Kenics
Competitive file

Compressed Air Sub-Surface Aeration

KENICS COMPETITIVE FILE

By STEPHEN LABERIS, Project Engineer, Kenics Corporation, Danvers, Mass.

Aeration of sewage and industrial wastes using compressed air is a common, well documented process. Extensive research has been done to improve upon the basic process of introducing air at some depth within a tank, and allowing the natural rise of the air bubbles and entrained water to provide oxygen transfer. Oxygen transfer depends upon surface area *(air bubble size), turbulence (mixing of air and water),* and contact time (length of air-water path).

In a typical aeration tank, the length of the air-water path is equal to the tank depth above the air inlet. Turbulence is produced by the drag of rising air bubbles, so that for fixed tank geometry, little can be done to improve upon these factors directly. The method of introducing the air, however, can easily be varied. This controls the bubble size, and indirectly affects turbulence and path length, due to a dependence on the velocity of rise of the bubbles.

Several ways of introducing air have been developed, each with its own particular advantages and limitations. Characteristics of the most common methods are summarized in the Table. The various methods for introducing air can be divided between two basic types of diffusers: porous and nonporous. Porous diffusers are high-maintenance devices due to clogging of the holes but they provide efficient oxygen transfer. Nonporous diffusers are low maintenance devices, but provide less efficient oxygen transfer. No totally satisfactory device has been developed which produces small air bubbles and is maintenance-free.

A new approach to the problem improves upon the compressed air method of aeration by starting with a maintenance-free, nonporous diffuser, increasing the path length, and air-water mixing, and reducing air bubble size after the introduction of air in order to increase oxygen transfer. The device is an in-line, no-moving-part, continuous mixing and processing unit. It is constructed of a number of short elements of right- or left-hand helices. These elements are alternated and oriented so that each leading edge is at a 90-degree angle to the trailing edge of the one ahead. The element assembly is then enclosed within a tubular housing.

When materials are passed through the mixer, two unique mixing actions (flow division and radial mix-

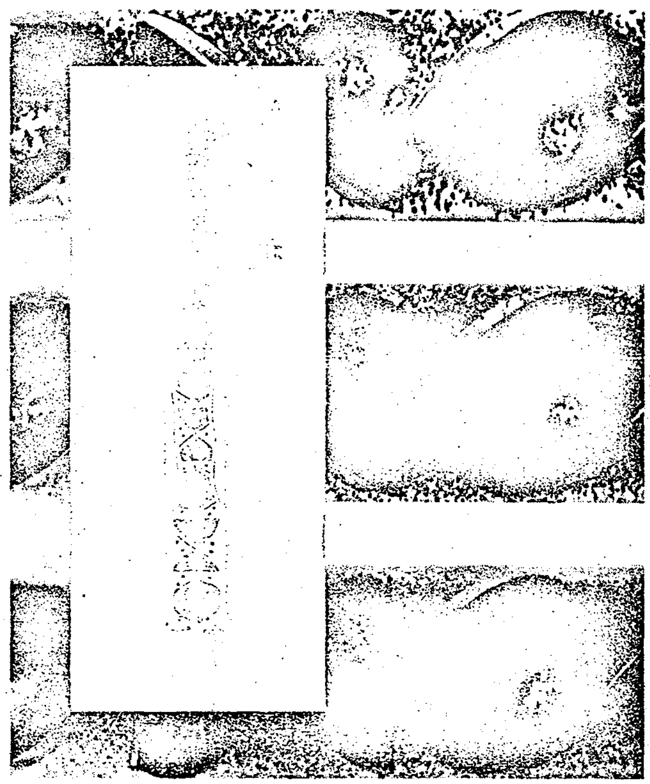


Fig. 1 Dispersion in static aeration device. Different drop sizes are produced by varying the velocity.

A. Surface turbulence; B. contacting in air-water phase; C. contacting in the aerator; D. bubble formation.

SUMMARY OF COMPRESSED-AIR AERATION METHODS

Type of Diffuser	Examples	Advantages	Disadvantages
Porous *(Fine bubbles)*	Ceramic plates and tubes *Saran pipe* Cloth bag	High oxygen transfer efficiency, reduced heat losses to ambient	High maintenance, clogging
Nonporous (Coarse bubbles	Spargers Nozzles Orifices Shear box Valves	Nonclogging, low maintenance, reduced heat losses to ambient	Low oxygen transfer efficiency

ing) operate simultaneously in the unit. This results in nearly plug flow characteristics. When two immiscible fluids are passed through the mixer, shear forces generated by the mixing action disperse one fluid within the other in the form of fine drops or bubbles. Intimate contact, as well as a high degree of interface, is the result, Fig. 1.

