United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-81-095 July 1981

EPA

Project Summary

Feasibility Study of Open Tank Oxygen Activated Sludge Wastewater Treatment

Kerwin R Rakness

The pilot plant for this study consisted of one oxygenation basin and two clarifiers capable of treating 151 L/min (40 gpm). The system treated primary effluent from the Englewood, Colorado, municipal wastewater treatment facility. The influent flow rate was adjusted to attain average aeration reactor detention times ranging from 0.94 to 3.3 hr. The pilot plant operation was conducted in two phases. Treatment performance during both phases was excellent. Final effluent BOD_5 concentrations and secondary BOD_5 removals averaged less than 20 mg/L and greater than 90 percent, respectively. No degradation in process removal efficiency occurred, even at organic loadings as high as 1.23 kg BOD_5 applied/day/kg MLVSS (1.23 lb BOD_5 applied/day/lb MLVSS) and volumetric loadings as high as 4.07 kg BOD_5 applied/day/m^3 (254 lb BOD_5 applied/day/1000 ft^3) of reactor capacity.

Analysis of pilot plant operations indicated that somewhat less sludge was produced with the oxygen system when compared with literature-cited, typical air sludge production. This decreased sludge production occurred and became more pronounced at higher organic loadings.

Comparisons were made between literature-cited, typical air-sludge and oxygen-sludge settling characteristics. In all cases, the oxygen-sludge initial settling velocity was greater than typical air sludge at given TSS concentrations.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The investigation of high purity oxygen for wastewater treatment was originally conducted by Okun in 1948. No significant further development was conducted until the late 1960's when a "closed tank" oxygenation process was developed. The closed tank process demonstrated that oxygen activated sludge treatment was feasible and economically attractive when compared with a parallel operated air activated sludge system. Two of the reasons for the attractiveness of the closed tank process were (1) its ability to treat wastewater with smaller aeration reactors than required for air systems and (2) its ability to achieve high (90 percent) oxygen utilization efficiencies.

There are many reasons why an "open tank" oxygenation system would be attractive: (1) extensive safety precautions are required with the closed tank system, (2) extra expense is involved in covering and sealing an aeration reactor as well as a requirement for 0.9 to 1.5 m (3 to 5 ft) of freeboard, (3) other high purity oxygen activated sludge treatment systems have been shown to be feasible and economically attractive at high oxygen utilization efficiencies, and (4) existing aeration basins may be easily converted to oxygen systems in an open tank concept.

To date, there is one known open tank high purity oxygen activated sludge system on the market, MAROX,* marketed by Zimpro Inc. The MAROX system was originally developed by FMC Corporation, but Zimpro has subsequently acquired the rights to the technology. The basis for performance of the MAROX system is an ultra fine bubble diffuser that achieves oxygen utilization efficiencies comparable with those obtained with closed tank reactor systems.

The MAROX system uses a unique bubble shear method for dissolution of pure oxygen to the mixed liquor. The fixed active diffuser hardware used in this project has two gas bars adjacent to each slot that emitted oxygen through very small capillaries where a high velocity mixed liquor stream sheared the bubbles on formation into 50μ- to 100μ-diameter gas bubbles.

Testing was completed using a pilot plant facility capable of treating secondary influent (primary effluent) flowrates up to 151 L/min (40 gpm). Seconday influent (SI) to the pilot plant was obtained from the primary treatment process of the Englewood facility. During the testing period, one oxygenation basin and either one or two clarifiers were in service. The program plan with both constant flow and the maximum-minimum diurnal flow conditions are shown in Table 1. Diurnal flow variations were selected based on the historical raw wastewater flow at the Englewood facility. The program was divided into two phases with the latter phase using a broader range of operational controls and monitoring.

Further information concerning open tank oxygen activated systems can be found in the EPA project report "Full-Scale Demonstration of Open Tank Oxygen Activated Sludge Treatment" (EPA-600/2-79-012). The follow-on, full-scale demonstration project used a rotating active diffuser, which in general required less power than the fixed active diffuser used in this project. The rotating active diffuser has supplanted the fixed active diffuser as the standard oxygen transfer device in the MAROX open tank oxygen system.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Results and Conclusions

The MAROX oxygen pilot plant provided data that led to the following conclusions:

