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Project Summary

Evaluation of the Two-Zone Wastewater Treatment Process at Norristown, Pennsylvania

Stephen R. Weech, Vernon T. Stack, and Graham Orton

A comprehensive demonstration study evaluated a novel biological wastewater treatment concept called the Two-Zone process*. Two-Zone utilizes a combination reactor/clarifier to incorporate biological treatment and liquid/solids separation in a single tank. The lower segment of the tank serves as the biological reactor zone, and the upper segment is used for clarification. Oxygen requirements are satisfied by injecting high-purity oxygen gas into a recirculating stream of mixed liquor that passes through a below-ground oxygen dissolving device and then back into the reactor section of the treatment unit.

Total secondary system volume requirements for biological reaction plus secondary clarification are 40% to 50% lower with the Two-Zone process than with conventional activated sludge. This makes Two-Zone a good candidate for upgrading the capacity of existing treatment facilities. Either aeration tanks, secondary clarifiers (preferably rectangular), or both can be retrofitted as single-tank reactor/clarifiers in a given plant.

This Project Summary was developed by EPA's Water Engineering 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

Economic and practical considerations, such as limited land area for siting new or upgraded treatment facilities, encourage investigation of alternatives to conventional strategies for wastewater treatment. One alternative is the Two-Zone process developed by Canadian Liquid Air, Ltd. (CLA) of Montreal, Quebec. The Two-Zone process is a novel activated sludge process that combines aerobic biological reactor and secondary clarifier functions in one tank for retrofit into existing plant tankage to increase capacity. A key feature of the Two-Zone process that allows integration of the two functions into a single tank is the oxygenation of the recycled biomass with pure oxygen in an external transfer device. Within the tank, oxygenated recycle sludge is blended with influent wastewater and passes upward through the sludge blanket into a clarification zone prior to displacement as effluent. A collector mechanism ensures the movement of heavy solids across the tank floor and provides scum removal at the surface of the clarification zone.

A 21.9-L/sec (0.5-MGD) demonstration of the Two-Zone process was carried out at the Borough of Norristown, Pennsylvania. The project originated from a mutual desire of CLA and U.S. EPA to demonstrate the Two-Zone process at a site in the United States. CLA had conducted extensive research and development on the process in Canada and demonstrated its feasibility. EPA was interested in the process because of its potentially optimum use of basin geometry and space and its possible retrofit into existing tankage to upgrade wastewater treatment facilities.

The project objectives were to:

- demonstrate the capabilities of the Two-Zone process to treat municipal

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

wastewater in facilities developed through modification (retrofitting) of a portion of an existing aeration basin, a modification that accomplishes secondary treatment in a smaller tank volume than required by conventional biological processes, and

- establish an improved understanding of the performance capabilities and stability characteristics of the Two-Zone process over a range of loading conditions.

System Description

As illustrated in the flow diagram of Figure 1, the Two-Zone process is relatively simple and straightforward. It basically consists of a reactor/clarifier with sludge recycle through an oxygenation unit where pure oxygen (either liquid oxygen stored and vaporized at the plant or on-site generated gaseous oxygen) is added. The recycled sludge must receive and transport all of the oxygen required by the process. The required recycle flow rate is typically three to six times the forward influent flow. The major components are:

- a baffled inlet chamber section in which the influent flow and recycle sludge are blended;
- a reactor/clarifier section equipped with a sludge scraper to help maintain solids in suspension in the reactor zone, ensure delivery of any heavier solids to the discharge side of the reactor/clarifier, and remove scum from the surface of the clarification zone;
- a pickup header to remove the sludge from the reactor clarifier;
- a sludge recirculation pump;
- a Dorr-Oliver below-ground oxygen transfer unit (oxygenator) and associated dissolved oxygen (DO) control equipment;
- distribution headers in the inlet chamber to blend recycle sludge with influent wastewater and distribute flow into the reactor/clarifier;
- an overflow weir; and,
- a skimmer and scum disposal pump

At Norristown, a 9.1-m by 9.1-m (30-ft by 30-ft) segment of an existing aeration tank was isolated for conversion to the Two-Zone demonstration system. Critical dimensions within the reactor/clarifier tank are shown in Figure 2.

Good distribution across the width of the tank required distribution headers for the incoming primary effluent flow and the recycled sludge flow. To dissipate kinetic energy from the orifices in the recycle sludge distribution header, the orifices were aimed upward into the inlet chamber. At the bottom of the inlet chamber, the cross-sectional area was increased to provide slower velocities and ensure the release and escape of gases. The opening at the bottom of the baffle wall served as a distribution orifice across the width of the tank for introduction of blended flow into the reactor/clarifier. The orifice velocity was about 9 cm/sec (3.5 in./sec) at maximum flow.

A skimmer pipe was located atop the baffle wall to remove accumulated scum.

