the summer-fall period. It is postulated that either or both of these factors may have influenced the settling characteristics. It is recommended that full pilot plant operations be continued at Blue Plains to determine the factors affecting biomass settling characteristics.

Since this study was done at relatively high clarifier loadings (average of about 1300 GPDPSF), it is recommended that more studies be done at the same overflow rate as most clarifiers that are in operation at present. This would mean an overflow rate of 600 to 800 GPDPSF. Under these conditions, it should be possible to maintain a recycle sludge with solids concentrations of 2 to 3 percent consistently.

It is recommended that the study be continued to more accurately determine the actual oxygen requirement under a wider range of operating conditions, to be able to distinguish between the oxygen consumed, e.g. with and without nitrification, endogenous respiration, and leakages if possible.

SECTION III

INTRODUCTION

Background-History

The use of pure oxygen within the activated sludge process dates back some 20 years. Pirnie (1) proposed a system of predissolving pure oxygen in high concentrations in the influent wastewater before entering a non-aerated mixed reactor. The process was termed "a bioprecipitation system". Biological success was achieved by Okun (2) in bench scale tests and later by Budd and Lambeth (3) on a pilot scale, but oxygen utilization efficiencies of 20 to 25 percent were too costly. Okun and Lynn (4) and later Okun (5) showed an increase in the effective sludge activity in the mixed liquor by reducing or eliminating anaerobic periods such as can occur in clarification.

McKinney and Pfeffer (6) more recently reviewed the use of oxygen in activated sludge. Increased metabolism rates, produced by eliminating periods of zero dissolved oxygen, would increase treatment efficiencies in overloaded plants and reduce the size required for new plants. Thus, potential reductions in capital investment were viewed possible for oxygen systems.

Union Carbide recently developed the UNOX System (7) which is an oxygen-aeration-activated sludge system with an oxygen utilization of over 90 percent. This oxygen-activated sludge process (UNOX) is presently being piloted in several locations and several, full-scale plants utilizing the pure oxygen process (UNOX) are under construction and will soon be in operation.

Purpose of Project

The District of Columbia must upgrade the existing Blue Plains Water Pollution Control Plant so that the effluent from the plant meets the Potomac River Water Quality standards. Furthermore, the plant is to be expanded so that it will be capable of treating an average flow of 309 MGD. The area of land available for expansion is limited and previous studies have shown that the available land may not be enough to provide adequate treatment for 420 MGD wastewater flow.

The use of pure oxygen in activated sludge enhances the transfer of oxygen into the wastewater for biochemical usage resulting in the ability of the system to support a high biomass in the wastewater. The rate of removal of biochemical oxygen demand (BOD) is proportional to the product of biomass (measured as MLVSS) and the time of reaction. If the biomass is increased, the time required for a given BOD removal can be reduced thereby reducing the area of land required for the reactor. It can be seen that a pure oxygen system which can maintain a higher biomass will offer a possible solution to the problem of land requirement.

The other problem is the removal of phosphates in the wastewater by chemical addition to precipitate the phosphates and then remove them by sedimentation. Since an activated sludge process requires sedimentation, a further reduction in land requirement can be achieved if the two systems can be combined by adding the chemical to the activated sludge system and removing BOD and phosphates in the same operation.

Proposed Study

The proposed study was to demonstrate the performance of the pure oxygen system with regard to high mixed liquor suspended solids concentration and short retention times as compared to a step aeration system. The pilot plant was to be operated on steady flow and diurnal variation simulation of flow at high mixed liquor suspended solids (MLSS) concentration.

In order to evaluate the degree of phosphate removal that can be achieved in the activated sludge system, alum was to be added under various operating conditions. 90 percent phosphate removal has been reported in literature but 98 percent removal is required at Washington, D.C. This test was to provide a basis for the decision on how adequate phosphate removal can be achieved.

Authorization, Scope and Content of the Report

The studies covered in this report were undertaken by the Environmental Protection Agency, Washington, D.C., with Union Carbide under contract to provide the engineering and the equipment required for the study, train the EPA operators and reduce data furnished by the EPA. The contract was signed on February 13, 1970 under section 302 (C)(15) of the Federal Property and Administrative Services Act of 1949, as amended, and Section (5) of the Federal Water Pollution Control Act, as amended. The contract was for $55,900 for engineering and equipment and for data reduction and the final report.

The ultimate goal of the project was to evaluate the oxygen-activated sludge process (UNOX) by determining process performance and operating requirements for the Washington, D.C. primary effluent wastewater. The basic facilities and equipment for the UNOX System test program are described in Section IV.

SECTION IV

OXYGEN ACTIVATED SLUDGE SYSTEM

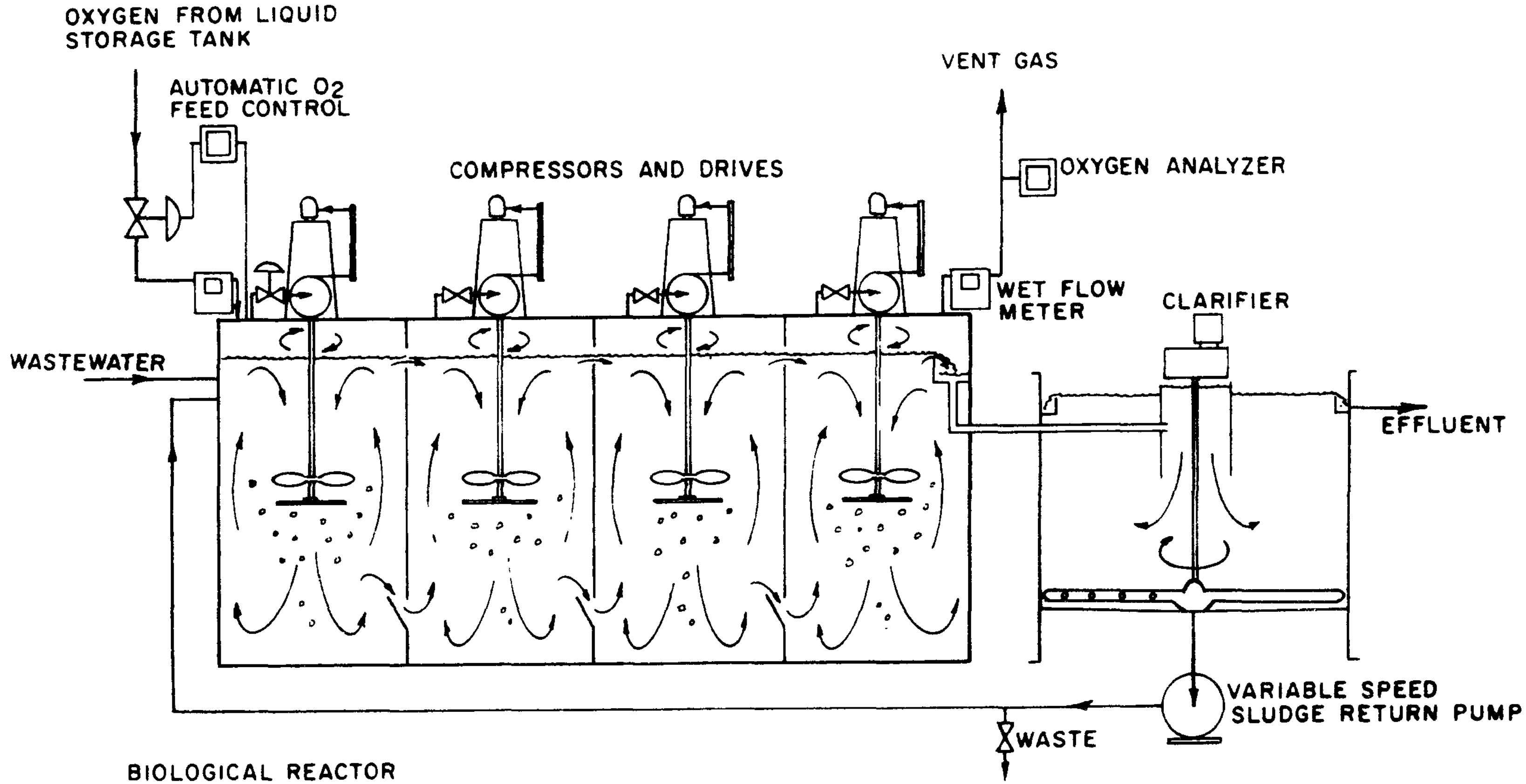
Pilot Plant Facilities

The UNOX System couples the use of pure oxygen with a highly effective mass transfer and contacting system to biologically remove organic contaminants. The EPA-DC pilot plant employs a unique gas-tight biological reactor with four stages operating in series. The reactor operated initially with a peripheral feed clarifier which was later modified to a conventional centerfeed gravity clarifier. A schematic diagram of the pilot plant facility is shown in Figure 1.

The gas tight biological reactor consists of four cocurrent gas-liquid stages. Each stage contains a sparge impeller contacting device. The sparger consists of rotating spokes equipped with orifices, whereas the primary liquid pumping device is a marine type impeller. Each of the stages is a completely mixed unit with the overall system approximating plug flow. The influent waste and the return sludge were mixed prior to entering the first stage. The wastewater feed and sludge return lines are both equipped with magnetic flow meters which are periodically calibrated.

The clarifier initially was a peripheral feed center take-off clarifier with a rapid sludge return type sludge removal system. The influent channel around the periphecy of the clarifier was separated from the upflow area by an apron which extended 70 inches below the water level. This clarifier was later modified to a centerfeed clarifier, but the apron was not removed. This resulted in a clarifier with a total area of 107 square feet and an upflow area of 78 square feet. This means that the total area of the clarifier is 37 percent greater than the upflow area as compared to full scale units where the difference is only 5 percent or less. Therefore, the upflow area was used in clarifier overflow rates in this report. Since the apron did not extend down to the compaction zone of the clarifier, the total clarifier area (107 sq. ft.) was used for clarifier solids loadings.