1. Final effluent (FE) BOD_5 concentrations averaged less than 20 mg/L, even at average volumetric loadings as high as 4.07 kg BOD_5 applied/day/m^3 (254 lb BOD_5 applied/day/1000 ft^3) of oxygenation basin capacity and maximum organic loadings of 1.23 mass BOD_5 applied/day/mass mixed liquor volatile suspended solids (MLVSS).
2. Better effluent quality was attained by operating at return flow/influent flow (R/Q) ratios between 50 and 60 percent as opposed to R/Q between 30 and 40 percent.
3. No significant nitrification occurred during the test program; oxygenation basin detention times ranged from 0.94 to 3.3 hr.
4. Excellent oxygen feed control response was achieved using a dissolved oxygen (D.O.) monitoring and control system to vary oxygen supply rate.
5. Oxygen utilization efficiencies averaged 91.5 and 92.5 percent during two separate oxygenation basin "off-gas" tests.
6. Oxygen-sludge mixed liquor suspended solids (MLSS) initial settling velocities were greater than literature-cited, air-sludge settling velocities at specific total suspended solids (TSS) concentrations.
7. Oxygen-sludge production values were somewhat lower than most literature-cited, air-sludge production values.

Recommendations

The following recommendations are made from the results of the MAROX pilot plant operation. For oxygen utilization efficiency verification in an "open" oxygenation basin, the following approach is recommended for activated sludge systems. (1) Compare the ratio of mass of oxygen supplied per mass of BOD_5 removed with expected ratios. If the calculated ratio is equal to or less than the expected ratio, then the oxygen utilization efficiency is acceptable. If the calculated ratio is greater than the expected ratio, then the oxygen utilization efficiency may not be acceptable and further verification testing is required. (2) An accurate oxygen utilization efficiency can be determined by using a cap or cover on all or a portion of the surface area of the oxygenation basin and conducting an off-gas analysis. Other indirect methods for obtaining mass of oxygen used are not acceptable alternatives

Discussion of Results

Phase I

The Phase I experimental program consisted of the first three test conditions identified in Table 1. Monitoring and operating results obtained during Phase I are shown in Tables 2 and 3, respectively. Most data listed in Table 2 are self-explanatory. Raw wastewater BOD_5 and TSS concentration values are Englewood laboratory results for the raw wastewater entering the treatment facility.

Phase I process removal efficiencies were satisfactory despite limited operational controls and low primary clarifier TSS removal efficiencies. MAROX secondary BOD_5 removal efficiencies ranged from 89.8 to 94.3 percent with TSS removal efficiencies from 78 8 to 87.7 percent. Primary treatment BOD_5 removal efficiencies were in an expected range of 21.8 to 40 percent. Primary treatment TSS removal efficiencies were much lower than expected, ranging from a negative 17 percent to a positive 21 percent. The low primary TSS removal efficiencies may be attributed to higher than desired TSS concentrations of various Englewood inplant recycle flows, namely anaerobic digester supernatant, and may have adversely affected the final effluent quality.

Final effluent during Phase I had BOD_5 concentrations less than 17 mg/L and TSS concentrations less than 27 mg/L. The slightly higher TSS values apparently were composed of inert suspended solids not captured in the final clarifier. The final effluent probably contained more inert suspended solids than normal because of (1) a long sludge detention time in the clarifier (2.0 to 3.9 hr), which contributed to degradation of mixed liquor quality and (2) a high concentration of anaerobic digester supernatant solids in the SI flow Degradation of mixed liquor quality was demonstrated by its poorer ability to capture solids in the clarifier. The long sludge detention time in the clarifier was caused by a lower return sludge flow rate than was established in Phase II. The excellent settling characteristics of the mixed liquor (SVI ranged from 65.9 to 81.5 ml/g) did not result in a clean-

Table 1. *Program Plan Operating Conditions*

Test No.	Average Daily Flow (L/min)[d]	Flow Condition	Maximum Daily Flow (L/min)	Minimum Daily Flow (L/min)	Reactor[a] Detention (hr)	Clar. No.	Clarifier[b] Overflow Rate ($m^3/day/m^2$)[e]	Clarifier[c] Overflow Rate ($m^3/day/m^2$)
1	37.8	Constant			3.30	1	15.2	16.7
2	37 8	Diurnal	47.3	22.7	3 30	1	15.2	16.7
3	56.7	Constant			2.20	1	22.9	25.1
4	75.8	Diurnal	102.0	45.5	1.65	1	30.5	33.5
5	94.5	Constant			1.32	2	19.1	21.0
6	113.5	Dirunal	133.5	75.8	1.10	2	22.9	25.1
7	132.5	Constant			0 94	2	26.7	29 3