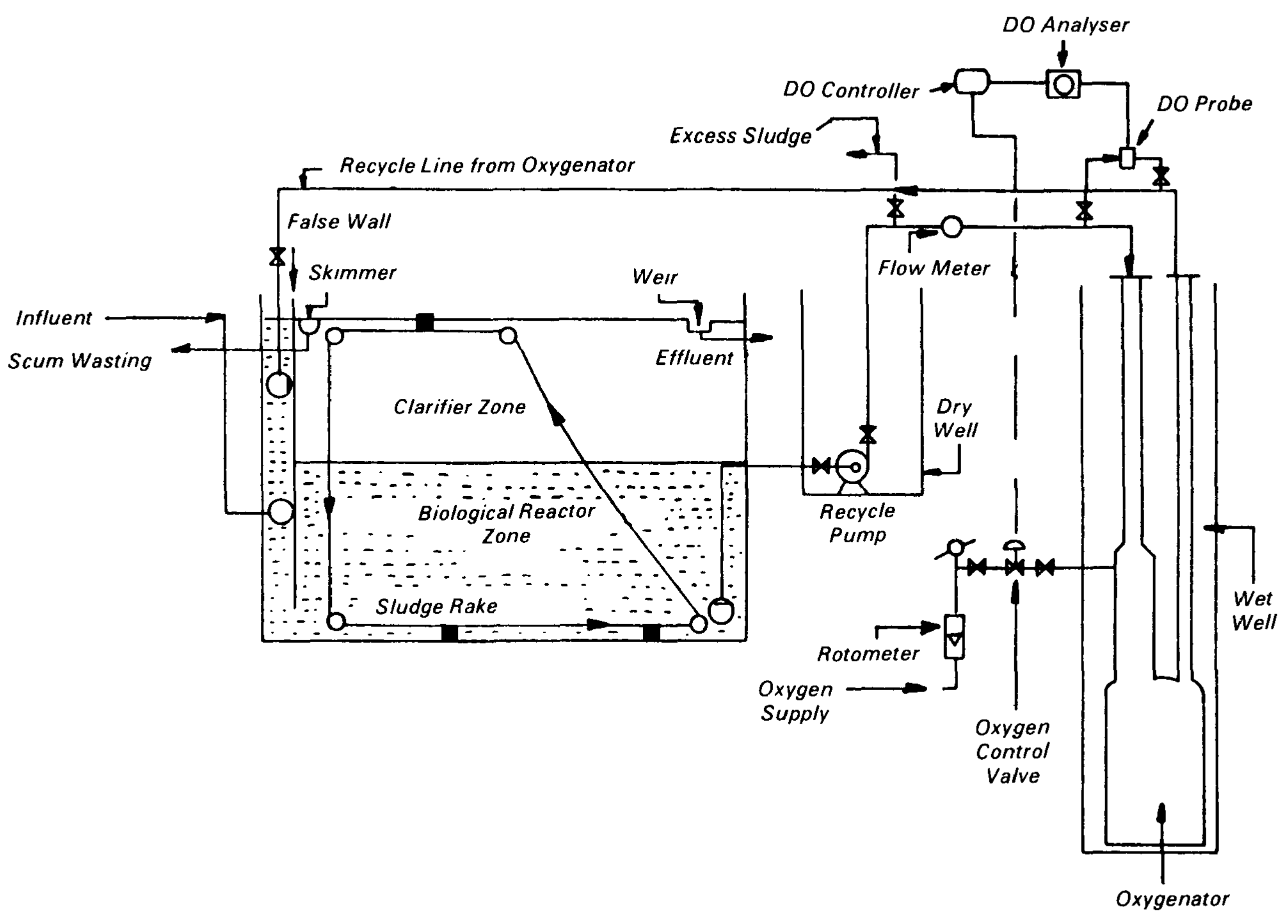

Figure 1. *Flow diagram of Norristown Two-Zone system*

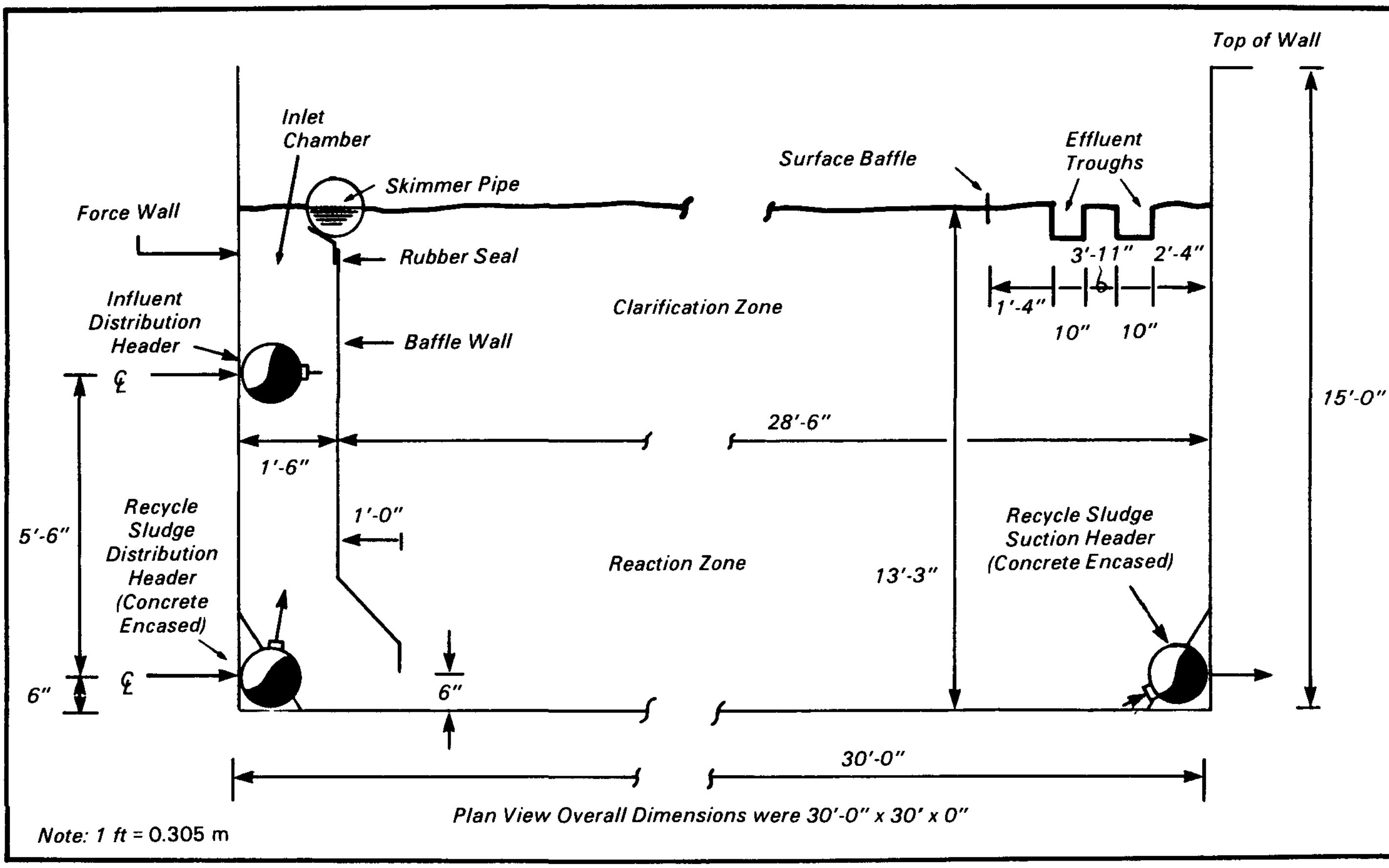

Figure 2. *Longitudinal section view of Norristown Two-Zone reactor/clarifier.*

Flow across the top of the baffle wall into the clarification zone was prevented by a rubber seal connecting the top of the wall to the skimmer pipe.

The capacity selected for the sludge recycle pump was related to system hydraulics. The controlling hydraulic parameter was the discharge rate from the inlet chamber into the reactor/clarifier. Based on its experience, CLA established the maximum flow rate through the opening at the bottom of the baffle wall as 1.24 m^3/min/m (100 gal/min/ft) of tank width. Thus, the total forward flow into the reactor/clarifier (influent flow plus recycle sludge flow) was limited to 11.3 m^3/min (3,000 gal/min). Sludge recycle pump maximum capacity, therefore, was nominally set at 11.3 m^3/min (3,000 gal/min).

Influent flow limitations were based primarily on overflow rate limits for the clarification zone. The average influent flow rate was nominally selected at 1.31 m^3/min (0.5 MGD), which corresponds to a surface overflow rate of 23 m^3/day/m^2 (555 gal/day/ft^2). The maximum influent flow rate was nominally selected at 2.27 m^3/min (0.86 MGD) based on a minimum 4 to 1 ratio of recycled sludge flow to influent flow, which would correspond to an overflow rate of 39 m^3/day/m^2 (960 gal/day/ft^2).

The oxygen transfer capacity of the oxygenator was selected on the basis of the maximum daily total BOD_5 (TBOD) concentration reported for the Norristown raw wastewater (385 mg/L). At a maximum diurnal peak flow of 37.7 L/sec (0.86 MGD) and an assumed oxygen consumption rate of 0.8 kg/kg TBOD applied, the desired maximum oxygenation rate was set at 45.5 kg/hr (100 lb/hr). The minimum oxygenation rate was estimated at 9.5 kg/hr (21 lb/hr), corresponding to a minimum influent flow rate of 13.1 L/sec (0.3 MGD), an assumed influent TBOD concentration of 150 mg/L, and an oxygen consumption rate of 1.35 kg/kg TBOD applied.