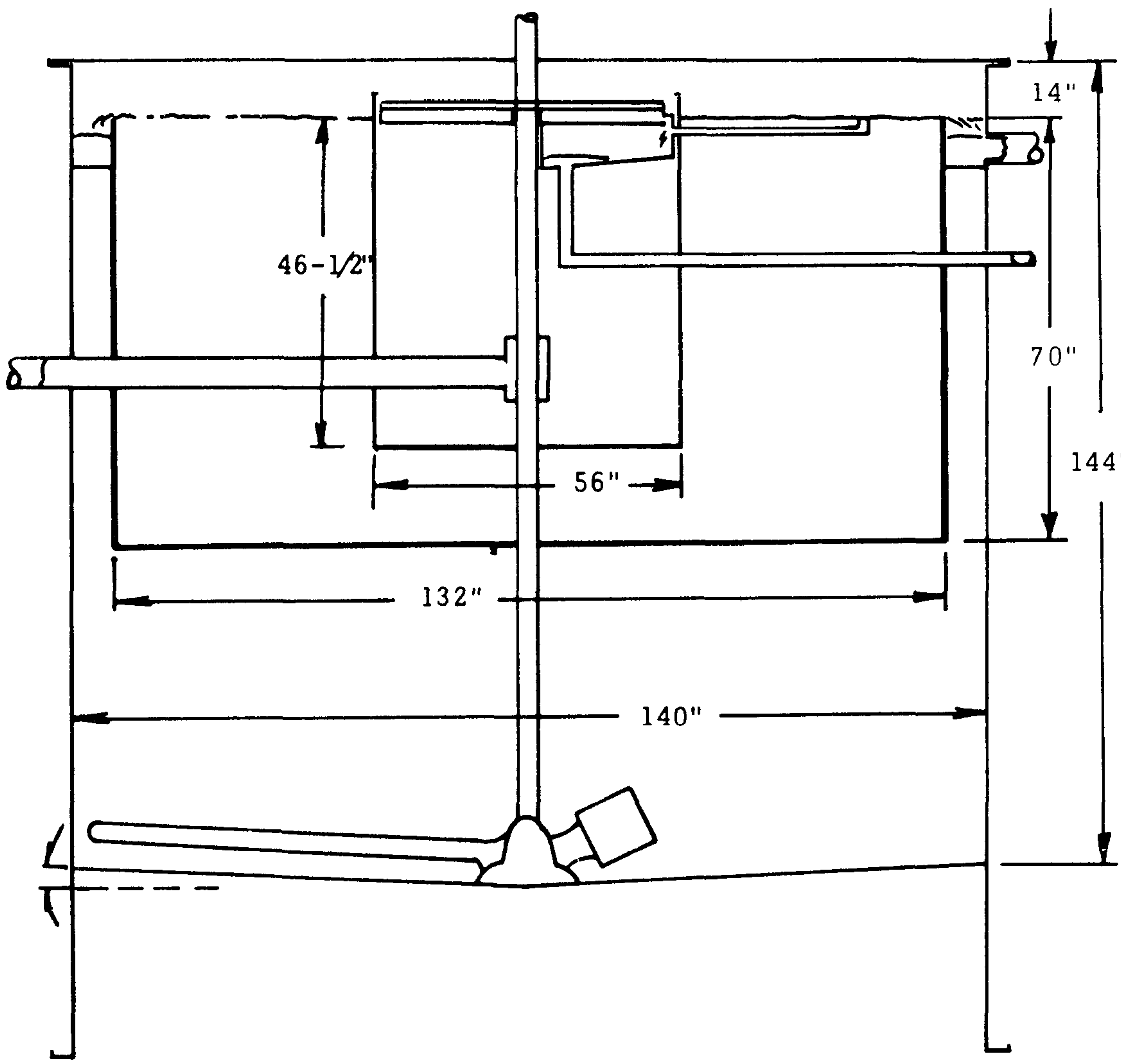
FIGURE 1
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
"UNOX" PILOT FACILITY



BIOLOGICAL REACTOR
LIQUID DEPTH = 11' 7"
STAGE VOLUME = 2025 gal.
TOTAL LIQUID VOLUME = 8100 gal.

	SECONDARY CLARIFIER
DIAMETER	11' 9"
LIQUID DEPTH	10' 10"
VOLUME	8800 gal.

FIGURE 2
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
INITIAL CLARIFIER UNIT



Influent Wastewater

Throughout the pilot plant study, the biological reactor influent was obtained from the effluent of the full-scale primary clarifiers. The quantitative variability of the clarified wastewater is shown in Table I. As noted, the daily BOD_5 varied between 50 and 170 mg/l with an overall average of about 114 mg/l. 80 percent of the time, the BOD was between 80 and 150 mg/l with the higher and lower ranges each occurring 10 percent of the time. A probability curve of influent BOD is shown in Figure 3. The average COD/BOD ratio was about 2.3. Suspended solids varied between 40 and 200 mg/l with an average of about 108 mg/l; the volatile content averaged 80 percent. The total Kjeldahl nitrogen and total phosphorus each averaged 26 mg/l. The lowest sustained influent waste temperature was 66°F. Periodically during the study, a filamentous type culture was noted in the wastewater. Microscopic analysis showed that this same culture was present on the full-scale primary clarifier weirs.

Process Monitoring

In addition to the routine monitoring of gas and liquid flow rates by appropriate recording and metering equipment, several basic parameters are measured in order to obtain a process performance evaluation. Daily composite samples are formed for six (6) grab samples taken at four (4) hour intervals for the biological reactor influent, the clarifier effluent and the recycle sludge. Mixed liquor composites are formed from three (3) grab samples taken at eight (8) hour intervals. All of the grab samples taken are volumetrically proportional according to the pilot plant influent. Settling information is collected daily through graduate cylinder settling tests. Solids are normally wasted four (4) to six (6) times per day (or as required) and the volume wasted is measured. Waste sludge solids concentration is the same as clarifier underflow concentration. Most of the analytical procedures are conducted as outlined in the 12th Edition of Standard Methods. All analytical tests are performed by the EPA-DC personnel at Blue Plains, and these results, together with the monitoring information are sent to Union Carbide to be reduced for use in this report.

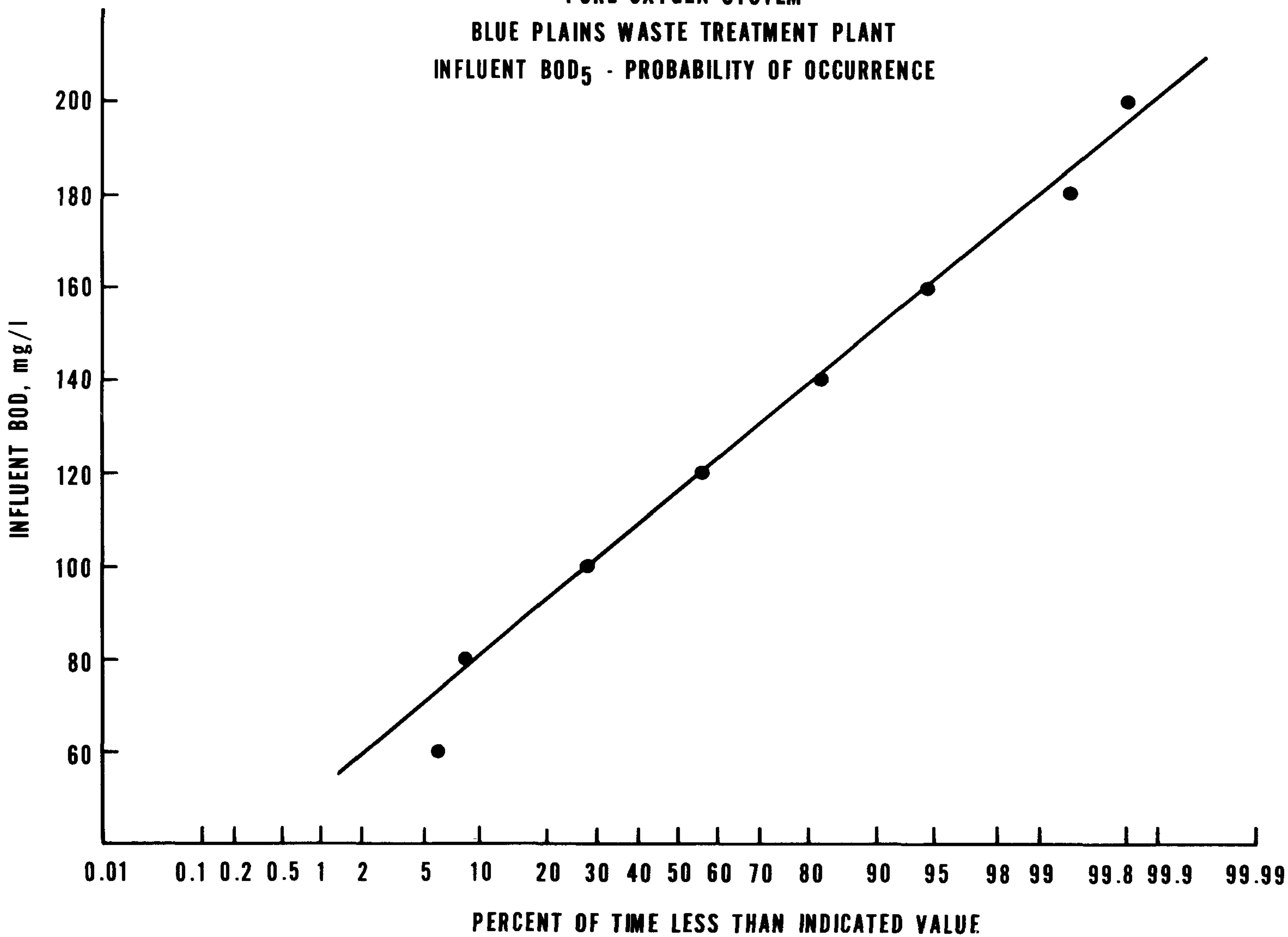
Mode of Operation

The EPA-DC Pilot Plant has been in operation since May 1970. Primary effluent from the District of Columbia's plant is fed to the oxygen reactor either with a steady flow or with a predetermined daily cycle or diurnal

TABLE I
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
INFLUENT WASTE CHARACTERISTICS

PARAMETER	24-HOUR COMPOSITES	
	95% Occurrence Range	Average
Chemical Oxygen Demand, mg/l	160-340	267
Biochemical Oxygen Demand, mg/l	50-170	114
Total Suspended Solids, mg/l	40-200	108
Volatile Suspended Solids, mg/l	40-140	81
Total Kjeldahl Nitrogen, mg/l	15-35	26
Total Phosphorus, mg/l	16-35	26
pH	6.8-7.7	7.3
Temperature, °F	66-87	75

FIGURE 3
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
INFLUENT BOD_5 - PROBABILITY OF OCCURRENCE



variation, normally with a 2.3:1 (45-105 gallons per minute) daily flow variation (Figure 4). The four stage system with 8,100 gallons capacity provides 1.94 hours of retention time at the nominal influent flow of 100,000 gallons per day. At the peak daily flows, the retention time is 1.3 hours.