[a]*Based on average daily SI flow.*
[b]*Includes clarifier centerwell.*
[c]*Excludes clarifier centerwell.*
[d]*L/min × 0.264 = gpm*
[e]*$m^3/day/m^2$ × 24.5 = gpd/ft^2*

Table 2. *Monitoring Results - Phase I*

Parameters	Run 1	Run 2	Run 3
Operating conditions			
Average SI flow, L/min	37.8	37.8	56.7
(gpm)	(10)	(10)	(15)
Flow pattern	Constant	Diurnal	Constant
Run length, days	47	25	54
Wastewater temperature, °C	22	20	13
BOD_5 data			
Raw wastewater, mg/L	183	179	245
SI, mg/L	131	140	147
Primary removal, %	18.4	21.8	40.0
FE, mg/L	10	8	16
Secondary removal, %	92.4	94.3	89.8
Primary plus secondary removal, %	94.5	95.5	93.5
Oxygen supplied, mass O_2/mass BOD_R	2.30	2.60	1.17
TSS data			
Raw wastewater, mg/L	197	153	157
SI, mg/L	187	179	124
Primary removal, %	5.1	17*	21
FE, mg/L	19	21	26
Secondary removal, %	84.4	87.7	78.8
Primary plus secondary removal, %	90.4	86.3	83.4

**This indicates an increase of 17%.*

sweeping sludge. If the R/Q ratio had been increased, the lower sludge detention time in the clarifier might have improved the mixed liquor quality.

During all periods of Phase I operation, manual D.O control was provided. The average D.O. concentration of the mixed liquor in each pass of the oxygenation basin was higher than desired during the first two Phase I tests During the last part of Phase I, the average D.O. concentration of the mixed liquor was in the desired range. In parts of Phase I operation, the mass of oxygen supplied per mass of BOD_5 removed was larger than expected because of higher than desired mixed liquor D.O. concentrations.

Phase I pilot plant operation demonstrated that the MAROX system can be satisfactorily operated at high MLVSS concentrations, high return sludge TSS concentrations, and long mean cell residence times (Table 3).

Phase II

The experimental program for Phase II included the last four test conditions cited in Table 1 plus reruns of test conditions Nos. 1 and 3. Monitoring and operating results obtained during Phase II are presented in Tables 4 and 5, respectively. All six periods of operation during Phase II demonstrated excellent BOD_5 and TSS removals. Final effluent BOD_5 and TSS concentrations ranged from 14 to 18 mg/L and from 11 to 15 mg/L, respectively.

Primary treatment BOD_5 and TSS removal efficiencies were acceptable, ranging from 13.1 to 39.7 percent and from 16 to 63.5 percent, respectively. The low primary TSS removal efficiency of 16 percent is attributed to anaerobic digester supernatant recycle flow The final effluent TSS concentration, however, was much improved over the Phase I overall final effluent TSS concentration Two reasons contributed to the better effluent quality during this period (1) operation at higher R/Q ratios and (2) lower sludge detention time in the clarifier. The R/Q ratio and clarifier sludge detention time were 50 percent and 1 hr, respectively During Phase I, these same parameters were approximately 40 percent and 3 hr.

During the 95-L/min (25-gpm) flow condition, the secondary influent TSS concentration was lower than the overall values for Phase I. The lower secondary influent TSS concentration may have contributed to the final effluent TSS concentration of 13 mg/L. In all but two periods of Phase II (37.8 L/min (10 gpm) and 56 7 L/min (15 gpm)), the sludge detention time in the clarifier was less than 1.4 hr. In these two periods, however, the sludge detention time in the clarifier was 3.3 and 2.5 hr, with SVI values of 204 ml/g and 184 ml, respectively Although the settling characteristics were poorer than desired, the final effluent quality did not deteriorate (12 and 14 mg/L TSS, respectively). Sludge in these two periods was clean-sweeping, even though