Process instrumentation provided readouts and recordings of wastewater flow, sludge recycle flow, and DO concentrations in the recycled sludge before and after oxygenation. The DO concentration before reoxygenation was used to modulate the oxygen feed rate to the recycled sludge. The influent flow to the process was adjusted using a weir that provided a desired flow split from the Norristown primary clarifiers. Thus, the feed to the process had approximately the same variability and diurnal pattern as the flow through the Norristown main plant.

Evaluation Program

Not all of the originally planned test conditions could be evaluated on this project because of various equipment, main plant, and process difficulties that required time and funds to correct. The evaluation program, therefore, was fashioned primarily by the interruptions that occurred. For the period of February 16 through December 15, 1982, six experimental run periods have been defined. The general scope and test conditions for these six runs are summarized in Table 1.

Process Performance

Reactor/Clarifier

Run-averaged operating and performance data for the six experimental runs are summarized in Tables 2 and 3, respectively. Overall performance was excellent at wastewater detention times varying from 3.3 to 7.0 hr. The only effluent TBOD or total suspended solids (TSS) average value over 30 mg/L was TSS for Run No. 2 (the highest loaded test phase) at 34 mg/L. The wastewater detention times given in Table 2 are based on the total reactor/clarifier volume (344 m^3 = 12,150 ft^3) and system influent flow (excluding sludge recycle). The relative proportions of detection time in the reactor and clarifier zones varied from run to run and can be estimated by dividing the sludge blanket depth by 4.0 m (13.5 ft), the tank sidewater depth (SWD).

Additional performance data based on more extensive test runs at lower wastewater temperatures (10 to 15°C), longer sludge retention times (SRT's), and lower food-to-microorganism (F/M) loadings would have been desirable. Nevertheless, it is believed that the information obtained is representative of Two-Zone process capabilities for operation in the 1- to 3-day SRT range. Firm projections of Two-Zone performance under lighter load conditions (i.e., longer SRT's) than experienced in this demonstration cannot be made without more data.

Oxygen Transfer Device

Liquid oxygen was trucked in and stored on-site to feed pure gaseous oxygen to the sludge recycle stream. A control valve modulated the oxygen feed rate based on a selected DO level in the sludge flow leaving the reactor. The oxygen transfer device was a Dorr-Oliver oxygenator. The main transfer chamber of the oxygenation unit was located in a pit 15 m (50 ft) below the surface level of the Two-Zone reactor where the static pressure aided oxygen transfer. The oxygen transfer objective for the unit was 90%. A limited examination of the oxygen transfer characteristics of the oxygenator indicated that the 90% objective was feasible.

A characteristic of the Dorr-Oliver oxygenator, and other devices that may generate supersaturation quantities of oxygen with respect to atmospheric pressure, is that the excess oxygen tends to

Table 1. *Test Conditions for Demonstration Runs*

Run No.	Dates (1982)	Days of Data	Average Influent Flow Rate*	Average Sludge Recycle Rate*	Average Wastewater Temp. (°C)
1	3/2 - 3/30	22	22.3 (0.51)	119.2 (2.72)	12.9
2	3/31 - 4/16	12	28.9 (0.66)	118.3 (2.70)	13.7
3	7/1 - 7/9	8	13.6 (0.31)	82.8 (1.89)	21.6
4	8/11 - 9/25	26	15.8 (0.36)	120.0 (2.74)	24.5
5	10/14 - 11/9	23	19.7 (0.45)	161.2 (3.68)	20.7
6	11/10 - 12/7	21	21.9 (0.50)	131.0 (2.99)	18.5

* L/sec (MGD)

Table 2. *Operating Data Summary for Demonstration Runs*

Parameter	Run No. 1	2	3	4	5	6
Reactor Zone MLSS, mg/L*	3135	3418	3641	5366	4222	3112
Reactor Zone MLVSS, mg/L*	2460	2687	2742	4215	3454	2334
Sludge Blanket Depth, m	2.3	2.3	0.7	1.4	2.0	1.7
ft	7.6	7.7	2.4	4.7	6.6	5.6
Clarifier Overflow Rate,						
$m^3/day/m^2$	24.6	32.1	15.0	17.6	22.0	24.2
$gal/day/ft^2$	604	789	369	431	539	594
Clarifier Solids Loading,						
$kg/day/m^2$	488	557	381	806	840	527
$lb/day/ft^2$	100	114	78	165	172	108
Sludge Volume Index, mL/g	58	92	57	58	51	54
Initial Settling Velocity, m/hr	—	—	9.8	4.9	5.2	6.4
ft/hr	—	—	32	16	17	21
F/M Loading, kg TBOD/day/kg MLVSS	0.64	0.77	0.41	0.33	0.40	0.95
Wastewater Detention Time, hr	4.3	3.3	7.0	6.0	4.8	4.4
Volumetric Organic Loading, **						
$kg\ TBOD/day/m^3$	1.57	2.16	1.63	1.35	1.39	2.13
$lb\ TBOD/day/1000\ ft^3$	98	135	102	84	87	133
SRT, days	2.1	1.5	1.5	3.7	2.6	1.2
Net Sludge Wastage kg TSS/kg TBOD removed†	0.95	1.07	2.01	1.27	1.26	1.37

* Based on calculated values.
** Calculated on basis of reactor zone volume as determined by sludge blanket depth.
† Excludes effluent TSS.

