United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-83-098 Jan. 1984

EPA

Project Summary

Evaluation of Deep Shaft Biological Wastewater Treatment Process at Ithaca, New York

Donald E. Schwinn, Donald F. Storrier, and Robert Butterworth

The major objectives of this study were to demonstrate the feasibility of the Deep Shaft biological treatment process* and to evaluate its application for the treatment of municipal wastewater. A 757-m³/day (0.2-mgd) pilot plant facility was constructed at the existing wastewater treatment plant site in Ithaca, New York, for this purpose.

The Deep Shaft process was evaluated under a variety of operating conditions including raw wastewater and primary effluent as influent sources, constant and diurnal (varying) flow patterns, with and without polymer as a flotation aid, and with alum added for phosphorus removal. Because partially ground screenings and abnormally strong anaerobic digester supernatant are returned to the main plant headworks at Ithaca, pilot plant influent characteristics were not the typical domestic raw wastewater or primary effluent that had been anticipated when the site was selected. Numerous operational problems also hindered the experimental program; however, 5 mo of reliable operating and performance data were obtained on which to draw conclusions about the process.

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).

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

Introduction

The Deep Shaft biological treatment process is a high-rate activated sludge process capable of operating at food-to-mass (F/M) loadings between 0.5 and 2.0 kg BOD_5/day/kg MLVSS. High volumetric loadings can be achieved because the system is capable of carrying and maintaining MLVSS concentrations between 5,000 and 10,000 mg/L. As a result, the bioreactor volume (aeration period) is much lower than that needed in conventional systems.

Deep shafts are self-contained vertical subsurface aeration reactors normally between 90 and 250 m (300 and 800 ft) deep with mean hydraulic retention times (HRT) of approximately 40 to 60 min for municipal-strength wastewater. The HRT generally increases with increasing wastewater strength.

Basically, the reactor is divided into downcomer and riser sections. Raw wastewater (after screening and degritting) and return sludge continuously enter the downcomer section and flow downward. From here the aerated liquid passes into the riser section and flows upward. A portion of the mixed liquor overflows the shaft to a solids separation process, and the remainder of the mixed liquor is recirculated to the downcomer section. Mixed liquor is circulated many times within the shaft during its residence in the reactor. Compressed air is injected into the Deep Shaft to provide the oxygen needed for treatment and to serve as the driving mechanism that maintains circulation velocities.

After the design of Eco I, improvements in its operation and geometry led to the development of Eco II. Rather than the one downcomer and one riser in Eco I, Eco II uses a multi-channel concept featuring one primary and one secondary downcomer and one primary and three secondary risers to minimize anoxic zones in the shaft and to maximize the driving force for inducing flotation clarification. The mixed liquor withdrawal point was also relocated from the head tank to the bottom of the largest secondary riser to increase the dissolved gas content of the mixed liquor being transferred to the flotation tank and to provide maximum treatment time per pass following initial contact of incoming substrate, biomass, and injected air.

Based on the experience gained with Eco I and II, a third generation system, Eco III, was developed. The Eco II Deep Shaft reactor configuration optimized the biological profile inside the reactor and stabilized the hydraulic flow pattern; the air supply requirements, however, maintained liquid circulation at peak flow conditions. With the Eco III design, the air flow rate is controlled to match the influent wastewater flow; the swirl tank and an extensive amount of process control instrumentation are eliminated; and the flotation unit is modified to strip and release coarse air bubbles from the mixed liquor feed stream and to promote better flocculation of mixed liquor solids.

Description of Ithaca Pilot Plant Facilities

The Deep Shaft pilot plant (Figure 1) evaluated at Ithaca was of the Eco II design. Degritted raw wastewater or primary effluent was pumped from the main treatment plant to a splitter box located in the pilot plant building. The flow rate to the shaft was controlled by a pneumatically operated valve that could be adjusted to provide a constant influent flow rate or be varied automatically in a diurnal flow pattern.

