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Project Summary

Parallel Evaluation of Air- and Oxygen-Activated Sludge

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To provide data on the relative merits of air and of oxygen in the activated sludge process, two 1,900-m^3/day (0.5-mgd) activated sludge pilot plants, one air and one oxygen system, were operated side-by-side at the Joint Water Pollution Control Plant, Carson, California. Although both pilot plants met the applicable discharge limitations for everything but three trace metals, the oxygen system provided a more stable operation.

Primary differences in performance concerned ammonia nitrogen removals. Calculated differences in energy consumption indicate a savings might be expected with the oxygen system. Differences in sludge production were not significant.

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

Since the introduction of high-purity, oxygen-activated sludge, a controversy has existed concerning the relative merits of air and of oxygen in the activated sludge process. Very little data, however, were available on side-by-side operation of relatively large-scale systems with comparable engineering.

As part of the research effort involved with federally-mandated secondary treatment at the Joint Water Pollution Control Plant (JWPCP) in Carson, California, the County Sanitation Districts of Los Angeles County constructed two 1,900-m^3/day (0.5-mgd) activated sludge demonstration plants. One incorporated the UNOX high-purity oxygen process, and one used an air-sparged mechanical aerator. The primary purpose of the study was to obtain data pertinent to the selection and design of an activated sludge system at the JWPCP, but the nature of the research facilities allowed a direct comparison of the two activated sludge processes. The pilot plants were operated on identical feed. Equal engineering care was taken in the design of the aeration system, and identical clarifiers were used. The research motivations in establishing the operating parameters for the two plants were different: the oxygen system was operated to refine specified design parameters, whereas the air system was operated to determine its capabilities and limitations.

The JWPCP is a 15-m^3/sec (350-mgd) primary treatment plant treating a *mixture of domestic and industrial* wastes. This facility allowed a good comparison of the two activated sludge alternatives for treating relatively concentrated municipal wastewater.

Selection and Description of the Pilot Plants

Air-Sparged Turbine System

Locating the Districts' JWPCP in an urban area placed a definite land constraint on the proposed secondary treatment system for that plant. When preliminary site layouts were made for a conventional activated sludge system with the standard 4.6-m (15-ft) deep aeration tanks and an optimistic 6-hr aeration period, no excess land was available for waste activated sludge processing. Because of this land constraint, the Sanitation Districts proceeded to evaluate activated sludge systems that could reduce the land area required for secondary treatment. One of those alternatives was the deep tank submerged turbine (DTST) system. The DTST system was selected not only because of the land savings from the deeper tank (7.6 m or 26 ft) but also because the submerged turbine is a more efficient oxygen transfer device than the conventional coarse bubble air diffusers. The land savings from the deeper tank and the possibility of reducing the aeration period made the DTST system a realistic candidate system for secondary treatment at the JWPCP.

High-Purity Oxygen System

One of the major advantages offered by the pure oxygen biological treatment process is the ability to reduce the period of time required for treatment of wastewater by increasing the rate at which oxygen can be dissolved into the mixed liquor within the biological reactor. The results of preliminary studies using Union Carbide's 0.6-L/sec (10-gpm) mobile pilot plant verified this claim since acceptable effluent quality was achieved at aeration periods as short as 1.5 hr (V/Q).

As a result of competitive bidding, Union Carbide Corporation* constructed the pure oxygen biological reactor, which was to utilize the existing pilot plant influent pumping station and final clarifier system. The reactor was designed to incorporate a submerged turbine/gas recirculation compressor arrangement for oxygen dissolution in each reactor stage.

Table 1 compares the design criteria for the air-sparged system and the high-purity oxygen system as well as the associated final clarifiers. Tables 2 and 3 summarize the operational parameters for the air and oxygen systems, respectively.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency.