Table 3. *Performance Data Summary for Demonstration Runs*

Parameter	Run No. 1	2	3	4	5	6
Influent TBOD (mg/L)	159	169	85	117	136	161
Effluent TBOD (mg/L)	21	28	15	9	19	24
TBOD Removed (percent)	87	83	82	84	86	85
Influent SBOD* (mg/L)	50	41	21	47	47	43
Effluent SBOD (mg/L)	5	4	3	2	2	5
$SBOD_5$ Removed (percent)	90	90	86	96	96	88
Influent TCOD** (mg/L)	327	333	285	318	321	394
Effluent TCOD (mg/L)	69	78	48	42	56	69
TCOD Removed (percent)	79	77	83	87	83	82
Influent TSS (mg/L)	198	223	170	151	143	199
Effluent TSS (mg/L)	23	34	18	11	21	24
TSS Removed (percent)	88	85	89	93	85	88
Effluent DO (mg/L)	3.8	3.7	4.6	4.9	3.2	3.3

* Soluble BOD_5.
** Total chemical oxygen demand.

come out of solution when the pressure is reduced. Release of supersaturated oxygen can be rapid if the stream being oxygenated contains solids to serve as sites for nucleation. Facilities using devices that produce supersaturation should, therefore, be designed to maintain the highest possible pressure on the oxygenated stream as it is returned to the process tank. Specifically, the stream should be returned at or below the bottom level of the reactor.

Return of the sludge recycle stream to the bottom of the reactor at Norristown would have required cutting through two aeration basin walls and was not acceptable to the Borough staff. Therefore, it was necessary to bring the sludge recirculation line over the end wall of the reactor, resulting in release of oxygen from solution. Part of the released oxygen was vented to the atmosphere through a valve on top of the horizontal run of pipe from the oxygenator to the reactor. Additional released oxygen escaped from behind the force wall before the blend of recycled sludge and wastewater was introduced to the reactor.

A series of tests evaluated how much of the oxygen transferred to the recycle sludge by the oxygenator was actually reaching the reactor zone. DO concentrations were measured at the discharge from the oxygenation device and the inlet to the reactor zone.

Oxygen transfer efficiencies for the range of sludge recycle flow rates examined are plotted against the concentration of oxygen fed to the sludge recycle stream from the cryogenic supply in Figure 3. Although approximately 85% oxygen transfer was accomplished by the oxygenator at recycle stream oxygen concentrations in the range of 20 to 50 mg/L, overall process oxygen transfer dropped to 68% to 80% over the same range. The difference was due to effervescence of supersaturated oxygen through the vent valve and behind the force wall as depicted by the curve of triangular dots in Figure 3. At oxygen doses where supersaturation did not occur, no loss was incurred due to effervescence.

The measurement of oxygenator outlet DO was made near the horizontal sludge recirculation piping, i.e., about 5.5 m (18 ft) above the bottom of the Two-Zone reactor/clarifier. At this elevation, some of the oxygen transferred by the oxygenator had already been released from solution. If the oxygen in solution had been measured at an elevation equivalent to the bottom of the reactor/clarifier, it is believed the transfer efficiency of the oxygen transfer device alone would have been nearer the 90% design level than the 85% value measured.

General Design Recommendations

The Two-Zone process was initially targeted for retrofit into existing treatment plants as a means of increasing hydraulic loading capabilities while maintaining secondary treatment standards. Another promising area is as a first-stage treatment system. In this application, the Two-Zone process could be retrofitted into an existing treatment plant to reduce carbonaceous loading to a subsequent treatment system. First-stage applications could be used either to reduce organic loading on an existing single-stage process to improve subpar performance or to allow the existing process to meet more stringent effluent criteria, such as newly mandated nitrification standards. As a first-stage treatment unit, Two-Zone could be retrofitted into existing plants or installed in new plants as a component of a two-stage system.

When evaluating the potential use of the Two-Zone process, the designer should consider the following general