After screening and flow measurement, the wastewater flowed into the trough at the influent end of the flotation tank where it was mixed with floating solids skimmed off the top of the flotation tank. Combined influent flow and return float solids then entered a holding tank adjacent to the shaft. Solids that sank to the bottom of the flotation tank were returned to the influent flow stream. From the bottom of the holding tank, influent wastewater and return solids were piped into the secondary downcomer section of the shaft. The secondary downcomer ends slightly above mid-depth of the shaft where it forms two U-shaped sections and turns up into two short secondary risers. Influent wastewater and return solids entering the secondary downcomer are consequently rapidly aspirated into the primary riser through these two short secondary risers.

The steel shaft casing had an inside diameter of 44 cm (17.25 in.) and a depth of 136 m (446 ft). The inner concentric primary downcomer had an outside diameter of 20 cm (8 in.) for slightly less than the top half of the shaft, an outside diameter of 30 cm (11.75 in.) for the remainder of the shaft, and a depth of 133 m (436 ft). The annulus formed between the outer casing and the inner primary downcomer constituted the primary riser.

At the average design flow of 757 m^3/day (200,000 gpd), the hydraulic retention time in the shaft was approximately 39 min. Air was supplied to the shaft from a 15-kW (20-hp) air compressor through three lines, one injecting air into the primary downcomer at a depth of 55 m (180 ft) and two injecting air into the two short secondary risers at a depth of 60 m (196 ft).

The head tank on top of the shaft was designed for an operating pressure of 2,800 kgf/m^2 (4 psig). Off gases plus foam generated within the reactor overflowed the head tank and were piped into the adjacent oxidation tank. The connecting pipe was submerged approximately 3 m (10 ft) below the water surface in the oxidation tank. This liquid head provided the back pressure in the head tank to force the aerated mixed liquor through the secondary riser withdrawal pipe and out of the shaft.

Mixed liquor was discharged from the shaft through the largest secondary riser, bypassing the head tank, directly into a swirl tank. Here sufficient detention time was provided (10 to 15 sec at average flow) to strip any large air bubbles that would disrupt flotation. Aerated mixed liquor was piped from the swirl tank into the flotation tank. The entrance to the largest secondary riser was slightly below the point at which influent wastewater was aspirated into the primary riser to avoid short-circuiting untreated or partially treated wastewater directly to the flotation tank.

Floating solids (float solids) were drawn by scrapers towards the front end of the flotation tank and collected on the beach and pushed over into the influent trough. There the solids mixed with the influent and flowed to the holding tank. Float solids were wasted through a hole in the beach. The valve to control wasting was operated manually or automatically at preset timed intervals. Solids that had sunk (sink solids) were collected by bottom scrapers and a screw conveyor and returned to the influent flow. Sink solids were wasted by opening a valve on the discharge pipe of the sink recycle pump.

Clarified liquid overflowed an adjustable weir at the end of the flotation tank into an effluent trough. Effluent was piped from there into the building sump for return to the main plant.

Operating and Performance Results

Operational Characteristics

Hydraulic characteristics and operational data are summarized in Tables 1 and 2, respectively. The average influent flow rate varied between 636 m^3/d (168,000 gpd) and 757 m^3/d (200,000 gpd). The design flow was 757 m^3/d (200,000 gpd). The sustained peaking factor for the diurnal flow periods ranged from 1.4 to 1.6. The volumetric organic loading ranged from 2.2 to 4.9 kg BOD_5/day/m^3 (137 to 304 lb/day/1000 ft^3), the MLSS level from 5,200 to 9,800 mg/L, and the F/M loading from 0.51 to 1.0 kg BOD_5/day/kg MLVSS. The sludge retention time (SRT) varied from 1.0 to 4.0 days based on shaft and head tank solids only.