Table 1. *Design Criteria for Pilot Plants*

Item	*Air System*	*Oxygen System*
Biological Reactors:		
Average flow, m^3/day (mgd)	*1900 (0.5)*	*1900 (0.5)*
Length, m (ft)	*6.1 (20)*	*7.3 (24)*
Width, m (ft)	*6.1 (20)*	*7.3 (24)*
Average water depth, m (ft)	*7.6 (25)*	*3.7 (12)*
No. of stages	*1*	*4*
Detention time (V/Q), hr	*3.5*	*2.5*
Oxygen Storage Tank:		
Number	—	*1*
Volume, m^3 (ft^3) NTP	—	*9900 (350,000)*
Capacity, m^3/hr (ft^3/hr)	—	*140 (4940)*
	Standard	*Large*
Final Clarifiers:		
Number	*2*	*1*
Length, m (ft)	*22 (72)*	*34 (111)*
Width, m (ft)	*3.0 (10)*	*3.0 (10)*
Average water depth, m (ft)	*3.0 (10)*	*3.0 (10)*
Overflow rate, m^3/m^2/day (gpd/ft^2)	*28.5 (700)*	*18.3 (450)*
Detention time (Q × 1/3 return), hr	*2.0*	*3.0*
Weir loading rate, m^3/m/day (gpd/ft)	*62.1 (5000)*	*62.1 (5000)*
Flowthrough velocity (Q × 1/3 return), mm/sec (ft/min)	*3.2 (0.6)*	*3.2 (0.6)*

Discussion of Results

Effluent Quality

Activated sludge systems consist of two component units—the reactor and the final clarifier. The quality of the final effluent is related to the interaction of the component parts, and poor effluent quality may be caused by an inadequacy of only one part. The effluent quality of the air and oxygen systems is described in Tables 4 and 5.

Soluble BOD

A primary indicator of the adequacy of the reactor in terms of oxygen transfer and treating the wastewater is the removal of soluble organics. In all phases, for both pilot plants, the soluble BOD_5 concentrations were 6 mg/L or less. These BOD measurements are low enough that differences between the two systems are not considered significant.

Suspended Solids

Secondary effluent solids concentrations depend on the effectiveness of the final clarifier. High effluent suspended solids, however, may be an indication of poor clarifier design, poor aerator design, or poor plant operation. During startup, both 1,900-m^3/day (0.5-mgd) pilot plants experienced periods of high effluent suspended solids and turbidity, which were alleviated by reducing the power input to the final stages of the reactors.

Sludge Production

One of the most important claims made on behalf of pure oxygen is that the net growth of solids in these systems will be less than a similar air system when operated at the same mean cell residence time (MCRT). Since a large portion of the cost of wastewater treatment is usually associated with solids processing and sludge handling, this claim would represent a significant savings in both capital and operating costs. The claim is based on a comparison between the two systems that shows the net sludge production of air systems to be greater for any given organic loading rate than a similarly operated oxygen system.

From an analysis of the data collected both from this and an earlier, smaller-scale study, the Districts have concluded there is little difference between the air