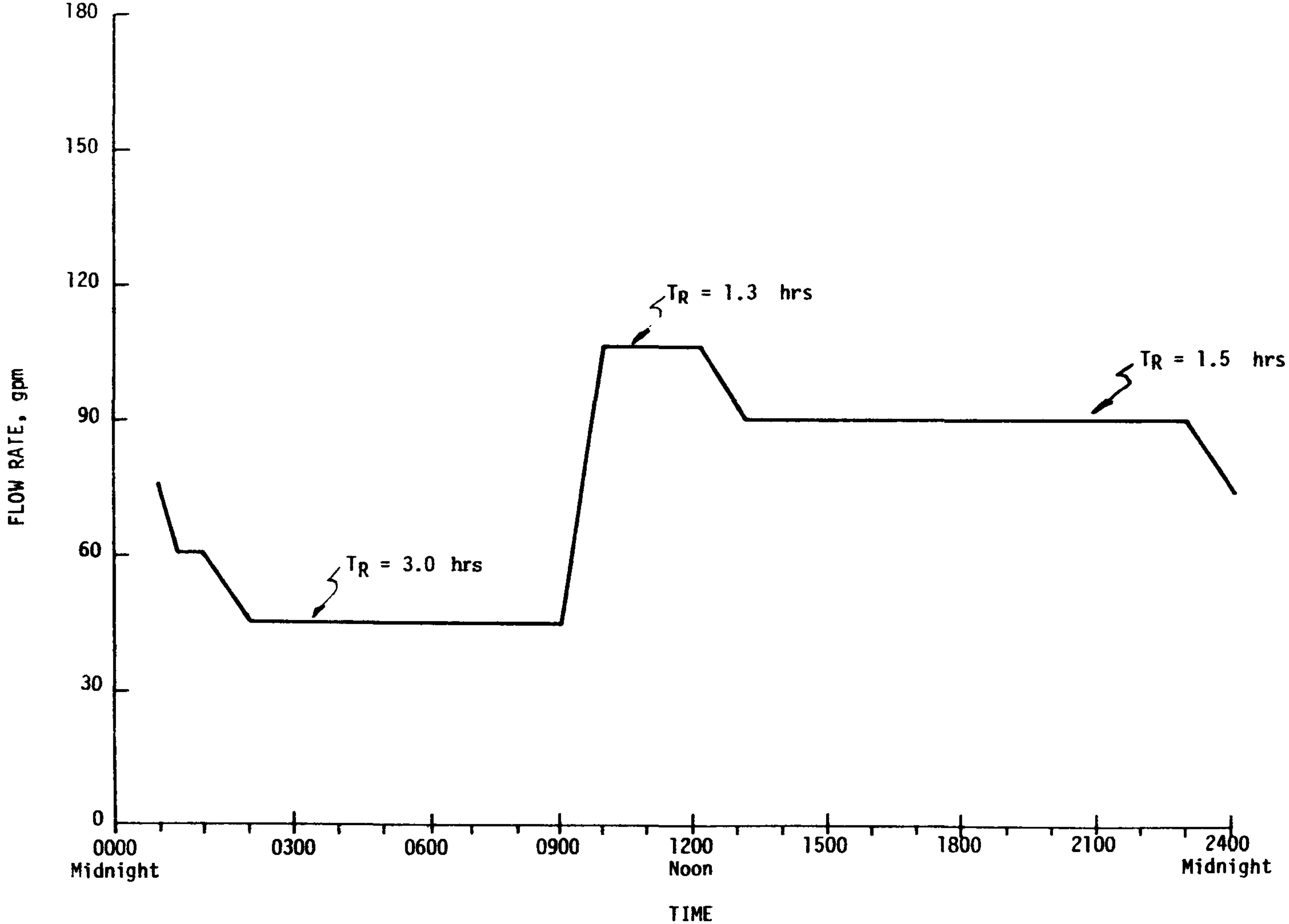
The reactor is sealed to prevent loss of oxygen and includes submerged hydraulic entrances and exits as well as simple water-sealed mixing equipment. It is divided into stages to provide the proper tank geometry for efficient mixing and oxygen usage.

The efficient oxygen usage is achieved by cocurrent contacting of the mixed-liquor and oxygen gas through the various stages. The addition of pure oxygen to the reactor is controlled by a pressure regulator. An inlet oxygen control valve actuated by the pressure regulator maintains the overhead gas at a selected pressure usually between 1" and 4" of water. Even with large instantaneous fluctuations in oxygen consumption, the oxygen control valve easily maintains the selected pressure. The overhead gas pressure is normally selected to produce an oxygen concentration at approximately 50 percent in the exhaust gas from the reactor. Pure oxygen is introduced to the first stage where the peak oxygen demand occurs. As the oxygen is used in biological metabolism, nitrogen stripped from the wastewater and the respirated carbon dioxide reduces the oxygen concentration in the overhead gas flowing cocurrently with the mixed liquor through the succeeding stages. The successive decrease of both oxygen supply and demand produces efficient oxygen use before the residual gas is exhausted from the reactor.

The dissolved oxygen level in the mixed liquor is controlled between 4.0 and 8.0 mg/l by adjusting the recirculation rate of the oxygen enriched gas within the individual stage. The compressor in each stage pumps the overhead gas through the rotating mixer impeller to provide efficient dispersion and mixing of the recirculated gas. The recirculation rate in each stage may be set either manually on the basis of a dissolved oxygen analysis or automatically in the first stage using a control system with a dissolved oxygen probe as a sensor.

In order to cope with foaming problems, water spray nozzles were installed at the exit from each stage. The spray nozzles are turned on as required to spray jets of water to dissipate the foam. A flap gate was also installed at the weir in stage 4 so that the liquid level in the reactor could be lowered. If the spray nozzles do not completely dissipate the foam, it could be removed from the reactor by lowering the liquid level.

FIGURE 4
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
DIURNAL FLOW VARIATION



Analytical Procedures

To evaluate the oxygen activated sludge process, appropriate samples were manually composited over a 24 hour period. Samples were stored at 3°C to minimize biological activity.

The 5-day biological oxygen demand (BOD) of the composite samples was determined by the probe method (10) and the ammonia (10) and nitrate-nitrite (11) on a Technicon Automatic Analyzer. The total phosphorus (12) was determined by the persulfate method. All other analyses employed Standard Methods (9). Soluble phosphorus and soluble BOD were filtered through a standard glass suspended solids filter before analyses.

SECTION V

PROCESS OPERATION AND PERFORMANCE

The pilot plant operation which started in May 1970 is still in progress. This report covers only the first six months of operation which can be divided into five operating phases. The different phases of operation are described in the following discussion and tabulated in Table 2 for easy reference. Table 3 summarizes the phase performances, and Tables 4 and 5 show the weekly summary of data obtained.

Phase I (May 24 to July 17, 1970)

This was primarily a startup period. In two weeks, the mixed liquor suspended solids (MLSS) had increased from 700 to 6000 mg/l and the influent flow increased to 65 gallons per minute (gpm). Sludge volume index (SVI) averaged 35. However, on May 31, the biomass was lost from the system when a waste sludge valve was inadvertently left open. In rebuilding the mixed liquor solids, a filamentous culture developed. By reducing the flow from 65 to 30 gpm, the filamentous growth was eliminated and flow was gradually increased to 80 gpm with a retention time of 1.66 hours.

The clarifier, shown in Figure 2, was originally a peripheral feed clarifier. The effluent from the UNOX reactor entered the feed channel located on the periphery of the clarifier at one point and is distributed by inlet ports at the bottom of the feed channel. With all the flow going in one direction, it means that some of the flow has to travel 360° around the clarifier which lessens the chance of equal distribution. In addition, some of the inlet orifices were plugged, thus aggravating any mal-distribution and causing short circuiting. This resulted in relatavely high effluent suspended solids which averaged 43 mg/l.

Effluent BOD averaged 15 mg/l at a biomass loading of 0.28 lb. BOD per lb. MLVSS. Average retention time was 2.5 hours and clarifier overflow rate averaged 770 gallons per day per square foot (GPDPSF).

Phase II (July 18 to August 13, 1970)

A steady flow of 75 gpm was maintained during this period of operation. Retention time was 1.8 hours. MLSS averaged 5200 mg/l with biomass loading averaging 0.33 lb. BOD per lb. MLVSS. Solids retention time (SRT) averaged seven days.

TABLE 2
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
OPERATING PHASES

Phase	Period of Operation	Mode of Operation
I	May 24 to July 17, 1970	Steady flow varying from 30 to 80 gpm with peripheral-feed clarifier
II	July 18 to August 13, 1970	Steady flow of 75 gpm with peripheral-feed clarifier
III	August 14 to Sept. 30, 1970	The peripheral feed clarifier was modified to a center-feed clarifier on August 14, 1970. Steady flow of 75 gpm was maintained until August 26, 1970 when a diurnal flow pattern averaging 75 gpm was initiated.
IV	October 1 to October 25, 1970	Alum addition with diurnal flow averaging 75 gpm with center-feed clarifier
V	October 26 to November 21, 1970	Steady flow varying from 50 to 70 gpm with center-feed clarifier

TABLE 3
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
PERFORMANCE SUMMARY

	Units					
Phase		I	II	III	IV	V
Period of Operation		5/24-7/17/70	7/18-8/13/70	8/14-9/30/70	10/1-10/25/70	10/26-11/21/70
Duration	weeks	8	4	7	3	4
Retention Time (Q)	hours	2.51	1.85	1.92	2.05	2.19
Recycle Ratio (R/Q)	%	44	40	34	43	42
Sewage Temperature	°F	78	83	82	72	71
Mixed Liquor Suspended Solids	mg/l	4890	5190	5790	8160	7100
Mixed Liquor Volatile Suspended Solids	mg/l	3080	3760	4490	5410	4890
Biomass Loading, lb. BOD_5/lb. MLVSS/day		0.28	0.33	0.30	0.26	0.28
Organic Loading, lb. BOD_5/1000 cu.ft/day		60	68	82	84	82
Influent Characteristics						
COD	mg/l	237	230	268	296	292
BOD_5	mg/l	100	90	105	114	122
SS	mg/l	118	96	102	126	107
Effluent Characteristics						
COD	mg/l	59	54	50	73	83
BOD_5	mg/l	15	18	15	13	16
SS	mg/l	43	36	24	33	34
Removals						
COD	%	75	77	81	75	72
BOD_5	%	85	80	86	89	87
SS	%	64	59	76	74	68
Clarifier Overflow Rate-gal/ft^2/day		770	1000	1310	1230	1170
Clarifier Loading-lb. SS/ft^2/day		44	60	63	87	74
Clarifier Underflow Concentration	% solids	1.09	1.32	1.34	2.31	1.81
Sludge Volume Index	ml/gm	71	53	-	-	-
Sludge Retention Time	days	20	7	10	5	9
Lb. O_2 Supplied/lb. BOD_A*		2.10	2.45	2.07	1.55	1.26
Lb. O_2 Supplied/lb. BOD_R*		2.69	3.43	2.57	1.95	1.48
Lb. WVSS/Lb. BOD_R		-	0.45	0.21	0.74	0.19

* O_2 Consumption has been shown on the basis of both BOD applied (BOD_A) and BOD removed (BOD_R). This is because most of the effluent BOD is associated with the biomass as effluent solids while total effluent BOD was 13 to 18 mg/l, soluble effluent BOD was less than 3 mg/l showing virtually complete insolubilization of influent BOD.