Only a limited amount of cold weather operational data could be obtained, and most of that was obtained while treating primary effluent. Influent wastewater temperatures ranged from 9° to 25°C.

BOD_5, COD, and Suspended Solids (SS) Removals

Because of the numerous mechanical breakdowns, excessive foaming, partial shaft blockages, and operational problems at the main plant that occurred throughout much of the study, there were only a few time periods when a normal, routine operation was established. The following results (Table 3) obtained during such time frames were considered to be more representative of process performance and Deep Shaft capability and, therefore, were focused on for evaluation purposes. Percent reductions represent removals across the pilot system only and do not account for any

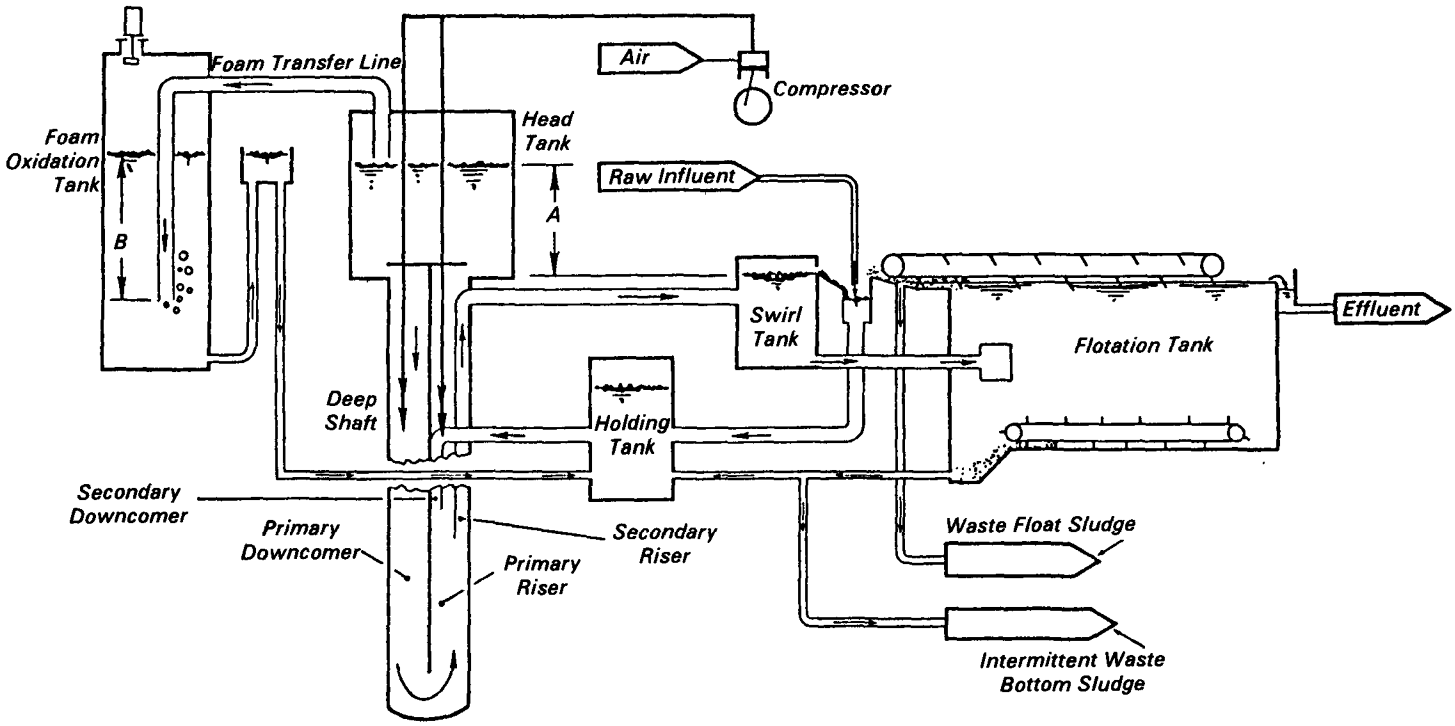

Figure 1. *Schematic of deep shaft system at Ithaca, New York.*

Table 1. *Pilot Plant Hydraulic Characteristics*

Operating Mode*	Influent Flow Rate		Bioreactor†	Solids Separation Unit†	
				HRT	Overflow Rate
(Dates)	m^3/day (gpd)	Peak/Avg.	HRT (min)	(hr)	$m^3/day/m^2$ (gpd/ft^2)
Raw Wastewater					
Constant flow - N.P.					
06/10/80-07/10/80	681 (180,000)	1.0	50	5.2	18.1 (444)
Constant flow - W.P.					
05/19/80-06/09/80	703 (186,000)	1.0	48	5.1	18.7 (459)
Diurnal flow - N.P.					
07/14/80-07/31/80	708 (187,000)	1.6	48	5.1	18.8 (462)
08/01/80-08/31/80	708 (187,000)	1.6	48	5.1	18.8 (462)
09/01/80-09/31/80	711 (188,000)	1.6	48	5.0	18.9 (464)
10/01/80-10/20/80	714 (189,000)	1.6	47	5.0	19.1 (467)
02/19/81-02/28/81	753 (199,000)	1.4	45	4.7	20.0 (491)
03/01/81-03/31/81	726 (192,000)	1.4	47	4.9	19.3 (474)
04/01/81-04/10/81	723 (191,000)	1.4	47	4.9	19.3 (472)
05/31/81-06/30/81	652 (173,000)	1.4	52	5.5	17.4 (427)
07/01/81-07/31/81	738 (195,000)	1.4	46	4.8	19.6 (481)
