SolarBee®

Circulating the World's Water

Solar-Powered Circulation:

Applications in Electrical Power Utility Waters

White Paper

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Overview

Solar-powered circulation (SPC) of water is used to solve a variety of water quality problems in drinking-source and recreational reservoirs, potable-water storage tanks, wastewater lagoons, storm-water runoff ponds and industrial water bodies. This report describes SPC technology and current applications in electricity generating utilities. These applications include: 1) enhanced evaporation and heat loss in cooling basins; 2) oxygenation and warming of reservoirs during winters in northern climates; 3) suppression of harmful algal blooms (HABs) and invasive macrophytes in nutrient-enriched water bodies; 4) prevention of noxious odor events in water bodies with high sulfide levels, and; 5) enhanced degradation of the anticorrosive compounds, hydrazine and ethanolamine (ETA), in wastewater.

SPC Technology

SolarBee, Inc., SPC units are comprised of three pontoons supporting a platform consisting of above water, near-surface and underwater components. Three 80 watt solar panels, an electronic control box, a low-voltage, high-efficiency brushless motor, and accessories are mounted on an above-water frame. The one-half horsepower, direct-drive motor operates at 90% or greater efficiency. A distribution dish, impeller and battery are attached to the frame and suspended just below the surface. A flexible intake hose, three feet in diameter, is attached to the base of the impeller. A steel plate suspended one foot beneath the hose causes water at that density layer to be drawn in radially with near-laminar flow from long distances. Water intake depth is adjusted using chains attached to the intake plate and secured to the frame. Two moorings attached to the frame with chains maintain the spatial position of the unit. The impeller operates continuously, day and night, at 80 RPM unless the controller is programmed to vary by time of day, or prolonged periods of low light incidence cause the electronic controller to reduce the RPM or deactivate the system temporarily. The largest units pump approximately 37.85 m^3pm (54,510 m^3pd; 10,000 gpm; 14.4 M gpd) of water to the surface. A direct flow of approximately 11.36 m^3pm (3,000 gpm) ascends through the intake hose and departs from the unit at low velocity immediately above and below the distribution dish. Another 26.5 m^3pm (7,000 gpm) of induced flow ascends outside of the hose and departs from the unit without turbulence below the distribution dish.

The SPC unit’s intake depth is set at a level determined by the water quality objective. For example, a shallow intake depth is used in hot water cooling ponds and lakes to enhance evaporative heat loss. The intake is typically set just above the thermocline for HAB and invasive macrophyte suppression. The intake is usually set near the bottom for odor control and oxygenation of the hypolimnion. Intakes in wastewater are generally set just above the anoxic zone where anaerobic bacteria in sludge digest some compounds.

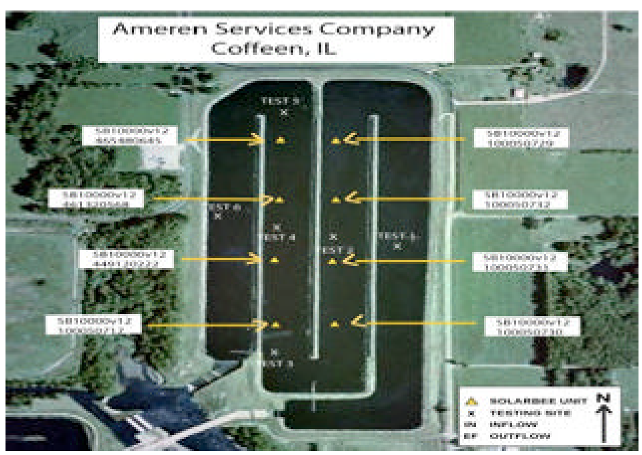
Enhanced evaporation and heat loss in cooling basins

Heated cooling water is often sent to cooling basins before release to receiving waters or re-use at power generation plants. Cooling is usually required for one of two reasons. First, National Pollutant Discharge Elimination System (NPDES) permits often specify a temperature that water cannot exceed when discharged into receiving waters. Second, fuel consumption in the plant declines with the temperature of the incoming cooling water. Condenser-vacuum loss decreases, and power generation efficiency increases, with decreasing temperature of the incoming cooling water.

Cooling in reservoirs occurs mainly through evaporation of surface water. Evaporation releases heat from the water body and cools a thin layer of water molecules at the surface. A convective current is formed such that the cooler molecules on the surface flow down as deeper and warmer molecules flow to the surface, thereby enabling evaporation to continue. However, the formation of convective currents is a slow process. SPC enhances the rate of evaporation by creating a circulation pattern that continually disperses warmer water across the surface.