TABLE 4
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
OPERATING PARAMETERS

Phase	Date (Wk. of)	Biomass Loading		Organic Loading		COD/BOD	Oxygen Utilization		Solids Accumulation		Clarifier			Solids Retention Time, days
		lb.BOD/ lb.MLVSS	lb.COD/ lb.MLVSS	lb.BOD/ 1000 cu.ft.	lb.COD/ 1000 cu.ft.		lb.O_2/ lb.BOD_R	lb.O_2/ lb.COD_R	lb.VSS/ lb.BOD_R	lb.SS/ lb.BOD_R	Overflow Rate, gal/ ft^2/day	Mass Loading, lb/ft^2-day	Underflow Concentration, % Solids	
I	5/31/70	-	-	85	161	1.89	1.56	0.88	0.00	0.00	820	-	0.61	14
	6/7/70	-	-	53	113	2.21	2.46	1.23	0.00	0.00	610	-	1.06	38
	6/14/71	0.26	0.44	49	85	1.72	2.97	0.99	0.00	0.00	700	35.1	1.20	23
	6/21/70	0.35	0.79	61	144	2.37	2.79	0.93	0.00	0.00	690	36.7	1.13	15
	6/28/70	0.42	1.13	56	156	2.77	3.39	1.11	-	-	740	41.7	-	-
	7/5/70	0.29	1.05	61	221	3.61	3.43	0.99	-	-	990	51.5	-	-
	7/12/70	0.27	0.62	64	149	2.35	2.00	1.40	0.00	0.00	870	56.3	1.45	10
II	7/19/70	0.45	1.00	76	190	2.25	3.00	1.15	0.05	0.10	1040	56.4	1.19	7
	7/26/70	0.35	0.77	82	183	2.29	3.03	1.54	0.11	0.15	1020	61.8	1.37	8
	8/2/70	0.25	0.76	60	189	3.18	4.60	1.18	0.63	0.86	1030	66.7	1.40	5
	8/9/70	0.29	0.76	70	186	2.66	3.10	1.18	1.02	1.34	900	55.8	1.30	8
III	8/16/70	0.39	0.95	89	221	2.46	2.34	0.94	0.09	0.18	1380	59.4	1.15	10
	8/23/70	0.26	0.88	68	215	3.14	3.17	0.97	0.12	0.16	1370	58.1	1.22	11
	8/30/70	0.30	0.84	78	222	2.84	2.50	0.94	0.35	0.47	1330	59.7	1.25	8
	9/6/70	0.31	0.71	81	187	2.30	2.36	1.13	0.17	0.22	1310	58.4	1.45	12
	9/13/70	0.27	0.71	79	206	2.60	2.70	1.04	0.29	0.37	1330	61.7	1.41	8
	9/20/70	0.28	0.69	84	210	2.50	2.67	1.17	0.23	0.29	1350	64.3	1.55	11
	9/27/70	0.26	0.62	93	208	2.24	2.26	1.64	0.24	0.30	1340	80.4	-	10
IV	10/4/70	0.30	0.69	95	223	2.36	1.87	1.24	0.52	0.74	1210	75.9	2.10	5
	10/11/70	0.26	0.65	83	210	2.54	2.06	1.41	0.58	0.87	1260	82.2	2.46	5
	10/18/70	0.21	0.59	74	216	2.95	1.93	0.71	1.11	1.70	1230	102.3	2.37	5
V	10/25/70	0.26	0.69	87	235	2.72	1.48	1.33	-	-	1230	91.5	2.51	-
	11/1/70	0.26	0.62	78	184	2.35	-	-	0.04	0.06	1130	66.8	1.67	12
	11/8/70	0.31	0.60	80	168	2.14	-	-	0.33	0.45	1150	64.7	1.25	6
	11/15/70	0.31	0.72	95	218	2.33	-	-	0.12	0.17	1260	70.2	1.44	17

TABLE 5
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
PERFORMANCE DATA

PHASE	Date Week of	Oxygenation Time, hrs.	Recycle Ratio % of Q	MLSS mg/l	MLVSS mg/l	Mixed-Liquor Temp, °F	Mixed-Liquor pH	Total Influent, mg/l COD	Total Influent BOD$_5$	Total Influent SS	Total Influent VSS	Total Effluent, mg/l COD	Total Effluent BOD$_5$	Total Effluent SS	Total Effluent VSS	Total Removal, % COD	Total Removal BOD$_5$	Total Removal SS
I	5-31-70	2.28	48	*	*	76	-	244	129	127	63	44	14	22	9	82	89	83
	6-7-70	3.21	50	*	*	77	6.4	241	109	94	53	46	16	45	17	81	85	52
	6-14-70	2.67	48	4060	3070	78	6.5	151	88	115	79	42	15	32	15	83	82	72
	6-21-70	2.71	49	4280	2940	79	6.3	261	110	115	92	48	22	31	22	81	76	72
	6-28-70	2.56	39	4890	2200	79	6.3	266	96	149	68	65	18	51	22	75	78	53
	7-5-70	1.89	33	4700	3400	79	6.3	278	77	114	72	66	19	44	25	74	74	62
	7-12-70	2.22	41	5500	3800	79	6.5	221	94	114	82	101	16	75	50	51	78	31
II	7-19-70	1.81	39	4700	3030	80	6.4	229	102	89	69	51	19	34	19	78	79	-
	7-26-70	1.84	38	5290	3790	83	6.3	224	98	91	67	63	17	45	27	71	82	48
	8-2-70	1.82	38	5620	4330	85	6.3	229	72	111	78	54	20	42	29	78	72	59
	8-9-70	1.91	46	5160	3880	83	6.3	237	89	100	80	46	15	21	15	80	73	78
III	8-16-70	1.87	42	5000	3730	83	6.2	275	112	102	80	49	14	21	15	82	87	78
	8-23-70	1.88	35	5180	3900	83	6.2	270	86	80	52	50	18	25	17	81	79	68
	8-30-70	1.94	35	5490	4210	83	6.5	287	101	115	88	49	14	23	16	83	86	79
	9-6-70	1.97	34	5500	4200	82	6.2	246	107	112	77	43	12	22	13	82	89	79
	9-13-70	1.93	29	5900	4630	82	6.5	265	102	98	73	53	12	27	18	80	87	71
	9-20-70	1.91	30	6050	4880	83	6.5	267	107	105	82	48	15	23	18	81	86	77
	9-27-70	1.92	33	7420	5850	80	6.7	266	119	103	81	59	17	25	20	73	86	75
IV	10-4-70	1.97	33	7200	5130	78	6.6	293	124	99	83	88	14	18	18	69	89	81
	10-11-70	2.14	43	7870	5210	77	6.7	300	118	157	117	70	15	39	32	76	87	75
	10-18-70	2.05	42	9420	5880	75	6.4	295	100	121	75	61	10	36	21	80	89	71
V	10-25-70	2.10	41	8680	5420	74	6.7	329	121	101	77	138	15	38	23	55	88	62
	11-1-70	2.30	43	6790	4780	71	6.7	282	120	130	85	67	17	39	34	76	86	70
	11-8-70	2.29	46	6430	4460	71	6.8	257	120	92	72	85	22	44	34	66	81	52
	11-15-70	2.05	38	6640	4820	69	6.7	298	128	92	72	44	12	16	8	84	90	84

The peripheral feed clarifier showed a little improvement over Phase I operation but effluent suspended solids averaged 36 mg/l at an overflow rate of 1000 GPDPSF. Effluent BOD averaged 18 mg/l even though the soluble effluent BOD was practically nil (see Tables 6 and 6A). With better clarification, a lower effluent BOD could be achieved. It was decided, therefore, to convert the peripheral feed clarifier to a centerfeed clarifier because of the operation problems described in Phase I.

Phase III (August 14 to September 30, 1970)

The first two weeks of this phase was run at steady flow with the new centerfeed clarifier. The flow was maintained at 75 gpm and when it was apparent the system had stabilized, a diurnal flow pattern, shown in Figure 4, was initiated. As shown, the reactor retention time varied between 1.3 and 3.0 hours with an average of about 1.8 hours. The daily flow variation was normally from 45 to 105 gpm. This diurnal pattern was the expected pattern for dry weather flow of the District of Columbia's future plant.

MLSS averaged 5800 mg/l with a volatile content of about 80 percent. Biomass loading was 0.30 lb. BOD_5 per lb. MLVSS per day and solids retention time averaged 10 days. Limited graduate cylinder tests showed settling velocities greater than 8 feet per hour.

In modifying the peripheral feed to a centerfeed clarifier, the baffle which extended 70 inches below the weir was left in place. In addition, a relatively large centerwell was installed (see Figure 2) so that the clarification zone available for upflow (the upper 70 inches of the clarifier) had an area of only 78 square feet as compared to the total area of 107 square feet in the thickening zone. Therefore, the clarifier overflow rate was based on the area available for upflow while the solids loading was based on the area available for thickening (107 square feet).

The clarifier overlow rate averaged 1380 GPDPSF during this phase of operation with a peak of 1940 GPDPSF at the peak flow of 105 gpm. As shown in Figure 4, the diurnal flow pattern includes a sustained 10 hour flow of 90 gpm giving an overflow rate of 1670 GPDPSF. Clarifier mass loading varied from 40 to 100 lb. per day per square foot. At these high loadings, the recycle sludge averaged 1.4 percent suspended solids and effluent suspended solids averaged 24 mg/l. Effluent BOD and COD were 15 and 50 mg/l, respectively, on the average. Sludge retention time averaged 10 days.