08/01/81-08/28/81	636 (168,000)	1.4	53	5.6	16.9 (415)
Primary Effluent					
Constant flow - N.P.					
11/09/80-11/21/80	757 (200,000)	1.0	45	4.7	20.1 (494)
Diurnal flow - N.P.					
12/07/80-12/12/80	703 (186,000)	1.4	48	5.1	18.7 (459)
01/24/81-01/30/81	737 (195,000)	1.4	46	4.8	19.6 (481)
Diurnal flow - W.P.					
12/14/80-01/12/81	745 (197,000)	1.4	45	4.8	19.8 (486)
Diurnal flow - W.A.					
01/13/81-01/23/81	745 (197,000)	1.4	45	4.8	19.8 (486)

*N.P. = no polymer; W.P = with polymer; W.A. = with alum.
†Based on influent flow.

Table 2. Pilot Plant Operations Data Summary

Operating Mode* (Dates)	Inf. Temp. (°C)	Chem. Dose (mg/L)	Vol. Org. Loading†	MLSS (mg/L)	MLSS (% Vol.)	F/M Loading‡	SRT (days)
Raw Wastewater							
Constant flow - N.P.							
06/10/80-07/10/80	19-23	—	3.3 (205)	5,700	67	0.93	1.9
Constant flow-W.P.							
05/19/80-06/09/80	16-20	1.5-2.8	2.5 (154)	5,210	69	0.88	1.0
Diurnal flow - N.P.							
07/14/80-07/31/80	24-25	—	2.8 (174)	7,817	64	0.91	1.4
08/01/80-08/31/80	23-25	—	2.8 (173)	6,408	64	0.68	1.9
09/01/80-09/30/80	23-25	—	3.9 (245)	8,633	67	0.75	2.2
10/01/80-10/20/80	21-23	—	4.4 (275)	6,931	70	1.00	1.6
02/19/81-02/28/81	11-14	—	3.3 (204)	5,700	72	0.77	—
03/01/81-03/31/81	11-13	—	4.9 (304)	6,908	75	0.95	1.9
04/01/81-04/10/81	11-16	—	4.4 (270)	7,151	75	0.79	—
05/31/81-06/30/81	19-22	—	2.5 (159)	8,261	63	0.52	3.7
07/01/81-07/31/81	22-25	—	3.7 (233)	7,772	69	0.54	3.3
08/01/81-08/28/81	24-25	—	2.6 (164)	9,771	59	0.51	2.5
Primary Effluent							
Constant flow-N.P.							
11/09/80-11/21/80	15-19	—	3.4 (214)	6,520	72	0.88	2.6
Diurnal flow - N.P.							
12/07/80-12/12/80	14-15	—	3.5 (221)	7,260	70	0.76	—
01/24/81-01/30/81	14-15	—	3.4 (215)	6,757	68	—	—
Diurnal flow - W.P.							
12/14/80-01/12/81	9-17	0.5-3.0	2.2 (137)	5,720	71	0.58	4.0
Diurnal flow - W.A.							
01/13/81-01/23/81	13-15	40.0	2.2 (137)	6,403	68	0.55	—