For compressed air aeration the unit is placed in a vertical position above an air inlet. Small bubbles of air are generated, and intense mixing of the bubbles with entrained water takes place. This combination of large surface area and intense turbulence transfers more oxygen. Also, the path of the air-water mixture is lengthened due to the winding channel imposed by the mixer elements.

Basically, oxygen transfer takes place in four steps. The first step occurs during bubble formation at the two orifices used to supply the aerator. The bubbles are formed by high-velocity air jets (100-200 ft/sec) where there is a high degree of turbulence and a high dissolved oxygen deficit. The contact time before the air enters the mixer is extremely short. The orifices—and therefore the bubbles—are large, since this reduces the risk of clogging and

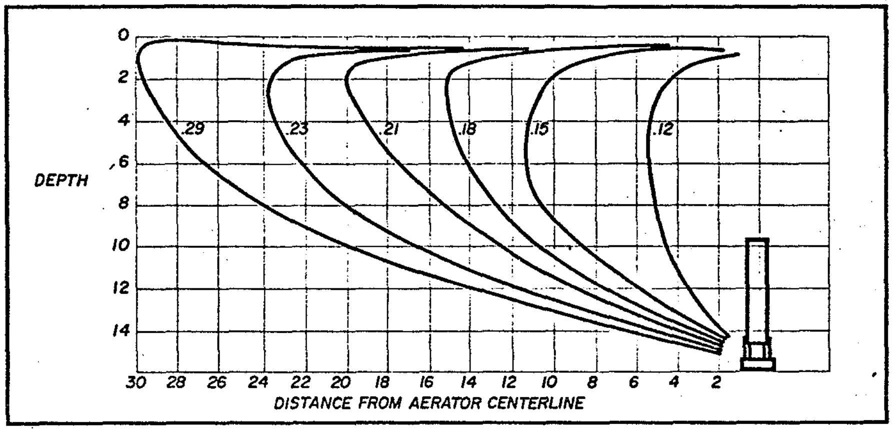


***Fig. 2** Sub-surface circulation currents for a single static aeration device operating at 25 scfm in 16 ft of water.*