TABLE 6
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
BIOCHEMICAL OXYGEN DEMAND

Date	Influent BOD_5, mg/l		Effluent BOD_5, mg/l		Average
(wk.of)	Range	Average	Range	Average	Removal, %
5-24-70	109-147	130	5-21	11	92
5-31-70	85-142	129	11-16	14	89
6-7-70	56-140	102	11-23	16	84
6-14-70	56-112	88	7-35	15	83
6-21-70	64-195	109	8-37	22	80
6-28-70	47-114	89	11-27	18	80
7-5-70	58-105	77	15-21	17	78
7-12-70	39-114	86	8-22	18	79
7-19-70	47-129	94	17-21	19	80
7-26-70	80-115	98	5-26	17	82
8-2-70	49-112	72	13-30	20	72
8-9-70	27-114	80	10-19	16	80
8-16-70	77-153	112	9-17	14	88
8-23-70	58-115	86	13-24	18	79
8-30-70	93-114	101	11-18	14	86
9-6-70	94-140	107	5-15	12	89
9-13-70	74-163	102	10-17	12	88
9-20-70	99-127	107	12-19	15	86
9-27-70	96-144	119	15-21	17	86
10-4-70	100-138	124	11-17	14	89
10-11-70	104-130	117	9-21	14	88
10-18-70	70-132	100	7-19	10	90
10-25-70	75-146	121	9-24	15	88
11-1-70	89-152	120	10-26	17	86
11-8-70	101-137	120	13-37	22	82
11-15-70	93-154	128	8-16	12	91

TABLE 6A
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
BIOCHEMICAL OXYGEN DEMAND

DATE	EFFLUENT BOD_5, mg/l	
	TOTAL	SOLUBLE
8-11-70	17	0.2
8-25-70	16	0.1
8-26-70	18	1.9
9-1-70	11	1.2
9-15-70	11	nil
9-21-70	19	1.2
9-28-70	15	0.2
9-29-70	15	2.4
11-2-70	12	2.5
11-9-70	37	2.5
11-10-70	25	3.1
11-16-70	9	0.6
11-17-70	11	nil
11-23-70	27	nil
11-24-70		3.4

Phase IV (October 1 to October 25, 1970)

During this phase of operation, alum was added in order to obtain phosphorus removal. The same diurnal pattern as for Phase III was maintained throughout this phase but due to inconsistency of the feed pump, average daily retention varied from 1.9 to 2.3 hours with a phase average of 2.05 hours.

Solid-liquid separation was improved by alum addition. The mixed liquor suspended solids averaged 8000 mg/l but the volatile fraction decreased from 78 percent in Phase III to 66 percent. These relatively high mixed liquor solids levels resulted in clarifier mass loadings ranging from 75 to 120 lb. per day per square foot (based on total clarifier area of 107 square feet). The recycle sludge concentrations went up to 3.0 percent with an average of 2.4 percent suspended solids. The clarifier overflow rate during this phase averaged 1230 GPDPSF. Effluent BOD averaged 13 mg/l and the removal averaged about 90 percent. Soluble BOD remained very low indicating that the alum did not hinder biochemical activity.

A summary of alum addition data is presented in Table 7. As noted, the alum addition did not correspond to the variability of the phosphorus feed. A rapid drop in mixed liquor pH was observed starting on October 20, 1970. Poorly flocculated mixed liquor was observed at the same time, resulting in poorer settling. This situation may have been the result of an excessive alum dosage to the system. Therefore alum addition was discontinued on October 25, 1970.

Phase V (October 26 to November 11, 1970)

Most of this phase was transitional operation. After alum addition was stopped, flow was reduced to 50 gpm to allow the system to stabilize and then gradually increased to 70 gpm. Mixed liquor suspended solids were decreased to about 6000 mg/l. Volatile fraction increased to about 70 percent. On the whole, retention time averaged 2.19 hours and biomass loading was 0.28 lb. BOD/day/lbMLVSS and a solids retention time of nine days was maintained. Solids wasting averaged about 0.2 lb. solids per lb. BOD removed.

Although this phase of operation was mostly transitional, good performance was maintained. Effluent suspended solids was about 34 mg/l and effluent BOD averaged 16 mg/l. Clarifier overflow rate remained very high with an average of 1170 GPDPFS.

TABLE 7
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
ALUM ADDITION

Date	Phosphorus Applied (as P) lb/day	Alum Added lb/day	Aluminum Added lb/day	Lb Aluminum Added/ Lb Phosphorus Applied	pH Units	% P Removal
10/1/70	10.4	11.1	1.0	0.10	6.6	44
10/2/70	9.2	79.6	4.5	0.49	7.2	56
10/3/70	8.6	78.1	7.0	0.81	7.3	69
10/4/70	-	134.4	12.1	-	6.5	-
10/5/70	-	124.6	11.2	-	6.1	-
10/6/70	7.0	116.5	10.5	1.50	6.35	38
10/7/70	8.1	92.5	8.3	1.02	6.8	81
10/8/70	7.5	147.5	13.3	1.77	6.7	87
10/9/70	8.1	117.5	10.6	1.31	7.1	83
10/10/70	7.2	94.0	8.5	1.18	6.9	82
10/11/70	7.3	135.5	12.2	1.67	6.0	87
10/12/70	7.5	22.0	2.0	0.27	6.2	83
10/13/70	7.8	102.0	9.2	1.18	7.1	75
10/14/70	7.4	63.5	5.7	0.77	6.6	72
10/15/70	6.4	105.5	9.5	1.45	7.45	75
10/16/70	5.7	112.5	10.1	1.77	6.3	-
10/17/70	6.9	60.0	5.4	0.77	7.3	74
10/18/70	7.1	82.5	7.4	1.05	7.3	75
10/19/70	9.1	56.0	5.0	0.56	6.7	50
10/20/70	6.8	64.5	5.8	0.87	6.1	84
10/21/70	5.8	108.5	9.8	1.65	6.5	77
10/22/70	6.5	116.7	10.5	1.70	6.2	92
10/23/70	8.0	112.1	10.1	1.27	6.2	90
10/24/70	8.2	97.0	8.7	1.08	5.8	83
10/25/70	6.4	127.5	11.5	1.76	6.0	80

Substrate Removals

A summary of the performance of the oxygen aeration system is shown in Table 3. A good quality effluent was produced throughout the operation with weekly average residual BOD varying between 10 and 22 mg/l. The soluble residual BOD shown in Table 6 averaged less than 3 mg/l indicating that most of the residual BOD in the effluent was associated with the effluent suspended solids. When proper clarification was provided, BOD removal averaged 92 percent with effluent BOD being below 10 mg/l 90 percent of the time (see Figure 6).

The chemical oxygen demand (COD) removal varied between 66 and 85 percent with residuals between 36 and 138 mg/l. The removal of COD was also dependent on the solids removal as evidenced by the results which show that with low effluent solids, COD removal averaged 84 percent with residuals ranging from 36 to 50 mg/l.

The effluent suspended solids were relatively high in the first six months of this study partly because of excessively high overflow rates that were maintained in the clarifiers. Overflow rates ranged between 600 GPDPSF at low flow periods to 1940 GPDPSF at high flow periods, with a 10 hour period at about 1700 GPDPSF resulting in effluent solids which averaged 20 to 40 mg/l. Since the completion of this program, operation of the plant at lower overflow rates (700 GPDPSF with a peak of about 1100 GPDPSF) has shown that effluent suspended solids can be maintained consistently below 20 mg/l.

TABLE 8
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
CHEMICAL OXYGEN DEMAND

Date (wk. of)	Influent COD, mg/l		Effluent COD, mg/l		Average Removal, %
	Range	Average	Range	Average	
5-24-70	215-448	288	33-51	45	84
5-31-70	200-279	248	18-59	50	80
6-7-70	114-302	241	24-60	46	81
6-14-70	194-288	256	35-40	41	84
6-21-70	205-322	261	31-50	41	84
6-28-70	211-337	266	55-80	65	76
7-5-70	214-359	278	35-128	66	76
7-12-70	169-255	221	45-164	101	54
7-19-70	162-304	229	21-78	50	78
7-26-70	180-278	224	37-94	63	72
8-2-70	202-258	228	32-84	54	76
8-9-70	181-297	237	16-59	46	81
8-16-70	247-306	275	36-61	49	82
8-23-70	208-369	270	39-86	50	81
8-30-70	187-337	286	29-57	49	83
9-6-70	179-316	246	37-57	43	83
9-13-70	220-289	265	34-98	53	80
9-20-70	239-284	267	39-54	48	82
9-27-70	132-305	266	35-87	59	78
10-4-70	259-366	293	41-169	88	70
10-11-70	256-330	300	40-129	70	77
10-18-70	247-388	295	33-117	61	79
10-25-70	248-470	329	51-264	138	58
11-1-70	226-337	282	46-94	67	76
11-8-70	214-321	264	61-128	85	68
11-15-70	241-372	298	23-60	44	85

TABLE 9
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
SUSPENDED SOLIDS

Date (wk. of)	Influent Suspended Solids, mg/l			Effluent Suspended Solids, mg/l			Average TSS Removal, %
	Range TSS	Average TSS	Average VSS	Range TSS	Average TSS	Average VSS	
5-24-70	74-970	253	121	5-78	33	10	87
5-31-70	104-168	127	87	7-31	22	12	83
6-7-70	46-116	94	96	21-77	45	17	52
6-14-70	92-146	115	79	12-96	32	15	72
6-21-70	88-138	115	92	14-66	31	22	73
6-28-70	61-468	149	68	23-101	51	23	66
7-5-70	78-208	114	72	15-110	44	25	61
7-12-70	90-162	114	82	22-122	75	50	34
7-19-70	8-132	89	67	10-71	34	19	62
7-26-70	60-122	91	67	14-64	45	29	51
8-2-70	80-148	111	78	10-78	42	29	62
8-9-70	76-122	100	80	14-30	21	15	79
8-16-70	68-111	102	80	8-34	21	15	79
8-23-70	58-126	80	52	16-38	25	17	69
8-30-70	70-136	115	88	12-39	23	16	80
9-6-70	78-158	112	77	7-40	22	13	80
9-13-70	80-126	98	73	10-62	27	18	72
9-20-70	68-136	104	82	16-26	23	18	78
9-27-70	86-116	103	84	21-30	25	20	76
10-4-70	82-110	99	83	9-24	18	12	81
10-11-70	86-214	157	117	25-91	46	32	71
10-18-70	100-156	121	75	10-53	36	21	70
10-25-70	74-124	101	77	30-224	86	49	15
11-1-70	76-184	130	85	14-68	39	34	70
11-8-70	56-128	92	72	30-100	56	39	39
11-15-70	86-102	92	72	13-21	16	8	83

