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*Improving Wastewater Mixing and
Oxygenation Efficiency*

White Paper

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The Problem

Mixing and oxygenation are required in most municipal and industrial wastewater treatment plants (WWTPs) to increase the rate at which bacteria digest organic material. WWTPs often use mechanical aerators to both oxygenate and mix wastewater (10 State Standards, 1997). However, much more aeration typically is needed to mix than oxygenate the wastewater. This imbalance creates an operational inefficiency when excessive horsepower (HP) for aeration is used to thoroughly mix the wastewater. Excessive HP usage increases electrical grid-power consumption, greenhouse gas emissions and operational costs (EPA 2005).

Background

The New Hampshire Department of Environmental Services directed studies at three WWTPs to evaluate the ability of solar powered circulation (SPC; Hudnell 2010, 2010a; Hudnell *et al.* 2010) technology to reduce or eliminate the need for grid-powered aeration. SPC creates long distance circulation of the water column between the depth at which the radial intake plate is set and the surface (Hudnell *et al.* 2010). SPC was expected to supply all required mixing and at least some of the required oxygen through diffusion at the air-to-water interface and entrainment of photosynthetically produced oxygen (EPA 2005). This report describes the water quality, odor control, sludge thickness, and kilowatt-hour (kWh) consumption and expenditure data 1 year prior to, and 1.25 years during, SPC treatment.

Mixing improves processing efficiency by distributing dissolved oxygen (DO) and homogeneously blending total suspended solids (TSS) and dissolved wastewater constituents (EPA 2005). Oxygenation supplies the DO required by bacteria to digest influent organic matter aerobically. Aerobic and facultative bacteria operating aerobically rapidly digest the organic matter when the biochemical oxygen demand (BOD) of the influent water is met (EPA 2002). The digestion process yields water and carbon dioxide (CO₂), and reduces carbon concentration when mixing promotes emission of the carbon dioxide to the atmosphere. Facultative bacteria operating anaerobically in the amorphous slurry near pond bottoms also digest organic matter, using oxygen supplied by nitrate (NO₃⁻) and sulfate (SO₄⁻²). This digestion process yields acids, alcohols, hydrogen sulfide (H₂SO₄) and other toxic and malodorous sulfur compounds. Anaerobic bacteria beneath the slurry in the weight-bearing sludge ingest the acids and alcohols,

producing carbon dioxide and methane (NH_3) through fermentation. Mixing promotes release of the carbon dioxide and methane to air, thereby lowering carbon and nitrogen concentrations in the water. Maintaining oxygen in the top few centimeters or more provides an odor cap by oxidizing the malodorous sulfur compounds to odorless sulfate.

Nitrogen from influent ammonia also is released to air as elemental nitrogen gas (N_2) when nitrification is followed by denitrification. Aerobic, nitrifying bacteria oxidize ammonia (NH_3) to nitrite (NO_2^-), and further to nitrate (NO_3^-), using DO and bicarbonates (forms of HCO_3^-) during energy production (EPA 2002a). The rate of nitrification is highest at pH of about 7.5-9.0 and temperature of about 15-35 °C (Shammas 1986). Denitrification primarily occurs when facultative bacteria oxidize organic matter in anaerobic areas of ponds. Heterotrophic, denitrifying bacteria reduce nitrate to nitrogen oxides (NO_3^- , NO_2^- , NO , N_2O), and ultimately nitrogen gas, during respiration. The rate of denitrification is highest at pH of about 7.5-8.5 and temperatures of about 25-35 °C (Zumft 1997). The nitrogen gas is emitted to the atmosphere, enabling effluent nitrogen-discharge levels to be met.

Mechanical aeration consumes most of the electrical power in WWTPs (10 State Standards, 1997). Approximately 1 HP for aeration is required to produce 0.9 kg DO/hr (2 lbs DO/hr). Each kilogram of influent BOD requires approximately 1.5 kg DO for digestion in aerobic lagoon systems. Approximately 4.6 kg DO are required to convert 1 kg of ammonia to nitrate during nitrification. Most of the DO is recovered if denitrification follows nitrification in the same pond. However, mixing usually determines the amount of aeration needed. HP requirements for oxygenation and mixing are calculated, and the larger of the two plus 15-20% excess capacity typically is installed.

Partial mix pond systems with 3-5 relatively large cells and 30-180 day detention times are the most common aerated systems in the U.S. Mixing requires approximately 8-15 HP/3,785 m³ (1,000,000 gal) wastewater in the primary cell, and 6-8 HP/3,785 m³ wastewater in subsequent cells. The HP required for mixing is usually much greater than that required for oxygenation in partial mix systems.

Total mix systems, relatively uncommon in the U.S., were designed to eliminate the inefficiency caused by the imbalance of HP needed for mixing and oxygenation. A small primary cell is generally sized to equalize the HP needed for mixing and oxygenation at 30 HP/3,785 m³ wastewater. The second cell is usually the last cell, and requires about 6 HP/3,785 m³ wastewater to suppress algae that could cause BOD and/or TSS permit violations.

Waste sludge storage ponds in activated sludge systems are usually aerated to provide an “odor cap” of 2 mg/l DO or more in the top 0.5-1.0 m to oxidize hydrogen sulfide and other malodorous sulfur compounds to odorless sulfate. Although the required DO is often supplied by algae and surface reaeration, odor events may occur during seasonal turnovers when the sulfur compounds move with bottom water to the surface without passing through oxygenated water. Odor events also may occur when aerobic digestion of dissolved organics such as sugars in the upper water column depletes the DO.