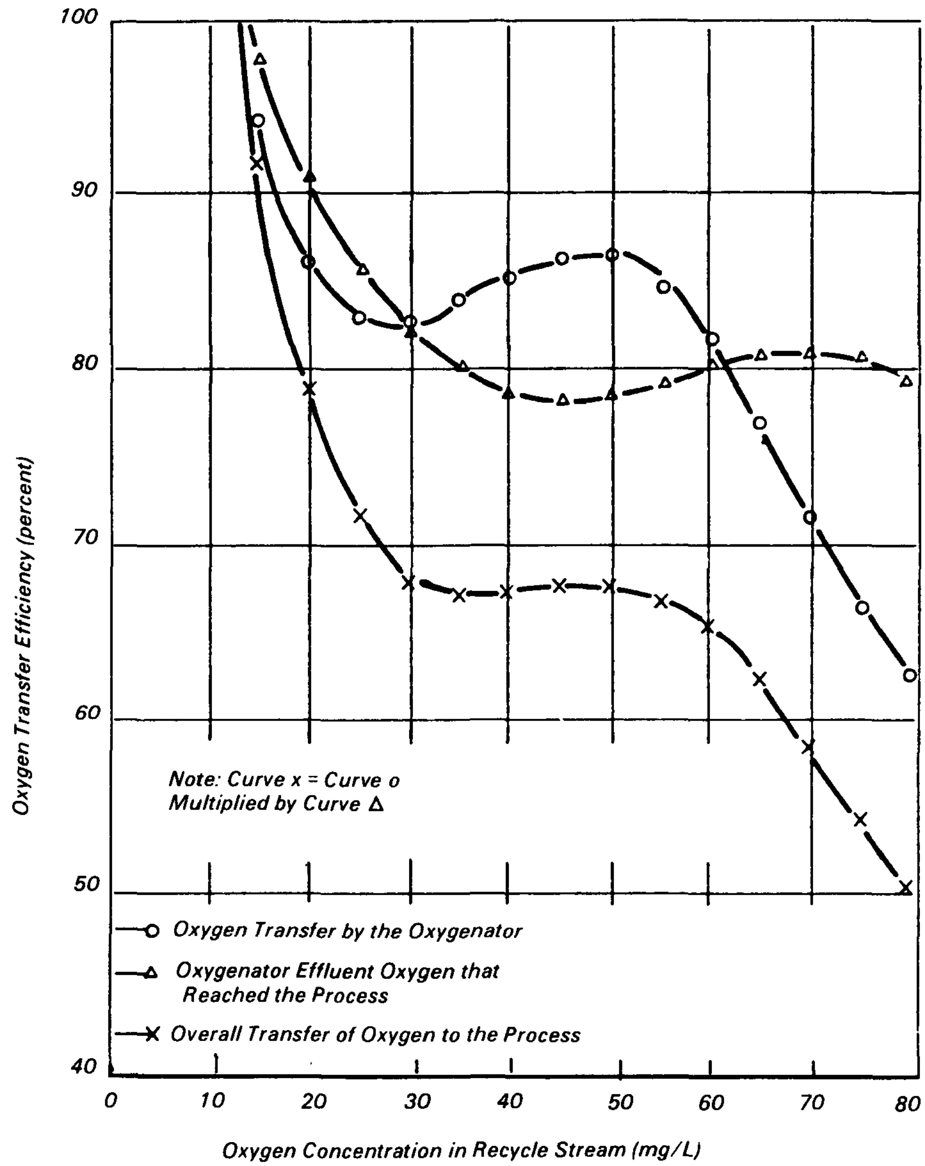

Figure 3. *Oxygen transfer performance.*

application guidelines prior to selection of the process:

- Unless Two-Zone is to be used in a first-stage application, flow equalization should be provided whenever the peak-to-average hydraulic loading ratio, including plant recycle flow streams, exceeds 2.4. Load equalization should also be provided whenever the peak-to-average carbonaceous loading ratio, including recycle loads, exceeds 2.5.
- The Two-Zone process should be preceded by primary treatment to ensure that heavy solids do not enter the Two-Zone reactor and foul the oxygenator. Influent flow to a Two-Zone system should be passed through a fine screening device for the same reason.
- Strong wastewaters with an average process influent TBOD level in excess of 200 mg/L and situations requiring nitrification within the Two-Zone process should be avoided. Actual oxygen dosages required to meet oxygen demand in these situations may result in undesirable flotation of the biomass within the reactor. Due to the associated high oxygen demand, nitrification within the Two-Zone process should be avoided whenever possible.
- Provisions should be made to chlorinate or otherwise sterilize the waste sludges from the Two-Zone reactor in the event of a Nocardial bloom. Two-Zone demonstrated a propensity for concentrating these organisms in the scum waste stream. In some situations, these organisms could disrupt other plant operations.
- If a Dorr-Oliver oxygenator is used with future Two-Zone installations, provisions should be made to backflush the oxygenator. Design requirements for backflushing the oxygenators should be obtained from the manufacturer. Due to the high volumes of flow required for backflush, these discharges should be hydraulically equalized prior to reintroduction to the treatment plant.
- If waste sludges are to be aerobically stabilized prior to disposal, the designer should confirm that the oxygenation system for the aerobic digestion process has sufficient capacity to cope with the higher oxygen demands of the Two-Zone sludge. This recommendation also applies to aerated sludge holding tanks and is a direct result of the relatively small amount of endogenous respiration that occurs in the Two-Zone process.
- The treatment plant should be staffed with technically qualified personnel. The Two-Zone process requires regular monitoring by personnel with a good technical background in biological treatment, physics, and a fundamental knowledge of the operation of pure oxygen systems. The owner must also be able to provide a well-staffed, on-site laboratory for process monitoring.