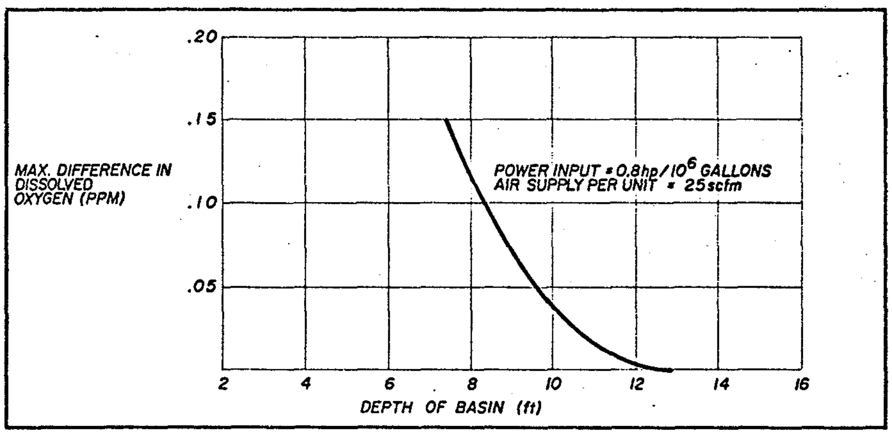


***Fig. 3** Maximum difference in dissolved oxygen level as a function of basin depth.*

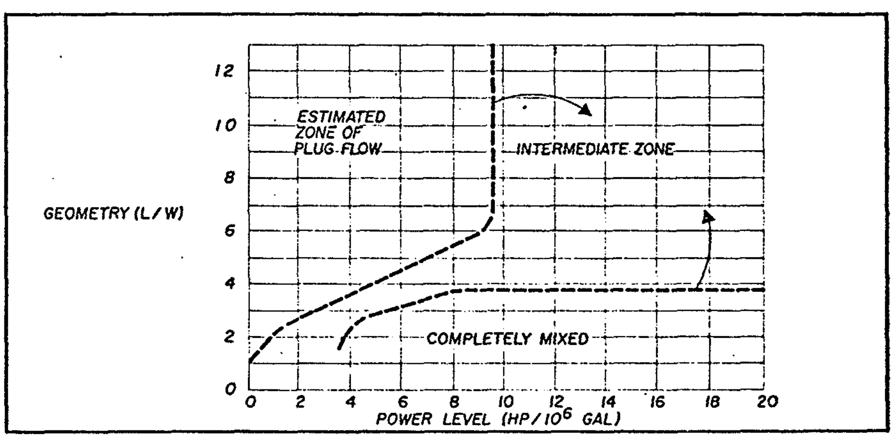


***Fig. 4** Mixing characteristics of aeration basin as a function of geometry and power level.*

provides a high circulation of water. Because of the large bubble size and short contact time, the contribution of this step to the total oxygen transfer is small.

The second step is the actual contacting of the air-water mixture in the device. As described previously, the action of the mixer elements breaks the air into fine bubbles, and completely mixes the oxygen-rich air with the low-oxygen water to give an outlet liquid of high dissolved oxygen content. The length of diameter ratio (pitch) of the elements, and the diameter of the unit are designed to give an optimum combination of dispersion, mixing, path length, and liquid circulation. The length (number of elements) is designed to provide a liquid which is nearly saturated.

The third step of oxygen transfer is the rising of the exit air-water column to the surface. As the stream rises, the air slips past the water and expands away from the center. Eddy currents at the boundaries of the rising column slow the rise of the water and actually cause interchange of oxygen-rich liquid with the oxygen-weak surrounding liquid. Additional oxygen transfer results as the rising air bubbles contact the oxygen-weak entrained liquid. Final oxygen transfer occurs in the turbulence created as the rising air-water column breaks the surface.

Aerators are anchored to the lagoon bottom by either a rigid support or a tether line. The elevation of each anchor is predetermined using a transit, and the length of each tether line is determined so that the aerators will be at the same elevation. For large variations in depth, where a considerable amount of water is below the aerators, draft tubes are installed. These extensions circulate the water below the aerators. The aerators lie on their sides during installation, but float to an upright position as the basin is filled.

Air is supplied by blowers at a sufficient pressure to overcome friction losses in the piping and the static head of water in the lagoon. Three types of blowers are commonly used. The positive-displacement rotary-lobe blower operates at constant volume and variable pressure, which permits variation in lagoon depth. Also, the volume can be varied by changing the speed of rotation. The second type is the helical screw positive displacement blower. It has the same operation characteristics as the lobe type, but is more efficient at higher pressures. It is, however, a more costly machine. The third type is the centrifugal blower, which operates at nearly constant pressure and variable volume. It is best suited for applications where air requirement varies.

Extensive testing has been carried out to determine the oxygen transfer and basin mixing characteristics of sub-surface aerator systems. Oxygen transfer is proportional to air supply and basin depth. The transfer capabilities of a single unit are given by the equation:

$$N = (.0252)\ (D\text{-}1)\ (A)\ (.67)$$

where
N = Oxygen transfer to pure water (lb/hr-unit)
D = Depth of the basin (ft)
A = Air supply per unit (scfm)

In general, great depths and low air supply per unit give most efficient operation.

A single unit will set up a circulation pattern in its immediate area. The general direction of flow is from the bottom of the basin into the mixer, out of the mixer to the surface, across the surface and down to the bottom, Fig. 2. Strong eddy currents are set up by the rising air water column, where up to 6 times flow rate through the mixer is entrained and carried to the surface.

Compressed air aeration is best suited for tank applications where the geometry of the tank (the side walls and bottom) can enhance basin mixing. For large lagoon applications, the natural circulation caused by the rising air bubbles is not sufficient to produce complete mixing without excessive power consumption. Circulation patterns must be induced by the placement of baffles, or the use of long, narrow tanks.

The area of influence of a single unit extends for a radius of over 50 feet, as evidenced by measurements of surface currents. Basin mixing is accomplished by a combination of surface and eddy currents. Since both of these effects depend on the depth, the degree of mix varies somewhat with lagoon depth. Figure 3 shows the maximum deviation of the dissolved oxygen level from the average as a function of depth.