The *Ameren Central Illinois Service Corporation,* Coffeen, IL, deployed SPC units in a serpentine cooling basin to model the increase in heat transfer rate during calm summer months. The 0.28 km^2 (70 ac), 4-channel basin has a depth of 1.83 m (6 ft). Measurements were made in four conditions:

1) no SPC;
2) 4 SPC units in arm 2, but none in the corners of the arm;
3) 8 SPC units in arms 2 & 3, but none in the corners of the arms;
4) 8 SPC units in arms 2 & 3 with 4 of the units in the arms' corners



Condition 3 above. The yellow triangle show placement of 8 SPC units in arms 2 & 3 of the Ameren cooling basin. None of the units are in the arms' corners.

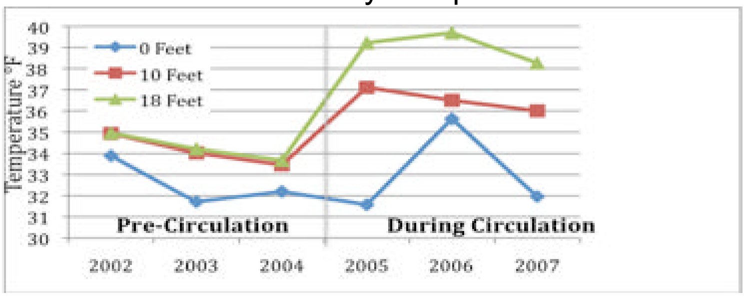
The utility's Mike Womack developed a model to estimate the increase in heat loss for conditions 2, 3, and 4 relative to condition 1. Measurements were made over 4 hr periods during 4-8 trials per condition. Model input parameters were water temperatures at the basin's inlet and outlet, ambient temperature, flow rate, wind speed, heat transfer rate, overall heat transfer coefficient, and dimensionless temperature ratio. The results indicated that heat loss increased by a mean of 0.74, 1.43, 2.63 °C (1.34, 2.58 and 4.73°F) during the 4 hr periods of conditions 2, 3 and 4, respectively. The enhanced cooling rate produced by SPC enabled the utility to meet NPDES limits while reducing retention times.

Oxygenation and warming of reservoirs during winters in northern climates

Utility reservoirs used for plant purposes and recreational fishing face operational challenges in northern climates where the reservoirs typically freeze over in the winter. Healthy fisheries require at least 3 mg/L of dissolved oxygen and temperatures around 3.88 °C (39°F) in bottom waters during winter. The water at the bottom of frozen water bodies is typically 3.88 °C because water density is greatest at that temperature. Reservoirs with high dissolved oxygen demand in the hypolimnion often become anoxic during winter, resulting in fish kills. The use of aerators to supply dissolved oxygen to the hypolimnion often prevents ice from forming on the surface, and transports the warmer bottom water to the surface. Heat escapes from the warmer water to air at the open surface, causing the mean temperature of the water body to decline. Fisheries decline in such reservoirs due to the cooler temperatures caused by aeration or anoxia when oxygen is not replenished at the bottom.

Dairyland Power, Alma, WI, is under state order to maintain a healthy fishery in a reservoir that is a backwater of the Mississippi River. The fishery in the reservoir was in decline due to anoxia in bottom waters during winter. High sulfur compound concentrations and HAB die offs created high chemical and biological oxygen demands. The utility installed an aeration system in the reservoir to supply oxygen during winters. Aeration prevented ice from forming on much of the surface, causing the fishery to further decline as bottom temperatures decreased when the warmer water was transported to the open surface. The utility installed one SPC unit in the 0.11 km^2 (27 ac), 5.49 m (18 ft) deep reservoir during 2004. Circulation supplied oxygen sufficient to support the fishery and oxidize the sulfur compounds while leaving only a small opening in the ice at the surface. Fishermen reported continuing improvement in fishery health the following two years. A massive snowstorm blanketed the solar panels on the SPC unit during 2007. A fish kill occurred when the SPC unit ceased operation because snow was not cleared from the panels. The fishery has continued to improve since that time, and operational costs remain lower because electricity for aeration is not required.

February Temperatures



SPC increased water temperatures at middle and deep depths in the Dairyland Power reservoir during winters relative to those seen when aeration was applied during the pre-circulation period.

Suppression of harmful algal blooms and invasive macrophytes in nutrient enriched water bodies

Freshwater harmful algal blooms, rapid and massive expansions of cyanobacteria (a.k.a. blue-green algae) or other phytoplanktonic populations, pose serious risks for human and animal health, aquatic-ecosystem sustainability and economic vitality. Dozens of HAB species produce some of the most potent toxins known, and huge bloom biomasses deplete dissolved oxygen after bloom die offs as the cells decay (Hudnell [Ed.], 2008). Cyanobacteria and other freshwater HAB organism most often bloom when four stimulatory factors are present: 1) warmth >20 °C (68°F); 2) nutrients (primarily N & P); 3) sunlight, and; 4) quiescent or stagnant water. Utility reservoirs, wastewater lagoons and cool basins often provide ideal conditions for HABs due to high temperatures and nutrient levels, and long detention times. Chemical approaches to HAB control cause adverse ecological effects, are not environmentally sustainable, and are expensive due to the need for repeated applications (Hudnell, 2009). Strong HAB suppression that strengthened over time was recently demonstrated using planktonic data collected by drinking source-water utility personnel before and during SPC (Hudnell, *et al.,* 2009). SPC unit density was approximately one per 0.14 km^2 (35 ac). Although comparable data are not available from electrical power utilities, observations and decreased pH levels indicate equally effective HAB suppression.