Specific Design Recommendations

General Sizing Criteria

Hydraulic loading is the primary variable controlling the size of the Two-Zone process tankage. Minimum surface area requirements should be based on limiting the average surface overflow rate to 20.4 m^3/ day/m^2 (500 gal/day/ft^2) or to 48.9 m^3/day/m^2 (1,200 gal/day/ft^2) at peak flow, whichever provides the greater surface area. Total influent flow, including anticipated plant recycle streams, should be used to establish the minimum surface area required.

Based on the Norristown experience, deeper liquid SWD's will improve oxygen transfer in the system. The minimum SWD should not be less than the 4.1 m (13.25 ft) used for the Norristown demonstration. Due to structural considerations, it would be anticipated that the practical limitation on SWD may be about 4.6 m (15 ft). Only about 0.3 m (1 ft) of freeboard is required above the working SWD of the tank at peak flow.

Empirically, the practical limitation of the sludge bed depth, which establishes the maximum reaction volume, is about 53% of the total SWD for applications without flow equalization. With flow equalization, the practical bed depth limitation might possibly be increased to 70% of the total SWD. These limitations are a direct consequence of observed expansion and contraction of the sludge release zone due to changes in influent flow and oxygen feed rates.

Tank Geometry

Rectangular or square shapes are preferred for the process tankage. Circular tank shapes do not appear to be as well suited for retrofit of the Two-Zone process. The actual length and width of the tankage is controlled in part by system hydraulics. Specifically, the width of the inlet end of the tank must be sized to maintain the total forward flow velocity, including recycle sludge flow, at less than 1.24 m^3/min/m (100 gal/ min/linear ft). A second factor that controls tank width is the practical width of available scraper mechanisms. Generally, standard widths for rectangular scraper mechanisms do not exceed 4.6 m (15 ft). The 9.1-m (30-ft) mechanism used at Norristown was obtained only with great difficulty as a special order unit from a manufacturer who, as a condition of fabrication, would not provide any guarantees. Dual-drive scraper mechanisms would not be acceptable due to interference with the fluidized bed crossing the reactor floor and the potential for developing areas of deposition. Given the success of the Norristown unit, other manufacturers may be less reluctant to provide similar scraper widths.

Inlet Chamber

The inlet chamber serves to blend the influent wastewater with the recycle sludge to provide a gas release zone and to distribute the flow evenly across the tank floor. It is critical that the outlet area at the bottom of the baffle wall be designed to reduce the average velocity of the forward flow into the process to about 0.14 m/sec (0.45 ft/sec) in order to capture free gas bubbles within the confines of the inlet chamber. This rate is approximately one-half of the anticipated slowest bubble rise rate (0.3 to 0.6 m/sec or 1 to 2 ft/sec).

Sludge Scraper

Two functions are served by the sludge scraper mechanism. The first is to prevent solids deposition by pushing the denser materials to the recycle sludge suction manifold located at the end of the tank opposite the inlet chamber. The second function is to sweep scum and flotation sludges at the surface of the clarification zone back to the skimmer pipe located over the baffle wall of the inlet chamber. The scraper must travel in the reverse direction from the scraper of a conventional rectangular clarifier.

Sludge Recycle Pumps

Hydraulic considerations dictate the maximum size of the sludge recycle pumps. Although lower recycle rates might reduce the sludge blanket depth requirements (by increasing reaction time), low sludge recycle rates would require higher than desirable oxygen feed dosages to the recycle streams. High oxygen dosages lower the overall efficiency of the oxygenation system, and they may lead to uncontrollable flotation of the sludge blanket. Therefore, it is imperative to provide variable speed pumping capabilities, with the maximum pumping rate set at the limit of the allowable flow through the outlet area at the bottom of the baffle wall of the inlet chamber. At least 100% reserve pumping capacity should be provided by installing reserve pumps to cover potential pump failures.

Oxygenator

Two oxygenation devices have been used with the Two-Zone process to date. In a prior demonstration in Vaudreuil, Quebec, CLA employed a 45.7-m-deep (150-ft-deep) U-tube. An oxygenator designed by Dorr-Oliver, Inc. was used with the Norristown project. The Dorr-Oliver oxygenator was located at 15.2 m (50 ft) below the surface level of the Two-Zone tank. At this time, it is not clear which oxygenator will be used by CLA in the future. It is presumed that the Dorr-Oliver unit would continue to be used due to its higher oxygen transfer efficiency and lower installation cost compared to a U-tube.

Oxygen Supply

From an operational viewpoint, liquid oxygen supply with on-site bulk storage would be preferred to on-site generation. The economics of either source of oxygen should be carefully evaluated on a case-by-case basis during the design phase of the project.

Outlet Weirs

From an empirical viewpoint, average weir overflow rates should be limited to about 49.7 m³/day/m (4,000 gal/day/linear ft) of weir length. Also, a scum baffle is required to limit the excursion of floated solids to the process effluent during potential process upsets.