In all cases, the degree of mixing is more than sufficient for waste treatment applications. Measurements of current velocity in the area of the aerator shows that the smallest velocities are at the bottom of the basin. In cases where the units are far apart (aerated lagoons), some settling of solids will take place. In cases where the units are closer together and the basin geometry plays an important part in the circulation pattern (activated sludge), insignificant settling takes place.

Studies have been performed to determine the mixing patterns in aeration basins. Most of the studies have been done with surface entrainment aerators, with the result that the type of mixing (i.e., completely mixed vs. plug flow) depends on the length-to-width ratio of the basin and the power input, Fig. 4. It is believed that small basins with short retention time are completely mixed using sub-surface aerators. For larger basins and longer residence time (aerated lagoon), the basin acts like a plug flow system, and the aeration must be tapered to allow for this.

For a copy of this article circle 155 on Reader Service Card

Kenics comp. file

Secondary treatment facilities at a northern newsprint mill

Design and operation

ABSTRACT

After considering a number of secondary treatment systems, a northern newsprint mill selected the extended aeration process. Design criteria were based on an estimated primary clarifier effluent flow of 25.0 million gal/day (94,750 m³/day), a BOD_5 of 42,500 lb/day (19,300 kg/day), and a total suspended solids of 20,000 lb/day (9100 kg/day). Proper design and control of operational parameters and equipment, such as nutrient requirements, mixed liquor volatile suspended solids concentration, oxygen requirements, neutralization requirements, secondary clarifiers, secondary solids generation, and secondary sludge dewatering, have enabled this facility to achieve required effluent limitation.

KEYWORDS
Secondary treatment
Systems
Design
Newsprint
Paper mills
Aeration

Arthur J. Condren
Edward C. Jordan Co., Inc., P. O. Box 7050, Downtown Station, Portland, Me. 04112

Patrick H. Welch
Great Northern Paper Co., Millinocket, Me. 04462

In April of 1973, the State of Maine Department of Environmental Protection established effluent limitations for Great Northern Paper Company's 1000-ton/day (907-metric ton/day) newsprint mill at East Millinocket. The discharge permit stipulated that by October 1, 1976, the effluent criteria shown in Table I must be met. The company subsequently started a program to design a secondary wastewater treatment system for this mill.

In evaluating the best system to be employed, a number of secondary treatment alternatives were considered. Because of site, weather, and treatability limitations, the extended aeration process was selected. To establish actual design criteria for this facility, pilot scale biotreatability studies were undertaken, and the results of these efforts are presented in Table II.

The design criteria were based on an estimated primary clarifier effluent flow of 25.0 million gal/day (94,750 m³/day), a BOD_5 of 42,500 lb/day (19,300 kg/day), and a total suspended solids (TSS) of 20,000 lb/day (9100 kg/day). Figure 1 presents a flow diagram of the wastewater treatment facilities as constructed.

I. Discharge permit limitations

Parameter	Average day value	Maximum day value
Flow, million gal/day	. . .	30.0
(m³/day)	. . .	(113,500)
BOD_5, lb/day	7,700	11,500
(kg/day)	(3,496)	(5,221)
TSS, lb/day	6,800	13,600
(kg/day)	(3,087)	(6,174)
pH	. . .	6.0-8.5

II. Laboratory derived design criteria

Parameter	Value
1. Aeration basin detention time, hr	31.0
2. Oxygen requirement, lb O_2/lb BOD_5 removed	1.2
3. Mixed liquor volatile suspended solids (MLVSS) at 68°F (20°C), mg/liter	1700-1800
4. Food/microorganism ratio lb BOD_5 applied/day/lb MLVSS under aeration	0.09
5. Biomass produced, lb/lb BOD_5 removed	0.3
6. Waste secondary solids, lb/day	24,500
(kg/day)	(11,100)
7. Secondary clarifier surface loading rate (avg.), gal/day/ft²	520
(m³/day/m²)	(21.2)
flux rate (avg.), lb MLSS/ft²/hr	0.8
(kg MLSS/m²/hr)	(3.9)
8. Secondary sludge consistency, % solids	1.0
9. Secondary sludge recycle rate (maximum), %	75