*N.P. = no polymer; W.P. = with polymer; W.A. = with alum.
†kg BOD_5/day/m^3 (lb BOD_5/day/1,000 ft^3).
‡kg BOD_5/day/kg MLVSS.

removals occurring in the main plant's degritting unit.

Discussion of Results

Treatment Efficiency

In evaluating the performance of the Deep Shaft process and its capability to remove pollutants, as measured by key parameters such as BOD_5, COD, and SS, it should be noted that the influent wastewater characteristics at the pilot plant were not the typical domestic raw wastewater or primary effluent that had been anticipated when Ithaca was selected as the site for the demonstration project. This resulted from such factors as abundant infiltration/inflow into the City's collection system, recycle streams from digester operations at the main plant, partial grinding of screenings at the main plant, trickling filter recirculation flows to the primary settling tanks, and suspected acid waste discharges from a local industry.

Influent wastewater pollutant concentrations were highly variable. The organic strength of the wastewater was quite low even with the presence of recycle streams back to the head end of the plant. During several periods, the average influent BOD_5 was less than 100 mg/L and some days it was less than 50 mg/L. BOD_5/COD ratios were less than would be expected for typical domestic wastewater. The ratios were generally in the range of 0.3 to 0.4.

The Deep Shaft system effectively removed BOD_5, COD, and SS during periods when a routine operation was established and when no major operational or mechanical difficulties were encountered. When such difficulties were encountered, process performance was adversely affected. Effluent soluble BOD_5 levels were consistently below 10 mg/L during all periods and conditions of operation.

Primary Effluent Versus Raw Wastewater Operation

The system appeared to be more effective in treating raw wastewater than in treating primary effluent. While treating primary effluent, the float blanket was very thin and usually dispersed with no distinct endpoint; while treating raw wastewater, it had a much more healthy appearance, was usually thick, and often had a distinct endpoint. This probably resulted from the lower organic strength associated with primary effluent and the lack of fibrous material to assist in forming floc particles that will more readily float.

Unless required for other reasons, the use of primary settling tanks is not necessary or economically advantageous with the Deep Shaft process. No savings in Deep Shaft energy requirements will be realized from the reduction in BOD concentration achieved with primary treatment unless the wastewater has a high organic settleable solids fraction.

Constant Versus Diurnal Flow Operation

The pilot plant was operated under constant and diurnal influent flow patterns on both raw wastewater and primary effluent feed. The system operated more efficiently under a constant flow pattern than under a diurnal flow pattern. Flow variations appeared at times to disrupt the float blanket in the flotation tank. Sometimes, under diurnal flow conditions, the float blanket would thicken during the morning, start to disperse by mid-afternoon, completely disappear at night, and reappear the following morning. This pattern may have resulted from the large variation in BOD_5 loading experienced throughout the course of a typical day. With experience, a better sludge wasting schedule was established and the float blanket was more controllable.