TABLE 10
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
NITROGEN AND PHOSPHORUS

Date	Influent Total Kjeldahl Nitrogen, mg/l		Effluent Total Kjeldahl Nitrogen, mg/l		Average	Influent Total Phosphorus, mg/l		Effluent Total Phosphorus, mg/l		Average
(Wk. Of)	Range	Average	Range	Average	Removal, %	Range	Average	Range	Average	Removal, %
5-24-70	24-31	28	14-21	17	39	24-37	29	17-24	20	29
5-31-70	23-29	26	15-20	18	31	20-31	25	18-26	21	14
6-7-70	20-33	27	15-26	21	22	22-40	31	17-30	25	20
6-14-70	22-33	26	13-20	18	31	22-30	29	22-28	25	16
6-21-70	20-26	23	14-21	16	30	25-37	28	17-37	26	10
6-28-70	22-28	24	13-16	14	42	25-36	28	19-31	25	9
7-5-70	18-27	23	11-21	15	35	17-34	25	14-50	25	2
7-12-70	7-31	23	9-27	17	26	20-28	24	10-20	16	34
7-19-70	5-32	18	6-18	13	28	22-26	24	2-23	19	21
7-26-70	26-39	35	10-29	22	37	21-41	27	17-25	20	24
8-2-70	22-45	33	9-33	21	36	19-26	23	18-32	23	2
8-9-70	15-25	22	6-13	9	59	19-26	23	16-19	18	22
8-16-70	21-32	25	4-12	9	64	20-36	26	11-21	18	29
8-23-70	20-24	22	5-9	7	68	22-26	25	17-28	20	20
8-30-70	23-25	24	6-17	10	58	17-29	25	15-26	21	17
9-6-70	20-28	24	5-13	10	58	21-31	26	17-22	20	22
9-13-70	24-35	27	11-15	13	52	23-33	26	17-21	20	24
9-20-70	23-34	27	9-15	12	56	24-29	25	20-23	21	16
9-27-70	21-30	26	10-13	11	58	24-36	28	9-24	19	31
10-4-70	27-30	28	11-18	13	54	26-29	27	3-16	7	74*
10-11-70	26-31	28	12-29	17	39	24-30	28	4-24	9	67*
10-18-70	23-31	26	13-24	16	38	21-32	27	2-16	6	79*
10-25-70	26-29	28	8-30	21	25	25-29	27	5-47	27	-
11-1-70	20-32	27	14-23	18	33	21-36	29	13-26	21	27
11-8-70	23-32	28	16-23	19	32	19-29	26	16-24	20	22
11-15-70	21-27	24	12-19	15	38	23-28	25	16-26	19	24