Table 3. Operating Results - Phase I

Parameters	Run 1	Run 2	Run 3
Operating conditions			
Average SI flow, L/min	37.8	37.8	56.7
(gpm)	(10)	(10)	(15)
Flow pattern	Constant	Diurnal	Constant
Run length, days	47	25	54
Volumetric loading, kg BOD_5/m^3/day	0.96	1.03	1.71
(lb BOD_5/1000 ft^3/day)	(60)	(64)	(107)
Aerator detention time (Q), hr	3.3	3.3	2.2
Sludge detention time-aerator (Q+R), hr	2.4	2.3	1.6
RAS[a] flow, L/min	14.8	16.7	20.8
(gpm)	(3.9)	(4.4)	(5.5)
R/Q ratio, %	39.4	43.6	36.4
Sludge detention time-clarifier (Q+R), hr	2.0	3.9	2.8
Clarifier mass loading, kg TSS/day/m^3	161	220	152
(lb TSS/day/ft^3)	(33.0)	(45.0)	(31.2)
Overflow rate[b], m^3/day/m^2	15.2	15.2	22.7
(gpd/ft^2)	(374)	(374)	(561)
Overflow rate[c], m^3/day/m^2	16.7	16.7	25.1
(gpd/ft^2)	(411)	(411)	(617)
Sludge age[d], days	13.9	13.0	3.3
Mean cell residence time, days	25.6	27.8	7.1
Sludge synthesis, mass excess VSS/ mass BOD_5 removed	0.44	0.57	0.77
F/M ratio, mass BOD_5/mass MLSS/day	0.18	0.15	0.46
Oxygen data			
Pass A mixed liquor DO, mg/L	9.3	9.1	3.7
Pass B mixed liquor DO, mg/L	9.5	10.1	3.6
Pass C mixed liquor DO, mg/L	8.0	10.5	4.3
Final effluent DO, mg/L	4.1	5.7	1.8
Solids data			
MLSS, mg/L	7,488	10,206	4,877
MLVSS, mg/L	5,390	7,111	3,870
MLVSS/MLSS ratio, %	72.0	69.7	79.4
RAS TSS, mg/L	26,755	24,448	14,139
RAS VSS, mg/L	19,325	17,234	10,951
RASVSS/RASTSS ratio, %	72.2	70.5	77.5
SVI, ml/gm	65.9	67.7	81.5

[a]RAS = return activated sludge
[b]Includes clarifier centerwell.
[c]Excludes clarifier centerwell.
[d]Based on TSS in secondary influent.

its settling rate was not as good. The sludge settling characteristics of the other four periods were excellent with SVI's ranging from 67.8 to 74.5 ml/g.

During Phase II, the automatic oxygen controller was in operation and performed very effectively. The D.O. concentration of the mixed liquor in each pass was within the satisfactory range of 1 to 4 mg/L. The mass of oxygen supplied per mass of BOD_5 removed varied from 0.92 to 1.49.

Results of the total nitrogen series analyses indicate that no significant nitrification occurred during Phase II. Limited TKN and NH_3-N removals were observed. Results of organic analyses indicated that the relationship of final effluent COD to final effluent BOD_5 was very erratic. The final effluent COD concentration ranged from 48 to 94 mg/L, whereas the final effluent BOD_5 concentration ranged from 14 to 18 mg/L. The final effluent turbidity test results were low and consistently ranged from 4.4 to 6.3 JTU.

No significant decrease in pH occurred between the SI and FE during Phase II. It is apparent that most of the CO_2 produced during the biological reaction was removed from the system in a manner that did not significantly decrease the pH of the final effluent.

System Evaluation

The average final effluent BOD_5 concentration for each test condition never exceeded 20 mg/L. Primary treatment removals showed wide variations; however, primary plus secondary BOD_5 removals always exceeded 90 percent. The TSS concentration of the FE never exceeded 30 mg/L during Phase I, nor 20 mg/L during Phase II. Primary removal efficiencies exhibited wide varia-