Waste Sludge and Scum Pumping

Waste sludge pumps should be sized based on the maximum quantity of waste sludge production anticipated. Variable-speed waste sludge pumps (including installed reserve pumps) should be provided to allow continuous wasting throughout the operating day.

A precise basis for estimating scum production does not exist at this time. Scum production due to flotation in the Norristown demonstration unit was significantly higher than anticipated during the project design phase. The pumps selected should be sized to take the maximum overflow rate anticipated from the skimmer pipe at a 2.5-cm (1-in.) immersion level without surcharging the skimmer pipe. These pumps should also be designed to pump dense sludges.

Conclusions

The major conclusions of this project, based on an in-depth evaluation of 10 months of operating and performance data, are as follow:

- The Two-Zone reactor/clarifier functions physically as a clarifier, the capacity of which is determined by the limiting sludge flux condition. This condition is controlled by managing the process sludge inventory. The sludge blanket level in the reactor/clarifier is routinely monitored and solids wasted to control the blanket depth within an acceptable range.
- High rates of sludge recycle in the process establish two hydraulic regimes in the sludge blanket: a hydraulic volume that is transported across the tank quickly (about 10 to 15 minutes in the Norristown demonstration unit) and a sludge release zone that has a longer residence time. Both zones are intimately related and are actively involved in biological stabilization of organic material. Thus, the Two-Zone process utilizes tank volume more efficiently than conventional activated sludge processes.
- Characteristic of a sludge maintained at high DO concentrations, the Two-Zone biomass exhibited excellent settling characteristics throughout the demonstration study. The minimal variations encountered in sludge settling rates did not present any problems in managing the sludge blanket. Management of the sludge blanket depth was influenced primarily by the wastewater influent flow rate, particularly diurnal fluctuations. Generally, loss of process sludge over the effluent weir did not occur if the average sludge blanket depth was kept at 2.7 m (9 ft) or less in the 4.0-m (13.25-ft) SWD tank. Consequently, sludge management practices were tailored to produce an average sludge blanket depth of about 2.1 m (7 ft).
- DO concentrations of the blended sludge recycle/influent wastewater mixture entering the reactor/clarifier had a significant impact on whether effervescense occurred or not. If the DO concentration exceeded saturation on an average daily basis, significant flotation of reactor solids was usually noted.
- The Norristown Two-Zone system functioned well and achieved 83% to 92% TBOD removal at the average F/M loadings of 0.33 to 0.95 kg TBOD/day/kg MLVSS, average total tank (reactor zone + clarification zone) detention times of 3.3 to 7.0 hr, and average SRT's of 1.2 to 3.‾ days evaluated throughout the study. Biological flocculation of the nonsoluble substrate (suspended solids) became more efficient as the SRT increased. Accordingly, effluent TSS concentrations of less than 20 mg/L could be produced at SRT's greater than 2.5 days.
- Norristown's wastewater has a soluble substrate content of 25% to 35%. The Monod constant for removal of soluble substrate was relatively consistent throughout the project with an average value of 0.0064 and a range of 0.0052 to 0.0088 day^{-1} per mg/L MLVSS.
- Process oxygen requirements were low, averaging 0.23 kg/kg TCOD removed (about 0.5 kg/kg TBOD removed) when corrected for oxygen consumed by nitrification. The low oxygen requirements occurred because the nonsoluble substrate components removed by the Two-Zone system apparently were not processed enzymatically for use by the biomass in energy and synthesis reactions. The lack of utilization of nonsoluble substrate can be attributed, at least in part, to the low SRT's under which the system was operated.
- Net wastage of scum and excess sludge averaged 0.66 kg/kg TCOD removed (1.54 kg/kg TBOD removed). This sludge production value is higher than expected from previous work and is a direct consequence of nonsoluble substrate not being metabolized to any significant degree by the demonstration unit. This high value may be characteristic of the Two-Zone process when operated at low SRT's, the Norristown wastewater itself, or a combination of both.
- The good performance of the Norristown Two-Zone system was achieved under conditions in which operator

attention was purposely maintained at low levels. Operators visually inspected the system at 1- to 2-hr intervals around the clock. Most process adjustments were made, however, only during the day shift, and then generally only when the project engineer or the plant supervisor was present.

The full report was submitted in fulfillment of Cooperative Agreement No. CS807404 by the Borough of Norristown, PA, under the partial sponsorship of the U.S. Environmental Protection Agency.

Stephen R. Weech is with BCM Eastern, Inc., Plymouth Meeting, PA 19462; Vernon T. Stack is with Smokey Stack, Inc., Cedars, PA 19423; and Graham Orton is with the Borough of Norristown, PA 19401.
***Richard C. Brenner** is the EPA Project Officer (see below).*
The complete report, entitled "Evaluation of the Two-Zone Wastewater Treatment Process at Norristown, Pennsylvania," (Order No. PB 87-234 506/ AS; Cost: $30.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
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