FIGURE 5
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
BOD_5 REMOVAL - PROBABILITY OF OCCURRENCE

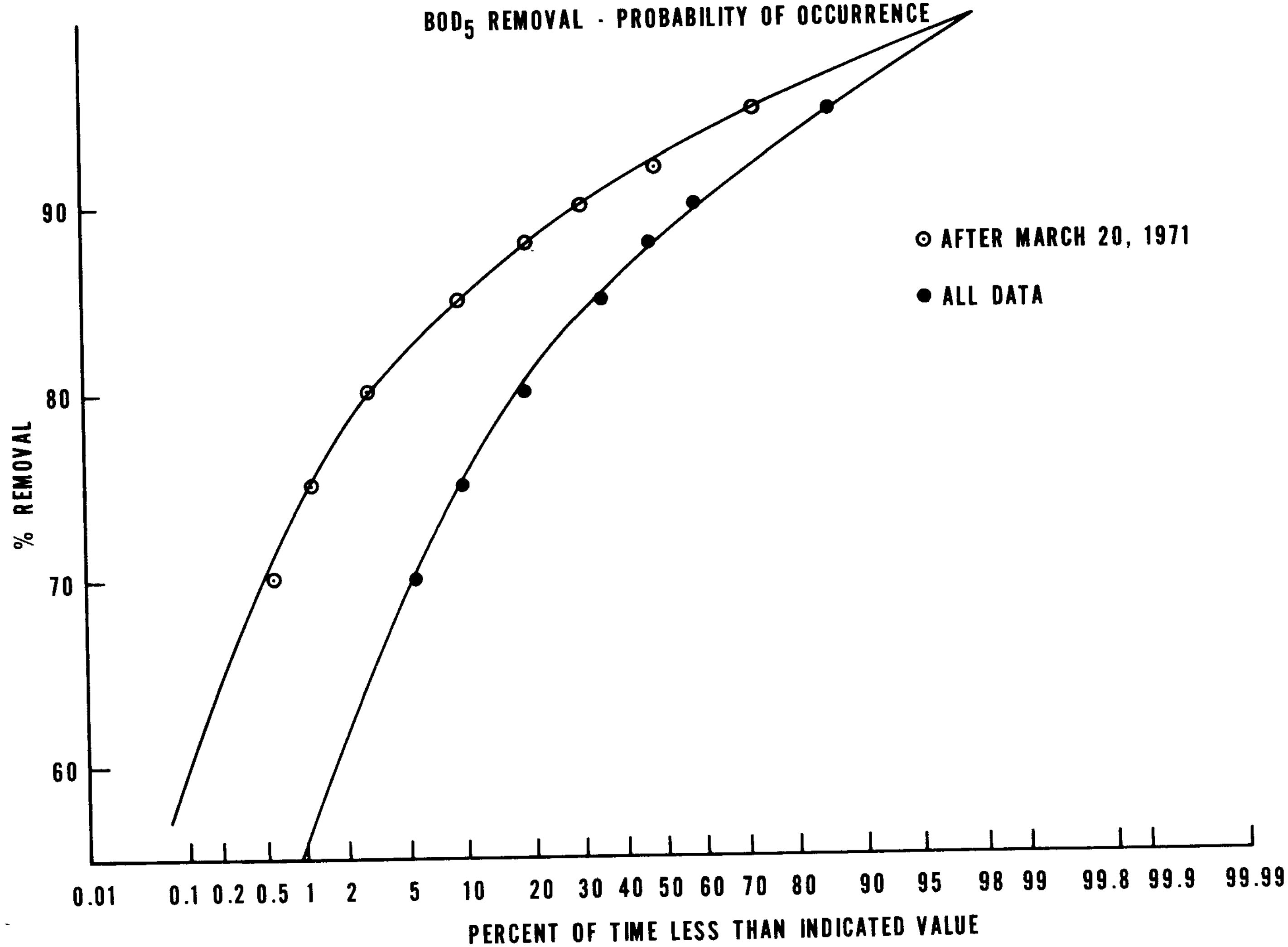


FIGURE 6
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
EFFLUENT BOD_5 - PROBABILITY OF OCCURRENCE

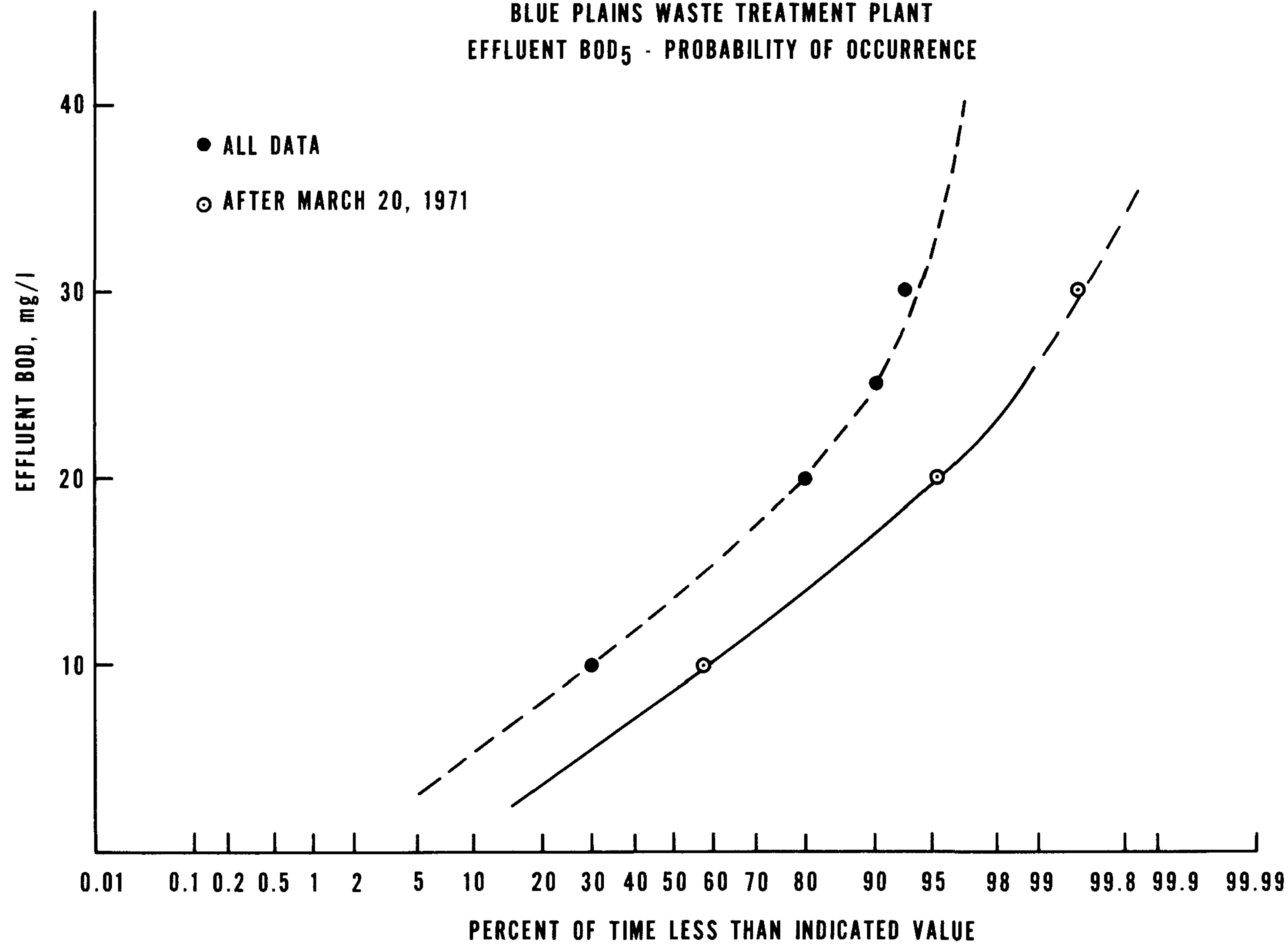
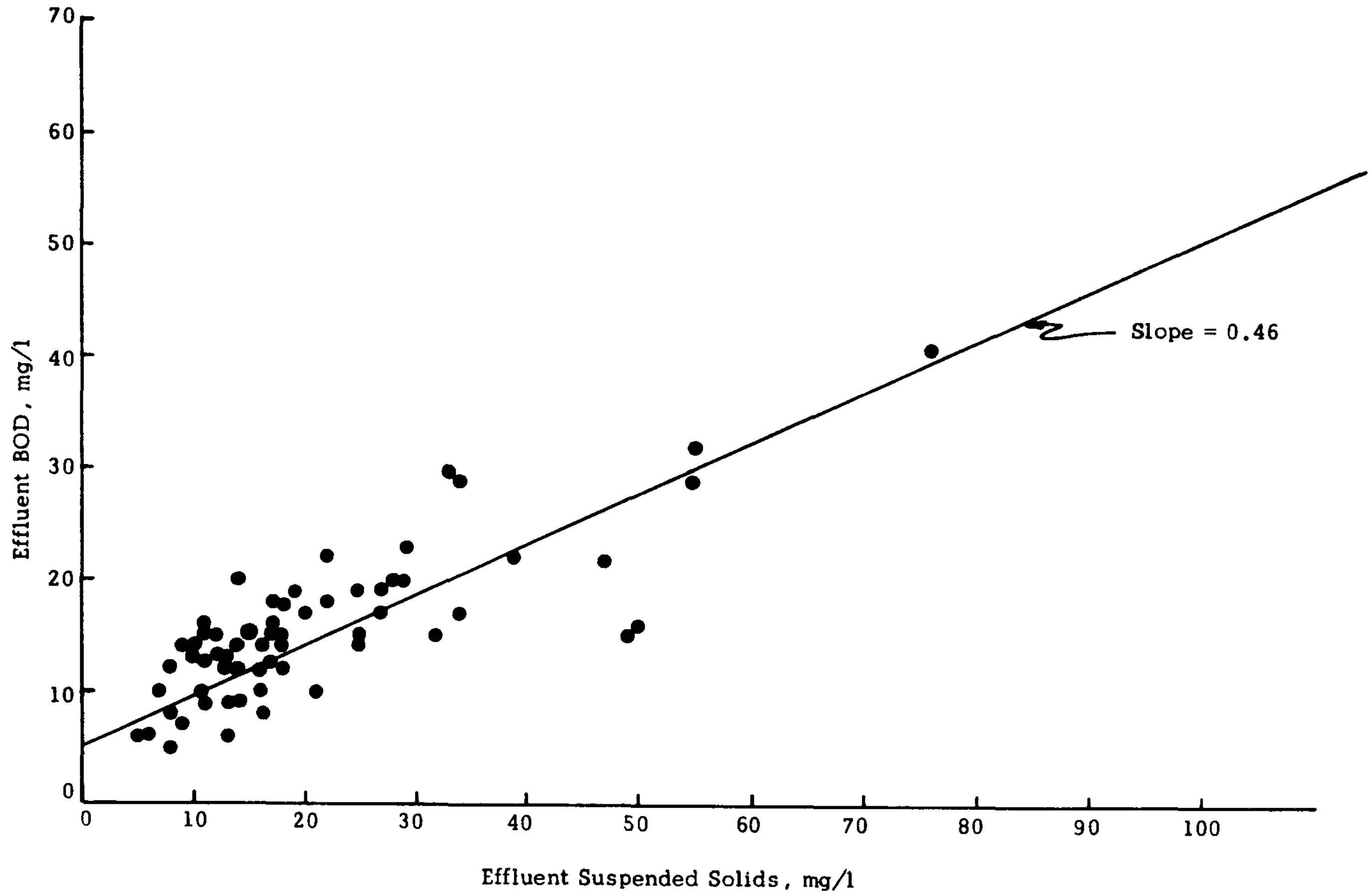


FIGURE 7
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
BOD CONTENT OF EFFLUENT SUSPENDED SOLIDS



Nutrient Removals

Nitrogen

In the warmer periods of the year (July to October) 70 to 90 percent of the total Kjeldahl nitrogen (TKN) was removed as compared to about 30 percent for the rest of the year. The increase in effluent nitrate during the period of high TKN removal showed that the increased removal was due to nitrification which occurred mostly at solids retention time of eight days or higher. This is in accord with various other work that has been done on nitrification and shows the ability of the pure oxygen system to nitrify as well as a conventional activated sludge system.

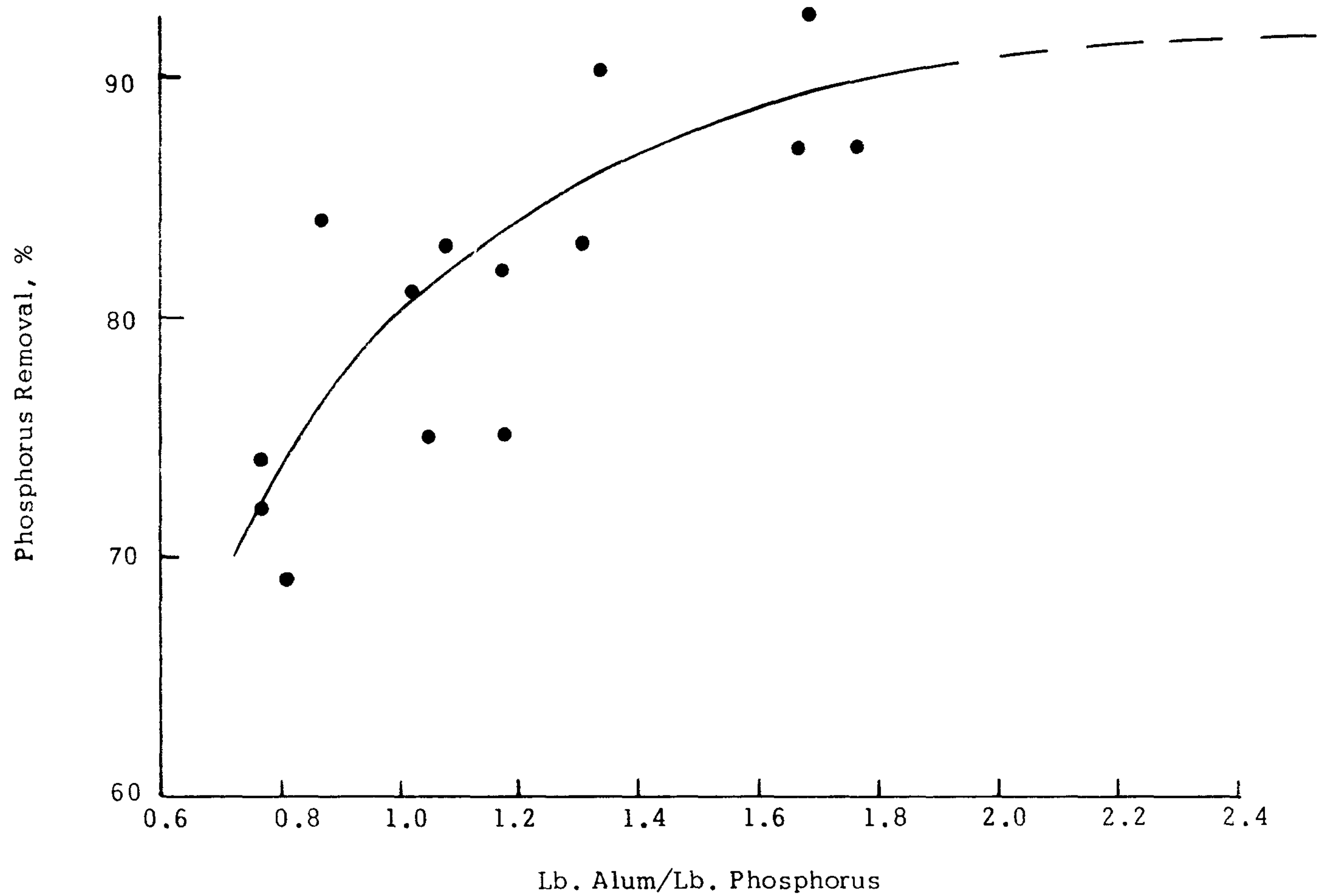
Phosphorus

In October 1970, alum was added to the fourth stage mixed liquor so that the phosphorus present in the wastewater could be removed by precipitation as phosphates. After the initial startup of this phase, phosphorus removals increased to about 80 to 90 percent. This removal was achieved at an alum dosage of about 1.4 to 1.8 lb. aluminum added to 1 lb. phosphorus present in the wastewater. Figure 8 shows the effect of alum dosage on phosphorus removal. It is apparent from Figure 8 that in order to maintain a 90 percent removal, about 1.8 lb. aluminum must be added for every pound of phosphorus present in the waste. The addition of alum, however, causes about 40 percent increase in the sludge production, and sludge wasting must be adjusted to accommodate this extra sludge production. It was observed that there was a rapid drop in the mixed liquor pH from about 6.7 on October 19, 1970 to 6.0 by October 25. This may have been caused by an excessive dosage of alum to the system. This resulted in a dispersed biomass. Thus, alum addition was stopped to a allow the mixed liquor to recover.

Biomass Characteristics

The mixed liquor suspended solids were similar visually to the microorganisms in conventional activated sludge. The mixed liquor biota was normally very well bioflocculated with active stalked ciliates growing on the bacterial mass. Zooflagellates and free swimming ciliates, although few in number, remained adjacent to or within the flocculated particles. Several varieties of large active rotifiers were plentiful. A few nematodes existed in the sludge. Normally, filamentous growth was not apparent. There was almost a complete absence of fragmented debris or unflocculated bacteria between the discrete particles.