Table. 2. *Summary of Operational Parameters—Air-Sparged Turbine System*

Parameter	Phase I	II	III	IV	V	VI	VII	VIII	IX
DATES:									
Start	2/9/75	3/9/75	4/6/75	5/11/75	7/20/75	9/28/75	10/26/75	11/27/75	3/4/76
End	3/1/75	3/29/75	5/3/75	6/21/75	8/30/75	10/25/75	11/20/75	12/25/75	3/25/76
Duration, days	21	21	29	42	42	28	26	29	22
Flow Pattern	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Steady
REACTOR:									
Influent Flow, m^3/day (mgd)	1200 (0.32)	1700 (0.45)	1700 (0.45)	1900 (0.50)	1700 (0.45)	1500 (0.40)	1500 (0.40)	1500 (0.40)	1300 (0.34)
Recycle, %	90	65	45	40	44	29	38	50	47
Hydraulic Detention Time:									
V/Q, hr	5.6	4.0	4.0	3.5	4.0	4.5	4.5	4.5	5.3
V/(Q×R), hr	2.9	2.4	2.8	2.5	2.8	3.5	3.3	3.0	3.6
MLSS, mg/L	3100	3400	2600	4000	2300	3300	3300	3600	2900
Volatility, %	72	73	74	73	73	70	71	70	70
Mean Cell Residence Time:									
Reactor Solids, days	5.1	3.7	2.2	3.7	1.8	3.0	3.2	3.4	3.6
Total System Solids, days	6.8	5.4	3.3	5.5	2.8	4.3	4.3	4.5	5.9
Organic Loading Rate:									
BOD_R/MLVSS, kg/kg/day	0.34	0.38	0.49	0.30	0.70	0.49	0.44	0.44	0.45
BOD_R/TPVSS, kg/kg/day	0.26	0.27	0.33	0.23	0.47	0.33	0.30	0.30	0.29
COD_R/MLVSS, kg/kg/day	0.80	1.07	1.30	0.90	1.61	1.16	1.00	1.00	1.10
COD_R/TPVSS, kg/kg/day	0.60	0.74	0.87	0.60	1.06	0.82	0.75	0.75	0.68
BOD_A, kg/m^3/day (lb/ft^3/day)	0.75 (12.0)	1.00 (16.0)	1.03 (16.5)	1.15 (18.4)	1.34 (21.5)	1.24 (19.9)	1.12 (17.9)	1.20 (19.2)	0.97 (15.5)
Sludge Production:									
VSS/BOD_R, kg/kg	0.51	0.64	0.79	0.73	0.70	0.56	0.63	0.63	0.60
VSS/COD_R, kg/kg	0.22	0.27	0.34	0.30	0.35	0.26	0.31	0.30	0.27
CLARIFIER:									
Overflow Rate, m^3/m^2/day (gpd/ft^2)	18.3 (450)	21.3 (523)	16.9 (415)	18.3 (450)	16.1 (395)	14.7 (361)	14.7 (361)	14.7 (361)	19.4 (476)
Dentention Time:									
V/Q, hr	4.0	2.8	4.3	4.1	4.5	5.0	5.0	5.0	3.6
V/(Q+R), hr	2.1	1.7	3.0	2.9	3.1	3.9	3.6	3.3	2.5
Solids Loading Rate, kg/m^3/day (lb/ft^3/day)	107 (1714)	117 (1874)	63 (1009)	103 (1650)	54 (865)	63 (1009)	68 (1089)	83 (1329)	83 (1329)
Return Sludge Concentration, %	0.7	0.9	0.9	0.9	0.9	1.2	1.1	1.1	0.9
SVI, ml/g	252	183	163	165	227	200	160	173	146

and oxygen systems in terms of sludge production. When an analysis of the system is made based on the mass of microorganisms contained within the biological reactor (which is the method used by proponents of pure oxygen), the data do indeed indicate that the oxygen systems produces less sludge. The authors believe, however, that the mass of solids within the entire biological system must be considered to obtain a true indication of the level of sludge production. This means that the solids present in the final clarifiers must be included when the total system solids are calculated. When the data are reexamined in this way, the oxygen system will no longer demonstrate an advantage over air systems in terms of sludge production. This reversal is because a greater portion of the total system solids will be contained within ıe clarifiers of an oxygen system than is typically encountered in air-activated sludge systems. Improved sludge settling and oxygen transfer capability allows the oxygen system to be operated as a high-rate system. As a result, as much as 50% of the total system solids will be carried in the final clarifiers. If the comparison of air and oxygen systems is based on reactor solids only, then a significant portion of the oxygen solid will be eliminated from the analysis, thus falsely indicating a higher organic loading rate than that imposed on the air system.

Sludge Settleability

Two parameters are commonly used to indicate sludge settleability. The sludge volume index (SVI) is the inverse of the settled sludge concentration expressed in ml/g, and the initial settling rate (ISR) is the maximum rate at which the sludge interface drops during the test.

ISR data are reported from one series of tests conducted during a period when the performance of both pilot plants was characterized as "good." In this series of tests, the oxygen sludge settled about three times as fast as the air sludge. Although these results are the product of limited testing, they are in qualitative agreement with the general operating experience of the JWPCP pilot plants.

The oxygen sludge definitely settled and gravity thickened better than the air sludge during this project. At this time, however, it's impossible to determine the extent to which this is an innate property of oxygen-activated sludge or a function of the reactor design.