Table 4. Monitoring Results - Phase II

Parameters	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Operating conditions						
Average SI flow, L/min	37.8	56.7	75.8	94.5	113.5	132.5
(gpm)	(10)	(15)	(20)	(25)	(30)	(35)
Flow pattern	Constant	Constant	Diurnal	Constant	Diurnal	Constant
Run length, days	30	31	31	23	30	31
Wastewater temperature, °C	18.1	19.5	21.5	14.6	19.0	16.8
SI pH	6.8	6.9	6.9	7.0	6.9	7.0
FE pH	6.7	6.9	6.9	6.9	6.9	6.9
FE turbidity, JTU	4.7	4.6	5.1	5.6	4.4	6.3
BOD_5 and COD data						
Raw wastewater BOD_5, mg/L	282	292	289	191	297	262
SI BOD_5, mg/L	212	210	208	166	179	159
Primary BOD_5 removal, %	24.8	28.1	17.6	13.1	39.7	39.3
FE BOD_5, mg/L	15	16	16	14	16	18
Secondary BOD_5 removal, %	92.9	92.4	92.3	91.6	91.1	88.7
Primary plus secondary BOD_5 removal, %	9.47	94.5	94.5	92.7	94.6	93.1
Oxygen supplied, mass O_2/mass BOD_R	1.49	1.32	1.08	1.17	0.92	1.08
SI COD, mg/L	396	345	321	332	259	305
FE COD, mg/L	48	48	61	95	57	74
COD removal, %	87.9	85.5	80.1	70.9	77.6	75.7
TSS data						
Raw wastewater, mg/L	205	202	175	131	233	200
SI, mg/L	134	119	115	110	85	85
Primary removal, %	34.6	41.1	34.3	16.0	63.5	57.5
FE, mg/L	12	14	15	13	11	15
Secondary removal, %	91.4	86.7	85.6	87.7	85.8	81.4
Primary plus secondary removal, %	94.1	93.1	91.4	90.1	95.3	92.5
Nitrogen data						
SI TKN, mg/L	31	27	27	36	29	26
FE TKN, mg/L	20	13	12	28	23	21
TKN removal, %	34.2	51.9	55.6	27.8	20.7	19.2
SI NH_3-N, mg/L	18	19	18	29	21	18
FE NH_3-N, mg/L	16	16	15	22	19	15
NH_3-N removal, %	10.6	15.8	16.7	24.1	9.5	16.7
SI NO_2-N + NO_3-N, mg/L	0.25	0.1	0.1	0.1	0.5	0.1
FE NO_2-N + NO_3-N, mg/L	0.25	0.15	0.15	0.15	1.3	0.16

tions, even including a negative TSS removal. Primary plus secondary TSS removal efficiencies were greater than 80 percent during Phase I and greater than 90 percent during Phase II.

During the study, the pilot facility was operated under a wide range of loading conditions. The BOD_5 substrate removal rate related to the F/M ratio for both phases is depicted in Figure 1. The graph was developed using weekly average test results for all test conditions. The straight-line relationship of the graph illustrates that no degradation in process BOD_5 removal efficiency existed even at the higher F/M ratios. The slope of the line indicated that on the average for all tests, 90.2 percent of the BOD_5 applied to the system was removed.

Table 5. Operating Results - Phase II

Parameters	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Operating conditions						
Average SI flow, L/min	37.8	56.7	75.8	94.5	113.5	132.5
(gpm)	(10)	(15)	(20)	(25)	(30)	(35)
Flow pattern	Constant	Constant	Diurnal	Constant	Diurnal	Constant
Run length, days	30	31	31	23	30	31
Volumetric loading, kg BOD_5/m^3/day	1.54	2.31	3.04	3.03	3.91	4.07
(lb BOD_5/1000 ft^3/day)	(96)	(144)	(190)	(189)	(244)	(254)
Aerator detention time (Q), hr	3.3	2.2	1.6	1.3	1.1	0.94
Sludge detention time-aerator (Q+R), hr	2.12	1.40	1.10	0.83	0.70	0.62
RAS[a] flow, L/min	20.6	30.2	37.8	56.7	64.6	69.2
(gpm)	(5.45)	(8.0)	(10.0)	(15.0)	(17.1)	(18.3)
R/Q ratio, %	54.5	53.3	50.1	60.0	57.0	52.3
Sludge detention time-clarifier (Q+R), hr	3.3	2.5	1.4	1.0	1.4	1.5
Clarifier mass loading, kg TSS/day/m^3	112	181	181	156	171	161
(lb TSS/day/ft^3)	(23)	(37)	(37)	(32)	(35)	(33)
Overflow rate[b], m^3/day/m^2	15.2	22.9	30.5	19.1	15.2	26.7
(gpd/ft^2)	(374)	(561)	(748)	(468)	(561)	(655)
Overflow rate[c], m^3/day/m^2	16.7	25.1	33.5	20.9	25.1	29.3
(gpd/ft^2)	(411)	(617)	(822)	(514)	(617)	(720)
Sludge age[d], days	4.5	3.2	2.6	2.0	2.2	1.5
Mean cell residence time, days	11.2	8.3	5.8	4.1	6.2	4.9
Sludge synthesis, mass excess VSS/ mass BOD_5 removed	0.61	0.60	0.46	0.74	0.50	0.61
F/M ratio, mass BOD_5/mass MLSS/day	0.39	0.57	0.95	0.77	1.02	1.23
Oxygen data						
Pass A mixed liquor DO, mg/L	3.0	3.5	1.7	3.8	3.7	4.4
Pass B mixed liquor DO, mg/L	2.7	4.2	2.3	4.0	5.2	4.5
Pass C mixed liquor DO, mg/L	3.1	4.5	3.9	4.8	4.4	6.1
Final effluent DO, mg/L	1.2	1.2	1.0	0.6	1.3	1.3
Solids data						
MLSS, mg/L	4,750	5,089	3,962	5,122	4,743	4,028
MLVSS, mg/L	3,952	4,044	3,361	4,008	3,886	3,436
MLVSS/MLSS ratio, %	83.2	79.5	84.8	78.4	81.9	85.3
RAS TSS, mg/L	13,103	13,131	10,850	11,583	12,221	10,487
RAS VSS, mg/L	10,842	10,390	9,080	9,078	9,820	8,695
RASVSS/RASTSS ratio, %	82.7	79.1	83.7	78.4	80.4	82.9
SVI, ml/gm	204	184	74.5	71.5	67.8	72.4