FIGURE 8
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
EFFECT OF ALUM DOSAGE ON PHOSPHORUS REMOVAL



Sludge Production

The total sludge production per pound of BOD applied, including the waste and effluent solids, was directly related to the solids retention time (SRT). The solids production in the pure oxygen system decreased with increasing SRT while the solids production in the step aeration sludge system increased with SRT up to 9.5 days and then started to decrease. At an SRT of 6 days or higher, the solids production in the pure oxygen system was significant.y lower than in the step aeration system. Solids production at 9.5 days SRT was at a maximum of one pound solids per pound BOD applied for the step aeration system compared to 0.5 pound solids per pound BOD applied for the oxygen system. Indeed, the total solids production decreased to 0.35 pounds solids per pound BOD applied at an SRT of 13 days in the pure oxygen system. The initial increase in solids production of the step aeration system was due to increased BOD removals by assimilation into the biomass.

Organic Loading

The performance of the pure oxygen system has amply demonstrated the ability of this system to operate efficiently at various loading conditions. Through this period of operation, effluent BOD has been maintained consistently below 20 mg/l. The soluble effluent BOD was negligible indicating extensive endogenous activity. This means that the system could have been operated successfully at biomass loadings higher than the 0. 5 lb. BOD/day/lb. MLVSS that was experienced during this operation. As has been noted before, it is apparent that complete assimilation of BOD into the biomass is achieved even at low retention times. Sludge production was very low because of the auto oxidation resulting from endogenous activity.

Oxygen Utilization

Consistently over 90 percent of the feed oxygen was utilized throughout this pilot plant operation. The vented stream usually contained 50 percent oxygen or less.

The oxygen consumption ratios shown in Tables 3 and 4 are very high compared to other available data on oxygen systems. This is due to a combination of the following factors:

1. The System operated at relatively low loading rates which resulted in extensive endogenous respiration.

TABLE 11
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
SOLIDS BALANCE

Date (Wk. of)	Influent Solids, lb/day SS	Influent Solids, lb/day VSS	Effluent Solids, lb/day SS	Effluent Solids, lb/day VSS	Waste Solids, lb/day SS	Waste Solids, lb/day VSS	Solids Accumulation lb TSS/ lb BOD_R	Solids Accumulation lb TSS/ lb COD_R
7/5/70	102.5	64.3	39.5	22.7	-	-	-	-
7/12/70	90.3	64.5	57.9	38.5	0	0	1.03	0.62
7/19/70	82.0	62.7	32.1	17.1	20.7	12.5	0.76	0.31
7/26/70	82.4	60.8	35.9	26.1	12.3	8.6	0.65	0.47
8/2/70	102.3	72.2	38.9	27.1	35.9	23.0	1.56	0.33
8/9/70	87.6	69.7	18.7	12.9	28.5	21.7	0.99	0.16
8/16/70	91.0	71.2	18.5	13.1	14.6	8.6	0.38	0.16
8/23/70	70.5	46.0	21.8	15.1	9.2	7.1	0.51	0.26
8/30/70	99.4	75.7	19.7	13.6	34.6	25.9	0.72	0.21
9/6/70	95.9	66.0	18.6	11.0	17.3	13.5	0.44	0.26
9/13/70	86.1	64.1	23.1	15.8	27.2	21.5	0.65	0.27
9/20/70	92.5	72.0	20.0	15.9	23.6	19.0	0.54	0.23
9/27/70	89.9	70.8	22.2	17.2	26.2	21.1	0.54	0.27
10/4/70	86.2	22.1	15.3	15.3	67.3	47.4	0.88	0.47
10/11/70	124.8	93.3	35.7	24.4	67.8	45.5	1.28	0.57
10/18/70	99.3	61.2	29.5	17.6	98.5	64.1	1.72	0.66
10/25/70	80.4	61.3	67.9	38.1	-	-	-	-
11/1/70	91.7	60.6	29.0	25.3	4.5	3.1	0.44	0.21
11/8/70	69.5	53.4	40.6	27.9	33.1	24.3	1.02	0.57
11/15/70	91.7	58.2	12.9	6.2	14.0	10.2	0.28	0.13

2. There was nitrification which accounted for some of the extra oxygen. It should benoted that about 4.6 lbs. of oxygen is required to convert 1 lb. of nitrogen to nitrate.

3. Leakages were found at various times during the operation and Table 13 shows that it amounted to 8 to 20 percent of the oxygen required by COD balance (assuming COD = 1.4 volatile suspended solids because COD analysis of the waste sludge was not done).

Table 12 shows consumption ratio on the basis of applied BOD and COD. Table 13 shows that oxygen supplied was more than required by theoretical calculation using a COD balance. It can be seen from Table 12 that as the study progressed, the oxygen requirement decreased. This was due to the fact that the endogenous respiration decreased and nitrification decreased with decreasing temperature.

Clarifier Performance

The purpose of this section of this report is to present, in a nut shell, a detailed report of the clarifiers that were employed with the oxygen activated sludge system.

Initially, a peripheral feed clarifier was used. The clarifier influent entered the influent channel at one point and was directed one way all around the clarifier to distribute the flow. However, since some flow is immediately introduced into the clarifier upon entering the influent channel, while some of the flow had to go all the way around the clarifier in the influent channel before entering the clarifier, the hydraulic distribution through the clarifier is likely to be uneven. This will result in poor clarification which was observed in the first two phases of operation when this clarifier was used.

When the clarifier was converted to a centerfeed, the clarification improved as evidenced by the decrease in the effluent suspended solids concentration in the last three phases of operation covered in this report.

The initial clarifier design necessitated a baffle that extended 70 inches below the weir all around the clarifier as shown in Figure 2. When the clarifier was modified, this baffle was left in place with the result that the area available for upflow (in the clarification zone) was only 78 square feet while the total area of the clarifier was 107 square feet. This reduction in clarification area means that the average flow rates were 1000 to 1300 GPDPSF in the clarification zone. During periods of diurnal flow variations, a peak overflow rate of 1940 GPDPSF was sustained for 2 hours and 1700 GPDPSF was sustained for 10 hours. Even at these high overflow rates, the average effluent suspended solids were 24, 33, and 34 mg/l respectively, during phases III, IV and V.

TABLE 12
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
OXYGEN CONSUMPTION

Date (Week of)	Lb O_2/lb BOD_A	Lb O_2/lb COD_A
7/5/70	2.19	0.60
7/12/70	1.77	0.72
7/19/70	2.06	
7/26/70	2.38	
8/2/70	2.85	0.90
8/9/70	2.98	0.98
8/16/70	1.90	0.76
8/23/70	2.39	0.76
8/30/70	2.12	0.74
9/6/70	2.03	0.88
9/13/70	2.15	0.82
9/20/70	2.23	0.89
9/27/70	1.89	0.84
10/4/70	1.65	0.70
10/11/70	1.79	0.69
10/18/70	1.61	0.55
10/25/70	1.16	0.43
11/1/70	1.30	0.55
11/8/70	1.16	0.53
11/15/70	1.32	0.56

TABLE 13
Pure O_2 System
Blue Plains Waste Treatment Plant
Oxygen Usage Compared to COD Balance

Operating Period Month Dates	1 June 12-30	2 July	3 August 1-25	4 September	5 October 3-21	6 November 10-30
Influent COD, lb./million gal.	2080	2030	2040	2090	2370	2290
Effluent COD, lb./million gal.	375	584	408	430	425	525
Waste COD, lb./million gal.	188+	42+	150+	217+	630+	247
Removed COD, lb./million gal.	1517	1404	1482	1443	1315	1518
Nitrate Demand, lb./million gal.	14	69	128	160	100	18
Exhaust Oxygen, lb./million gal.	85	54	75	85*	87	85*
Effluent D.O., lb./million gal.	10*	10*	10	10	10	10*
Total	1625	1537	1695	1698	1512	1631
Oxygen Supplied, lb./million gal.	1750	1825	1775	1900	1650	±

\+ COD = 1.4 volatile solids

* Estimate

± Inlet meter malfunctioned

@ Increase sampling and greater losses of O_2 through sample ports

TABLE 14
PURE OXYGEN SYSTEM
BLUE PLAINS WASTE TREATMENT PLANT
DIURNAL FLOW OPERATION

Flow Rate GPD	Flow Duration Hrs/Day	Oxygenation Time Hrs.	Clarifier Overflow Rate gal/sq.ft/day	Clarifier Mass Loading lb/sq.ft/day	Clarifier Retention Time Hrs.
65,000	7	2.99	830	43	2.6
108,000	5	1.80	1380	72	1.6
151,000	2	1.29	1940	101	1.15
130,000	10	1.50	1670	87	1.31

Subsequent operation of the pilot plant which will be reported on separately soon, showed that at more conventional overflow rates (700 gpdpsf average and 1100 gpdpsf maximum) a suspended solids effluent concentration below 20 mg/l can be consistently maintained. This has been documented in the paper presented by J. B. Stamberg, D. F. Bishop, and G. W. Kumke. (14)

The total clarifier area (107 sq. ft.) was used to compute the solids loading in the clarifier. The loadings varied from 40 to 60 lbs. per day per square foot at average condition with peak loads of 70 to 90 lbs. solids per day per square foot.

Clarifier underflow concentrations averaged 1.4 percent solids normally and increased to 2.2 percent during the period of alum addition. Subsequent operation of this pilot plant at lower overflow rates have shown clarifier underflow concentrations of 2.0 to 2.7 percent as reported by John B. Stamberg, et al (13).

These results show the excellent solid-liquid separation characteristics of the pure oxygen system. As a result, the mixed liquor suspended solids of 5000 to 7000 mg/l were maintained. Further work is in progress to evaluate the effect that temperature may have on solid-liquid separation.

SECTION VI

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SECTION VII

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16. Abstract

The oxygen activated sludge system (UNOX) consisted of a unique, four stage, gas tight biological reactor that employed co-current gas-liquid contacting. In less than 1.85 hours of oxygenation, the system removed 90 percent of the influent BOD_5 and utilized over 95 percent of the supplied oxygen. The microbial organisms visually were essentially the same as those found in a typical conventional system. Their rate of activity, however, was greater than those of the air system. Satisfactory solid-liquid separation was achieved at clarifier overflow rates varying between 300 and 1940 gallons per day per square foot. The clarifier underflow concentrations varied from 1.0 to 2.4 percent and mixed liquor suspended solids were maintained between 4000 and 7600 mg/l. Solids production averaged between 0.2 and 0.5 lb. solids wasted per lb. BOD removed.

17a. Descriptors

* Oxygen Requirements
Activated Sludge
Micro-organism
BOD Sedimentation Rates
* Dissolved Oxygen

17b Identifiers

* Oxygen Activated Sludge
Plug Flow Reactor
Mixed Liquor
Alum Addition
Phosphorus Removal
Endogenous Respiration
Sludge Production

17c. COWRR Field & Group 05D

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