One factor that affected the sludge settleability in both of these systems was power input. To produce an acceptable effluent during the startup of

Table 3. *Summary of Operational Parameters—Oxygen System*

Parameter	Phase I	II	III	IV	V	VI	VII	VIII	IX	X	XI
DATES:											
Start	9/22/75	10/27/75	12/1/75	2/1/76	2/18/76	3/31/76	6/21/76	9/30/76	10/28/76	11/9/75	12/10/76
End	9/25/75	11/10/75	12/30/75	2/17/76	2/29/76	5/20/76	9/14/76	10/13/76	11/7/76	11/24/76	12/23/76
Duration, days	4	15	30	17	12	51	85	14	11	16	14
Flow Pattern	Diurnal	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Dirunal	Dirunal	Diurnal
REACTOR:											
Influent Flow, m^3/day (mgd)	1900 (0.51)	1500 (0.40)	1400 (0 37)	1700 (0.45)	1900 (0.51)	1900 (0.51)	1800 (0.48)	1900 (0.51)	1900 (0.51)	1600 (0.43)	1600 (0.43)
Recycle, %	40	40	44	44	42	40	38	40	39	47	39
Hydraulic Detention Time:											
V/Q, hr	2.5	3 1	3.4	2.8	2.5	2.5	2.6	2.5	2.5	3.1	3.0
V/(Q+R), hr	1.8	2.2	2.3	1.9	1.6	1.8	1.9	1.8	1.8	2.1	2.2
MLSS, mg/L	3800	2800	4200	4600	3300	3900	4100	4420	3700	3990	3840
Volatility, %	75	73	74	72	75	74	77	75	70	70	77
Mean Cell Residence Time:											
Reactor Solids, days	1.8	2.5	3.4	1.9	1.7	1.9	2.7	2.1	2.0	3.0	2.8
Total System Solids, days	3.4	5.9	6.8	5.6	3 4	4.4	4.8	3.8	4.2	6.6	5.4
Organic Loading Rate:											
BOD_R/MLVSS, kg/kg/day	0.70	0 74	0.52	0.60	0.83	0.69	0.57	0.48	0.67	0.55	0.51
BOD_R/TPVSS, kg/kg/day	0.31	0.31	0.26	0.20	0 42	0.29	0.33	0.27	0.32	0.24	0.27
COD_R/MLVSS, kg/kg/day	1.67	1.52	1.14	1.31	1.61	1.54	1.15	0.95	1.46	1.07	1.05
COD_R/TPVSS, kg/kg/day	0.89	0.64	0.56	0 45	0.81	0.64	0.66	0.54	0.69	0.47	0.55
BOD_A, kg/m^3/day (lb/ft^3/day)	2.15 (34.4)	1.73 (27.7)	1.62 (25.9)	2.03 (32.5)	2.05 (32.8)	2.00 (32.0)	1.76 (28 2)	1.63 (26.1)	1.94 (31.0)	1.54 (24.6)	1.44 (23.0)
Oxygen Utilization:											
O_2/BOD_R, kg/kg	1.36	—	—	—	—	—	—	1.52	1.24	1.48	1.49
O_2/COD_R, kg/kg	0.71	—	—	—	—	—	—	0.81	0.69	0.71	0 70
Sludge Production:											
VSS/BOD_R, kg/kg	0.97	0.60	0.64	0.63	0.78	0.80	0.69	0.84	0.98	0.74	0.66
VSS/COD_R, kg/kg	0.48	0.29	0.28	0.29	0.40	0.36	0.33	0.42	0.38	0.38	0.37
CLARIFIER:											
Overflow Rate, m^3/m^2/day (gpd/ft^2)	18.7 (459)	23.2 (570)	21.2 (521)	25.4 (625)	28.4 (698)	27.9 (686)	27.5 (676)	18.1 (445)	28.4 (698)	23.3 (573)	23.2 (570)
Detention Time:											
V/Q, hr	3.7	3.0	3.3	2.8	2.4	2.5	2.5	3.8	2 5	2.9	2.9
V/(Q+R), hr	2.8	2.2	2.3	1.9	1.7	1.8	1.8	2.7	1.8	2.0	2.1
Weir Loading Rate, m^3/m/day (ft^3/ft/day)	79.1 (852)	62.6 (674)	52.2 (562)	68.9 (741)	77.0 (829)	101.2 (1089)	99.4 (1070)	101.5 (1092)	102.3 (1101)	84.2 (906)	85.8 (923)
Solids Loading Rate, kg/m^3/day (lb/ft^3/day)	98 (1568)	90 (1440)	127 (2032)	168 (2688)	134 (2144)	152 (2432)	141 (2256)	113 (1808)	147 (2352)	141 (2256)	126 (2016)
Return Sludge Concentration, %	1.05	1.06	1.40	1 54	1.18	1.36	1.22	1.34	0.88	0.99	0 94
SVI, ml/g	78	153	99	65	83	77	83	113	124	114	101

each pilot plant, the mixer power had to be reduced. Excessive power input shears the floc, which can cause poor settleability of the sludge and a turbid effluent.