[a]RAS = return activated sludge
[b]Includes clarifier centerwell.
[c]Excludes clarifier centerwell.
[d]Based on TSS in secondary influent.

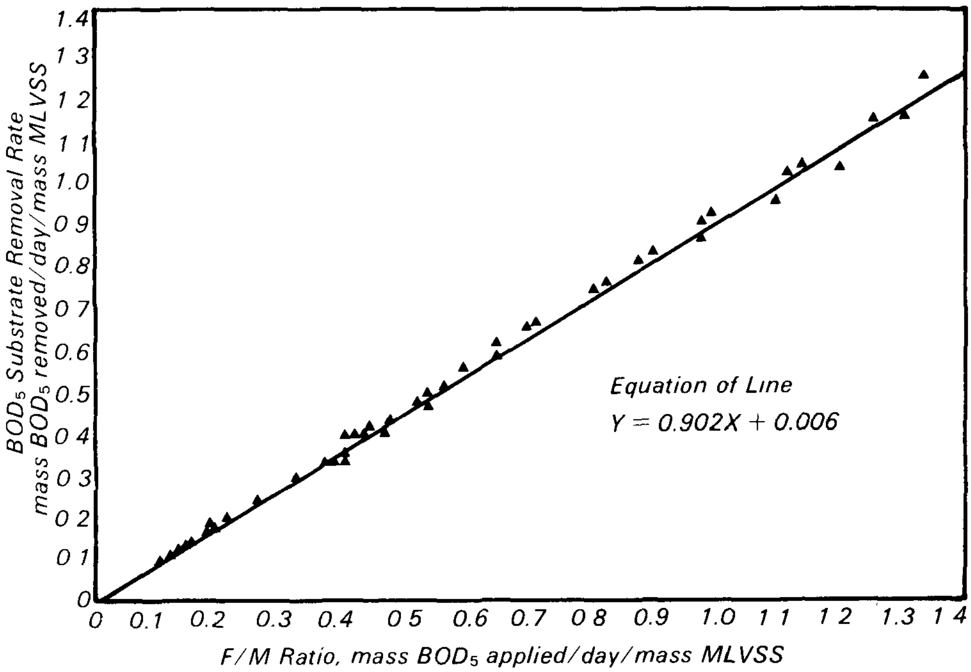

Figure 1. BOD substrate removal rate versus F/M ratio.

Kerwin R Rakness, at the time of this project, was with FMC Corporation, Englewood, CO 80110; he is now with M&I Consulting Engineers, Fort Collins, CO 80525

Richard C. Brenner is the EPA Project Officer (see below)

The complete report, entitled "Feasibility Study of Open Tank Oxygen-Activated Sludge Wastewater Treatment," (Order No. PB 81-213 274; Cost: $8.00, subject to change) will be available only from.

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Municipal Environmental Research Laboratory
U.S Environmental Protection Agency
Cincinnati, OH 45268

U S GOVERNMENT PRINTING OFFICE 1981 757-012/7249

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

RETURN POSTAGE GUARANTEED

Third-Class
Bulk Rate

MERL0063240
LOU W TILLEY
REGION V EPA
LIBRARIAN
230 S DEARBORN ST
CHICAGO IL 60604