A U.S. Environmental Protection Agency evaluation of SPC use at several WWTPs concluded that SPC reduces electrical grid-power consumption and operational costs, as well as odor events, greenhouse gas emissions and sludge buildup (EPA 2005). The current study sought to quantify the effects of SPC on operational efficiency, water quality, odor events and sludge thickness.

Goals and Objectives

The New Hampshire Department of Environmental Services established the primary goal of increasing operational efficiency at WWTPs while meeting National Pollutant Discharge Elimination System (NPDES) standards. Secondary goals were to reduce grid-power consumption and operational costs while improving or maintaining effluent quality. The Department directed pilot studies at WWTPs in Rochester, Exeter and Pittsfield, New Hampshire, to assess the efficacy of solar-powered circulation (SPC; Hudnell *et al.*, 2010; Hudnell 2010) at mixing wastewater and reducing the need for mechanical aeration. Objectives of the studies were to discontinue usage of some aerators after initiating SPC, monitor water quality parameters, sludge thickness and odor events, and calculate reductions in kilowatt-hour (kWh) consumption and expenditure.



Figure 1.

SB10000v18
deployed in a
Pittsfield, New
Hampshire,
WWTP lagoon.

Methods and Results

Study site descriptions, HP used for aeration, SPC unit deployment and kWh usage are provided in Table 1. BOD, TSS, DO, ammonia and nitrate levels were systematically measured (Eaton *et al.*, 2005) throughout the study period of April 2006 through June 2007 for comparison with data collected the year immediately prior to SPC deployment. Malodorous events were monitored throughout the study period, sludge and slurry thickness were measured at the beginning and end of the study period, and cost savings through reduced grid-power consumption were calculated at the end of the study period.

Table 1. Study site descriptions, aeration HP, SPC units and kWh usage before & during study

	Total # Lagoons used in study	Total Surface Area (acres)	Total Water Volume (million gallons)	Total Aeration HP in place	# SPC Units Used	Mean kWh/ month Pre- SPC¹	Mean kWh/ month During- SPC¹
Exeter²	3	28.1	77.4	327.5	6	166,313	91,960
Pittsfield²	4	5.2	12.3	78	4	50,043	28,373
Rochester³	2	18.3	41.7	140	5	83,400	7,709

¹ kWh is all electrical-grid power used at the plants, including that used for aeration

² Partial mix pond system using aeration and mixing in the initial lagoons

³ Activated sludge system using aeration and mixing in the raw septage and sludge storage lagoons

Exeter met all NPDES limits throughout the study. Effluent levels of BOD, TSS, ammonia and nitrate were similar before and during SPC. DO levels initially dropped below 2 mg/l in all three lagoons when six SPC units and only 87.5 of 327.5 HP aeration were deployed. DO concentration in Lagoons 2 and 3 recovered to ≥ 2 mg/l within 1 and 4 months, respectively, with additional aeration. The additional aeration was discontinued after 5 months. DO was consistently between 0.5 and 1.8 mg/l in Lagoon 1. Odor events were not experienced. Sludge levels decreased in Lagoons 1 and 2, but increased in Lagoon 3, resulting in no net change during the study period. Electrical-grid power consumption decreased by 1,115,295 kWh, resulting in an annualized cost savings of \$89,160 and a 3-year payback period.

The results from Pittsfield were similar to those of Exeter; all NPDES limits were met throughout the study. Aerators were activated as needed to maintain DO levels above 2 mg/l after the 4 SPC units were deployed. Ammonia reductions >95% from June through early November indicated enhanced nitrification. Odor events were not experienced. Sludge levels increased in Lagoons 1-4 by 0.1, 0.04, 0.02 and 0.006 m, respectively. Annualized electrical-grid power consumption decreased by 260,040 kWh, resulting in a cost savings of \$32,037 and a 3.9-year payback period.

Rochester successfully converted Cells 1 and 2 from aerated lagoons to equalization basins when SPC was deployed. The basins received sludge from Cell 3, raw septage, filter backwash and raw sewage during the rainy season. Rochester met all NPDES limits without using mechanical aeration during the study. Pre- versus during-SPC comparisons indicated slight increases in BOD and TSS as expected due to the conversion. Sludge thickness increased slightly, but was deemed to increase at a slower rate than pre-SPC, although objective data were not available. Pre- and during-SPC comparisons indicated no change in ammonia and nitrate concentrations, and marked improvements in pH and alkalinity. Metals were not resuspended into the water column during SPC. Annualized electrical-grid power consumption decreased by 908,292 kWh. Annualized cost savings was \$127,449, including \$3,760 realized through reclassification to a lower rate schedule due to reduced consumption. The payback period was 1.5-years.

Discussion and Conclusion

Each of the pilot studies was considered a success; operational efficiency was increased and NPDES limits were met. Grid power consumption fell sharply when SPC supplied the mixing and part of the oxygenation previously obtained through aeration. Operational costs declined as SPC reduced or eliminated the need for aeration while maintaining or improving effluent quality. Each of the WWTPs continues to deploy SPC. Innovative mixing design powered by solar panels conserved DO, reduced electrical grid-power consumption and operational costs while reducing greenhouse gas emissions.

For additional information visit the SolarBee home page: <http://www.solarbee.com/>, or call 866-437-8076.

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