Power Consumption

In the present economic climate, energy consumption is one of the most important factors involved in comparing the air and oxygen activated sludge processes. Since power intensity problems in both pilot plants required the aeration equipment to be operated at speeds lower than design, a comparison based on the pilot plant data is inappropriate. Additionally, because the effects of scale would be difficult to predict, estimates based on typical aerator efficiencies produce more applicable results.

The results of power consumption estimates made using the above ground rules indicate that the oxygen systems use substantially less energy. The surface aerator oxygen system, in fact, is estimated to require only 52% of the energy used by the air system, and the submerged turbine oxygen system, 62%. Because of land constraints at the JWPCP, aeration tank depths greater than 5 m (15 ft) would be required with an air system, so surface air aeration was not evaluated.

Conclusions

Both air- and oxygen-activated sludge systems can produce effluents meeting the JWPCP discharge limitations for everything but certain trace metals, which require source control. The oxygen system is somewhat more stable and flexible in its operation.

The two systems obtained good removals of soluble organics, and factors affecting solids separation in the final clarifier are most significant i terms of their effects on effluent quality The most notable detrimental factor encountered in the study were excessiv input of aerator power, which sheare the flocs in both systems, and nitrifica tion-denitrification, which caused th settled sludge from the air system t resuspend.

The major difference between the tw systems in terms of pollutant removal concerns ammonia nitrogen. The oxyge system did not nitrify. At the JWPCF where the ammonia discharge limitatio is high enough to impose no constrain this characteristic is an advantage i that it eliminates rising sludge resultin from nitrification-denitrification.

Claims have been made that oxygen activated sludge processes produce les sludge than air-activated sludg processes. In this study, the total plar solids were compared and the differen

Table 4. *Summary of Effluent Quality—Air Stream*

Parameters	*Phase*								
	I	*II*	*III*	*IV*	*V*	*VI*	*VII*	*VIII*	*IX*
Aeration Period (V/Q), hr	*5.6*	*4.0*	*4.0*	*3.5*	*4.0*	*4.5*	*4.5*	*4.5*	*5.3*
MCRT (Total System), days	*6.8*	*5.4*	*3.3*	*5.6*	*2.8*	*4.3*	*4.3*	*4.5*	*5.9*
Flow Pattern	*Steady*	*Steady*	*Steady*	*Steady*	*Steady*	*Steady*	*Steady*	*Steady*	*Steady*
Suspended Solids:									
Influent, mg/L	*167*	*179*	*167*	*170*	*204*	*204*	*165*	*216*	*177*
Effluent, mg/L	*89*	*80*	*67*	*22*	*110*	*36*	*37*	*54*	*29*
Removal, %	*47*	*55*	*60*	*87*	*46*	*82*	*78*	*75*	*84*
Total BOD_5:									
Influent, mg/L	*178*	*167*	*172*	*171*	*224*	*234*	*212*	*226*	*211*
Effluent, mg/L	*15*	*17*	*15*	*8*	*16*	*12*	*12*	*13*	*18*
Removal, %	*92*	*90*	*91*	*95*	*93*	*95*	*94*	*94*	*92*
Soluble BOD_5:									
Influent, mg/L	*118*	*102*	*98*	*101*	*126*	*132*	*129*	*109*	*119*
Effluent, mg/L	*2*	*3*	*3*	*4*	*5*	*4*	*2*	*2*	*2*
Removal, %	*98*	*97*	*97*	*96*	*96*	*97*	*98*	*98*	*98*
Total COD:									
Influent, mg/L	*458*	*447*	*453*	*460*	*513*	*556*	*483*	*515*	*517*
Effluent, mg/L	*118*	*152*	*130*	*77*	*191*	*91*	*92*	*111*	*84*
Removal, %	*74*	*66*	*71*	*83*	*63*	*84*	*81*	*78*	*84*
Soluble COD:									
Influent, mg/L	*262*	*247*	*234*	*241*	*265*	*257*	*270*	*256*	*282*
Effluent, mg/L	*49*	*56*	*59*	*56*	*72*	*57*	*55*	*48*	*54*
Removal, %	*81*	*77*	*75*	*77*	*73*	*78*	*80*	*81*	*81*
Grease (By Hexane Extraction):									
Influent, mg/L	*51*	*41*	*37*	*38*	—	—	—	—	—
Effluent, mg/L	*8*	*6*	*5*	*1*	—	—	—	—	—
Removal, %	*84*	*85*	*86*	*97*	—	—	—	—	—
Ammonia Nitrogen:									
Influent, mg/L	*35*	*32*	*35*	*35*	*31*	*36*	*33*	*34*	*38*
Effluent, mg/L	*14*	*20*	*28*	*32*	*28*	*32*	*28*	*32*	*31*
Removal, %	*60*	*38*	*20*	*9*	*10*	*11*	*15*	*6*	*18*