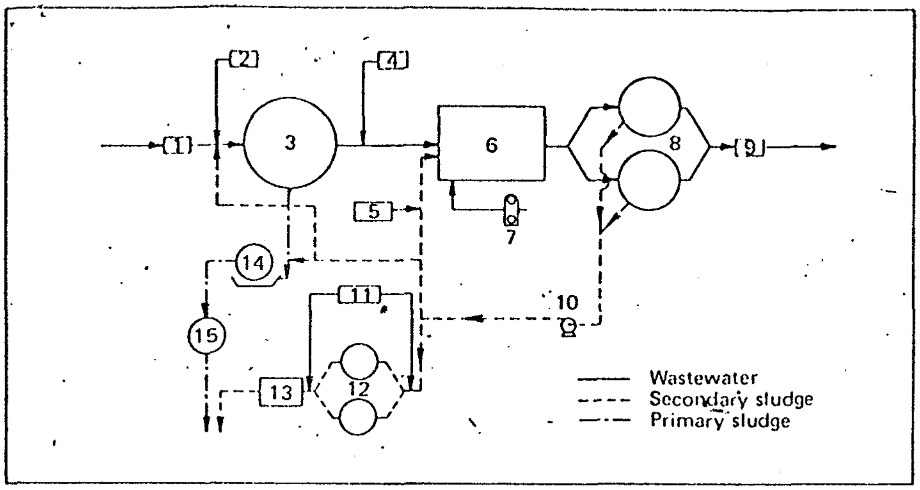
System performance

Secondary system influent characteristics

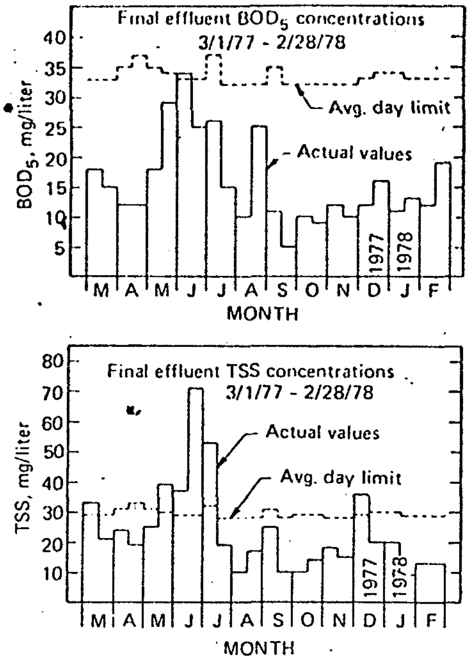
Following start-up of the wastewater treatment system, a comparison of actual operating design data for the primary clarifier effluent characteristics was undertaken. A statistical summary of daily data for the time interval from March 1, 1977, through Feb. 28, 1978, is presented in Table III. The median flow rate encountered was greater than the original average design value while both BOD_5 and TSS loadings to the secondary system were less than anticipated.

Secondary system effluent characteristics

Flow to the secondary treatment system was initiated on October 1, 1976. During the following three months, all components of the secondary system



1. Flow diagram of wastewater treatment facilities, East Millinocket, Me.: (1) mill wastewater flow and sampling stations; (2) lime feed system (3 ton/day, max.); (3) primary clarifier (220 ft diameter, 14 ft side water depth); (4) ammonia feed system (1700 lb NH_3/day, avg.); (5) phosphoric acid fee system (60 gal/day of 62% H_3PO_4, avg.); (6) aeration basin (32.3 million gal capacity, 21 ft water depth, 1314 submerged static aerators); (7) Blowers (six, each 4000 std. ft³/min); (8) secondary clarifiers (two; 175 ft diameter, 15 ft side water depth); (9) parshal flume; (10) sludge recycle pumps (three; 4350 gal/min each, max.); (11) polymer feed system; (12) dissolved air flotation units (two; 12 ft diameter); (13) centrifuge (90 gal/min, max.); (14) coil filter (11.5 ft diameter, 12 ft long); (15) V-press.



2. Bimonthly average effluent BOD_5 and TSS concentrations.

were scrutinized and their performance optimized. Secondary clarifier effluent daily data for the time interval from March 1, 1977, through Feb. 28, 1978, were subsequently subjected to statistical analyses and the results are presented in Table IV.

Figure 2 presents the bimonthly average effluent concentrations of both BOD_5 and TSS for the data period from March 1, 1977, through Feb. 28, 1978. The BOD_5 bimonthly average concentration exceeded the average day permit limitation only once during the data year analyzed and yet the monthly average encompassing this data interval was well within limitations. However, the TSS bimonthly average concentration did exceed the average day permit limitation on several occasions, and the reasons for these occurrences and corrective actions taken will be discussed subsequently.