Polymer Addition

Process performance with polymer (a floatation aid) added under different operating conditions was compared with performance without adding polymer. The goal was to operate the system without polymer because it represents a potential significant operating cost.

Adding polymer did not improve effluent quality. The concentration of solids in the float blanket did not increase although the quantity of float solids relative to the quantity of sink solids increased substantially.

In general, polymer was not needed to develop a healthy float blanket or a good quality effluent although, on occasion, the blanket did become quite thin and dispersed without it. Contributing factors probably included one or more of the following: colder wastewater temperatures, weak influent strength, lack of fibrous material, digested or partially digested solids, and process upsets. At a full-scale facility, adding polymer would be beneficial on an intermittent or seasonal basis to ensure a good, thick, healthy float blanket at all times.

Alum Addition

While the pilot plant was treating primary effluent, alum (for phosphorus removal) was added with and without polymer. The float blanket became quite thin and dispersed as most of the solids sank to the bottom of the flotation tank. A thin, milky scum appeared on the surface of the flotation tank. When polymer was added, it did not significantly improve the situation.

Alum was not added to the pilot system while raw wastewater was being treated. In full-scale applications, the need for tertiary treatment of Deep Shaft effluent to obtain phosphorus removal will depend on the yet-to-be determined compatibility of in-process alum or iron addition with Deep Shaft operations when the system feed is degritted raw wastewater rather than primary effluent.

Organic and Hydraulic Shock Loadings

The pilot plant was subjected to a number of severe organic shock loadings, sometimes several a week, primarily as a result of digester operations at the main plant. Shock organic loadings consisted of digester supernatant, filtrate from sludge dewatering, and digested and partially digested solids from the sludge holding tank. During startup, before the primary effluent piping was installed, the pilot plant received the full impact of these recycle streams. After the piping was installed, the influent to the pilot plant was generally switched to primary effluent during the "dump" periods.

During a typical digester "dump" period (lasting approximately 5 hr), the influent SS load increased to 3,800 mg/L and the COD concentration increased to 5,000 mg/L. Effluent SS rose to mg/L from a value below 30 mg/L, and effluent soluble COD reached a peak of 140 mg/L from a value of 100 mg/L. The process was adversely affected only on a short-term basis and rapidly recovered within 12 to 24 hr following cessation of the "dump" period.

The pilot plant was operated under a diurnal flow pattern with sustained peak flows to simulate dry-weather conditions at a typical domestic wastewater treatment facility. It was not possible, however, to evaluate the capability of the process to handle the large instantaneous or short-term peak flows typically encountered during wet-weather periods at most treatment plants. The design of the Ithaca shaft was such that the total hydraulic capacity including recycle flows was 1,666 m^3/day (440,000 gpd). The maximum influent flow limit was established at approximately 1,060 m^3/day (280,000 gpd).

Sludge Production and Thickening

Significant amounts of solids had to be wasted from the sink recycle line as well as from the float return to properly control the process. It had been anticipated that most solids would float, forming a very thick blanket that would be the primary source of sludge wasting, and that float recycle would be the primary mechanism for controlling the shaft MLSS level. The relative rates of float and sink solids wasting varied considerably. At times, the quantity of sink solids wasted exceeded that of float solids wasted; at other times, the opposite was true. This variation was a function of the quantity and condition of digester solids received from sludge processing operations at the main plant as well as such factors as polymer addition.

The shaft MLSS level was controlled primarily by controlling the sink solids inventory. The concentration of float solids was not as high as anticipated, and the float return rate was much less than the sink recycle rate. Float solids concentrations were about 4 percent, and sink solids concentrations were around 2 percent. The float return rate was about 76 m^3/day (20,000 gpd); the sink return rate was always at least 303 m^3/day (80,000 gpd) and often over 379 m^3/day (100,000 gpd). Consequently, the process was primarily controlled by the wasting and recycle rates for the sink solids.