was found to be insignificant at the 90% confidence level. The trend, however, was for the oxygen system to produce more sludge.

Because of modifications made to the pilot plant's aeration equipment to prevent floc shear, an energy consumption comparison was considered inappropriate. A paper study indicates that substantial energy savings may be expected with the oxygen system.

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Table 5. *Summary of Effluent Quality—Oxygen System*

Parameters	Phase										
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Aeration Period (V/Q), hr	2.5	3.1	3.4	2.8	2.5	2.5	2.6	2.5	2.5	3.1	3.0
MCRT (Total System), days	3.4	5.9	6.8	5.6	3.4	4.4	4.8	3.8	4.2	6.6	5.4
Flow Pattern	Diurnal	Steady	Steady	Steady	Steady	Steady	Steady	Steady	Diurnal	Diurnal	Diurnal
Suspended Solids:											
Influent, mg/L	189	165	242	201	172	202	142	140	150	130	120
Effluent, mg/L	17	18	28	54	28	21	17	14	48	34	20
Removal, %	91	89	88	73	84	90	88	90	68	74	83
Total BOD:											
Influent, mg/L	219	221	231	238	219	212	187	176	204	173	185
Effluent, mg/L	11	7	12	20	21	12	8	5	13	12	6
Removal, %	95	97	95	92	90	94	96	97	94	93	97
Soluble BOD_5:											
Influent, mg/L	131	132	105	122	121	115	93	90	134	100	124
Effluent, mg/L	4	3	3	5	6	3	2	1	1	2	2
Removal, %	97	98	97	96	95	97	98	99	99	98	98
Total COD:											
Influent, mg/L	467	523	554	561	486	536	438	400	415	431	446
Effluent, mg/L	81	87	94	122	100	88	82	71	116	97	83
Removal, %	83	83	83	78	79	84	81	82	72	78	81
Soluble COD:											
Influent, mg/L	249	213	258	279	283	279	255	260	272	280	305
Effluent, mg/L	62	68	58	59	67	66	64	58	64	63	65
Removal, %	75	68	78	79	76	76	75	78	77	78	79
Grease (By Hexane Extraction):											
Influent, mg/L	43	38	47	56	42	62	64	46	46	39	41
Effluent, mg/L	1	1	3	4	3	2	2	1	6	3	2
Removal, %	98	97	94	93	93	97	97	98	87	92	95
Ammonia Nitrogen:											
Influent, mg/L	32	34	33	32	36	37	32	34	28	34	37
Effluent, mg/L	26	31	31	31	31	32	30	29	28	29	34
Removal, %	19	9	6	3	14	14	6	15	0	15	8

Scott Austin and Fred Yunt are with, and Donald Wuerdeman was with, Los Angeles County Sanitation Districts, Whittier, CA 90607.
***Irwin J. Kugelman** was the EPA Project Officer (see below).*
The complete report, entitled "Parallel Evaluation of Air- and Oxygen-Activated Sludge," (Order No. PB 81-246 712; Cost: $8.00, subject to change) will be available only from:
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