Operational considerations

Nutrient requirements

The secondary system at East Millinocket was started up employing a BOD_5:N:P ratio of 100:5:1. Following system stabilization, measurement of the ammonia and the soluble orthophosphate concentrations in the secondary clarifier effluent indicated levels in the 1 to 2 mg/liter range. The nutrient feed rates were adjusted to maintain a concentration of 0.5 mg/liter NH_3 (as N) and 0.25 mg/liter soluble orthophosphate (as P) in the secondary effluent. The resulting nutrient budget, using effluent concentrations as the control parameter for nutrient addition rates, approximated 0.4 lb (0.18 kg) P and 3.8 lb (1.73 kg) N per 100 lb (45 kg) BOD_5 removed.

Calculations have indicated that the unconsumed nutrients in the system are adequate to compensate for an increase in BOD_5 loading of approximately 5000 lb/day (2270 kg/day) before the system becomes nutrient deficient. Daily monitoring of these parameters has allowed nutrient feed rates to be minimized while achieving acceptable levels of BOD_5 and TSS removal.

Optimization of MLVSS concentration

As previously stated, the bench scale biotreatability studies indicated the maintenance of a mixed liquor volatile suspended solids (MLVSS) concentration of 1700 to 1800 mg/liter when the wastewater temperature was approximately 68°F (20°C). During the data period analyzed, aeration basin temperature was observed to vary from 50°F (10°C) to 99°F (37°C). Operation of the system during the summer months with a MLVSS concentration equal to or greater than 1700 to 1800 mg/liter led to certain operational problems, namely negligible dissolved oxygen levels throughout the basin and the emission of odors. Field measurements and calculations as well as actual practice have indicated that a more appropriate summertime MLVSS concentration is 1100 to 1200 mg/liter. Wintertime operation has indicated that up to 2200 to 2300 mg/liter MLVSS may be maintained in the system with no detrimental effects.

Oxygen requirements

A total of 1314 submerged static aerators were installed in the aeration basin to maintain an average dissolved oxygen concentration of one mg/liter

III. Primary clarifier effluent characteristics

Frequency of occurrence	Flow, million gal/day (m³/day)	BOD_5, lb/day (kg/day)	TSS, lb/day (kg/day)
Median (50%-tile)	28.2 (106,900)	39,100 (17,750)	14,200 (6,450)
99%-tile	30.3 (114,850)	57,000 (25,900)	28,000 (12,700)
Design value (avg.)	25.0 (94,750)	42,500 (19,300)	20,000 (9,100)

IV. Secondary clarifier effluent characteristics

Frequency of occurrence	Flow, million gal/day (m³/day)	BOD_5, lb/day (kg/day)	TSS, lb/day (kg/day)
Average	28.0 (106,100)	3,625 (1,650)	5,490 (2,500)
Median	28.2 (106,900)	3,125 (1,400)	3,900 (1,750)
Maximum day/month	30.3 (114,850)	9,200 (4,200)	15,200 (6,900)

in the wastewater being treated. Field measurements indicated that actual levels in certain areas of the basin sometimes fell below the desired concentration. When these low levels occurred, the emission of odors was evident.

An analysis of this situation revealed that: (a) oxygen transfer by the aerators was less than that stated at the time of their purchase; and (b) there was a slight maldistribution of oxygen supplied to the plug-flow basin. To alleviate the above situation, additional blower capacity was installed and supplemental static aerators were placed in oxygen-deficient zones within the aeration basin.

During June and July, when the MLSS concentration reached approximately 3300 mg/liter, the emission of odors from the aeration basin was a constant problem. Oxygen uptake rate measurements taken throughout the aeration basin indicated an oxygen consumption of approximately 2.5 lb O_2/lb BOD_5 removed. Decreasing the MLSS concentration to the more appropriate level of 1100 to 1200 mg/liter lessened the oxygen consumption to 1.2 to 1.3 lb O_2/lb BOD_5 removed and subsequently minimized odor emissions. The difference in oxygen consumption was felt to be due mainly to biomass autoxidation.