Process Control

The system was more complicated to operate effectively than had been originally anticipated—partly because of the abnormal number of mechanical breakdowns and instrumentation malfunctions and also because of the operator understanding and judgement needed to make effective decisions. Daily control variables included float solids wasting, sink solids wasting, sink recycle rate, float skimmer speed, addition of flotation aids, and sink recycle by pump or gravity return.

Table 3. Representative Deep Shaft Performance at Ithaca

	BOD_5 (mg/L)			COD (mg/L)			SS (mg/L)		
Period	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.
5/19 - 7/10/80	91	17	80	261	63	76	172	21	88
4/01 - 4/10/81	137	17	88	331	64	81	207	28	86
5/31 - 8/28/81*	105	22	79	250	52	79	267	31	88
Weighted avg.	102	20	80	263	59	78	231	27	88

**Effluent BOD_5 results may relect some nitrogenous oxygen demand; nitrification inhibitors were not used in the BOD_5 analysis although partial nitrification did occur in the system during a portion of this time period.*

Conclusions

Numerous problems including operator control, mechanical breakdowns, partial shaft blockages caused by partial grinding and subsequent return of screenings to the influent flow at the main plant headworks, foaming conditions, and abnormally strong digester return adversely affected process performance and often resulted in inconclusive and inconsistent data. However, sufficient reliable data were obtained to reach the following conclusions:

- The Deep Shaft process is a high-rate, high-intensity activated sludge process utilizing flotation for solids separation. At the Ithaca pilot plant site, F/M loadings ranged from 0.5 to 1.0 kg BOD_5/day/kg/MLVSS, SRT's were 1 to 4 days, and bioreactor HRT's were 45 to 53 min, exclusive of recycle flows.
- During those periods when routine operation on raw wastewater feed was established, effluent concentrations of BOD_5 and suspended solids averaged 20 and 27 mg/L, respectively, and percent removals were 80 and 88 percent, respectively. These percent removals are for the Deep Shaft process only and do not account for any reductions that may have occurred in the main plant degritting unit. Nitrification inhibitors were not used in the BOD_5 analysis, although partial nitrification occurred near the end of the study.
- The process was more effective in treating raw wastewater than in treating primary effluent, perhaps because of the latter's more dilute nature (lower organic loading) and lack of fibrous material.
- The system operated better under constant flow conditions than under diurnal flow variations. The peak hydraulic capacity of the system was such that wet-weather peak flow conditions typical of Ithaca could not be simulated.
- Adding polymer increased the quantity of the float blanket but did not significantly improve effluent quality. Low polymer dosages caused some sink solids to remain suspended and, thus, adversely affected solids separation.
- While treating primary effluent, alum was added for a short time to remove phosphorus; this caused solids to sink and apparently adversely affected the float blanket.
- The Deep Shaft process handled shock organic loadings from solids processing returns very well and recovered within 12 to 24 hr after the shock loads ended.
- Ithaca's Deep Shaft system required significant operator training, attention, and control. Control of the solids inventory and maintenance of a good, thick float blanket required operator judgment in wasting float solids, wasting sink solids, and determining the sink recycle rate on a day-to-day basis. Problems at the main plant made operating the pilot plant substantially more difficult.

The full report was submitted in fulfillment of Cooperative Agreement No. CS806081 by the City of Ithaca, NY, under the partial sponsorship of the U.S. Environmental Protection Agency.

Donald E. Schwinn, Donald F. Storrier, and Robert Butterworth are with Stearns & Wheler, Cazenovia, NY 13035.
***Richard C. Brenner** is the EPA Project Officer (see below).*
The complete report, entitled "Evaluation of Deep Shaft Biological Wastewater Treatment Process at Ithaca, New York," (Order No. PB 84-110 485; Cost: $16.00, 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

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use $300

U.S. OFFICIAL MAIL
U.S. POSTAGE
CINCINNATI OHIO
APR 6 '84

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984-759-102/837