Neutralization requirements

The 3-ton/day (2.7-metric ton/day) lime feed system has proven adequate in size to maintain a neutral pH (6.5 to 7.5) in the secondary treatment facility when the system is in equilibrium. However, during June and July of 1977 when the MLSS concentration was subsequently above the proper operational level, supplemental alkalinity had to be added, not only to maintain a neutral pH but also to suppress odor emissions. Increased alkalinity consumption approximated 100 to 110 mg/liter (as $CaCO_3$).

Secondary clarifiers

The secondary clarifiers were sized from settling column tests to afford not only an effluent low in TSS but also a concentrated return secondary sludge. The tests indicated a return sludge concentration of up to 1% solids was feasible.

A review of operational data has indicated that when the solids flux rate on the secondary clarifiers is in the vicinity of 0.3 to 0.4 lb/ft²/hr (1.5 to 2.0 kg/m²/hr) and a sludge recycle rate of approximately 10% is utilized, the return sludge concentration approaches 1.2-1.5% solids. Associated sludge blanket depth has been about 5 ft (1.5 m). At a flux rate of 0.5 to 0.7 lb/ft²/hr, a sludge recycle rate of 50%, and a blanket depth of 2 ft (0.6 m), return sludge concentration has been noted to decrease to approximately 1.0% solids.

The MLSS built up throughout the winter of 1976-1977. By mid-June, the MLSS concentration had reached 3300 mg/liter. The corresponding flux rate increased to approximately 1.0 lb/ft²/hr (4.9 kg/m²/hr). At that point, the secondary clarifier effluent TSS increased an average of 35 to 40 mg/liter for about a 4-week period. By late June, with increased sludge dewatering, the MLSS was beginning to decrease. By last June, with increased sludge dewatering, the MLSS was beginning to decrease. By mid-July, the MLSS concentration had been decreased to approximately 1200 mg/liter and the final effluent TSS were once again controllable.

During the latter halves of both February and November, filamentous growths developed in the secondary treatment systems. Sludge volume index values of up to 400 were measured. Due to poor settling characteristics of the MLSS, TSS in the final effluent once again increased. By dewatering above normal quantities of secondary sludge, these growths were brought under control and TSS concentrations in the final effluent decreased to more acceptable levels.

Secondary solids generation

At the design F/M ratio of 0.09, it was originally estimated that biomass production would approximate 0.3 lb/lb BOD_5 removed. Coupling this growth with the supplemental accumulation of nonbiodegradable TSS in the secondary system yielded a waste secondary solids estimate of 975 lb/million gal (0.12 kg/m³) of wastewater treated. Operational data have indicated that actual waste secondary solids generation/accumulation have ranged from 765 to 1020 lb/million gal (0.09 to 0.12 kg/m³) of wastewater treated.

Secondary sludge dewatering

The secondary sludge dewatering system consists of two 12-ft (3.7-m) vertical dissolved air flotation thickeners and a solid bowl centrifuge. Under normal operation, the loading to the dissolved air flotation thickeners has approximated 5 lb/ft²/hr (24 kg/m²/hr). An average polymer dose of about 15 lb/ton (7.5 kg/metric ton) of dry solids has yielded a float in the range of 3 to 5% solids. Feed of the thickened sludge to the centrifuge while employing an additional polymer dose approaching 20 lb/ton (10 kg/metric ton) has yielded a cake in the vicinity of 9 to 11% solids. Field determinations of the capture efficiencies of these units have indicated in excess of 95% for the thickeners and in excess of 90% for the centrifuge.

In mid-June 1977, it was established that as many as 630,000 lb (286,000 kg) of excess MLSS had to be removed from the secondary system to achieve the more appropriate MLVSS concentration of 1200 mg/liter. To accomplish this task, the rate of flotation unit operation was increased to 7 lb/ft²/hr (34 kg/m²/hr). Polymer dose at this rate was 20 lb/ton (10 kg/metric ton). The corresponding polymer dosage for effective centrifuge operation was estimated to be 30 lb/ton (15 kg/metric ton).

Summary

Basic design criteria for the secondary wastewater system at Great Northern Paper Company's East Millinocket newsprint mill were derived from in-depth laboratory studies. Identification and control of critical operating parameters has enabled this facility to consistently achieve the effluent limitations established by the State of Maine Department of Environmental Protection.

Received for review May 26, 1978.
Accepted Oct. 16, 1978.
Based on a paper published in *TAPPI '78 Environmental Conference Proceedings*, a copyrighted publication of the Technical Association of the Pulp and Paper Industry, Inc., Atlanta, Ga.