The *Platte River Power Authority*, Ft. Collins, CO, experienced *Microcystis* blooms year round in their 1.94 km^2 (480 ac) cooling source-water, Hamilton reservoir. The perpetual HAB caused pH to remain above 9, increasing the amount of scaling in the cooling towers. The utility unsuccessfully attempted to terminate and control the HAB using 200 HP of continually deployed aeration equipment. The HAB was terminated within 6-8 weeks after deploying SPC units in 2005. Secchi disk measures of water clarity improved from a mean of < 0.91 (3 ft) to > 2.74m (9 ft). The HAB remains suppressed and pH values are consistently under 9. Aeration was terminated and chemical applications for scaling were reduced. Similar results were obtained in *Fort St Vrain, Xcel Energy*, Platteville, CO. cooling source-water ponds.



Left, Microcystis, a producer of hepatotoxic microcystins and other cyanotoxins, continually bloomed in the nutrient rich and warm waters of Hamilton Reservoir prior to SPC. Middle, Eleven SPC units were deployed for HAB control in 2005 (1 SPC unit/43.6 ac). Right, one of the SPC units in Hamilton Reservoir.

Partial lake treatment was applied in a 0.17 km^2 (4.1 ac) cove home to a park and marina in the *Sheerness Generating Station*, Alberta, Canada, 5.26 km^2 (1,300 ac) cooling source-water reservoir. The reservoir and cove experienced HABs, and prolific growth of the invasive macrophyte curly-leaf pondweed (*Potamogeton crispus*), during summers prior to SPC. A harvester was used frequently to remove the macrophyte from the cove, but was ineffective against the blue-green algae. One SPC unit was deployed in the cove during the spring of 2004. HABs have been suppressed consistently since that time. Blooms blown from the reservoir into the cove by seasonal winds were dissipated within a few days. John Armstrong, the Park Supervisor, estimated that curly-leaf pondweed coverage was reduced by 50-60% during the first year of SPC. Harvesting was discontinued the second year because little curly-leaf pondweed was observed in the cove, even as the macrophyte thrived in the rest of the reservoir.



Left, a diagram showing the SPC unit location (yellow triangle) in the cove of the Sheerness Reservoir. Middle, the harvester and curly-leaf pondweed at docks of the marina in the cove. Right, the SPC unit in the cove with the Sheerness power utility in the background.

<u>Prevention of noxious odor events in water bodies with high sulfide levels</u>

Malodorous sulfur compounds such as hydrogen sulfide, a toxic and flammable gas, are produced by anaerobic bacteria in the sludge at the bottom of wastewater lagoons. Large quantities of the compounds are produced in waters high in sulfate concentration. The compounds accumulate in the hypolimnion, beneath the thermocline, until quantities are sufficiently large to create a "release event" during which the gas bubbles to the surface. Such events may last for months, during which the "rotten egg" smell plagues surrounding areas. Utilities commonly oxidize the compounds with chlorine, often in the form of sodium hypochlorite or hydrogen peroxide, to form compounds that do not cause foul odors or tastes. Costs of the chemical applications can be very high. Aeration systems also are used to continually oxidize and transport some of the sulfur compounds to the epilimnion and atmosphere.

An alternative approach to aeration and chlorine-based oxidization is enriching the water with oxygen from the air using SPC. Oxygen is transported to the hypolimnion, and small amounts of the sulfide compounds are continuously transported through the oxygen rich epilimnion, when the SPC unit intake is set near the bottom. This method of oxidizing the compounds prevents "odor events" and significantly reduces operational expenses.

Sulfur compound "odor events" occurred for 2-3 months each year at the *Excel Energy Pawnee Plant*, Brush, CO. The utility regularly applied large quantities of chlorine to oxidize the compounds in the 0.55 km^2 (137 ac) reservoir where detention times are 137 days. Two SPC units were deployed in 2007 with intakes extended 7.01 m (23 ft) into the deepest portion of the reservoir. "Odor events" have not occurred since SPC deployment. Ken Weiser, a manager at the utility, reported saving $200,000 per year on chlorine applications since circulation was initiated.

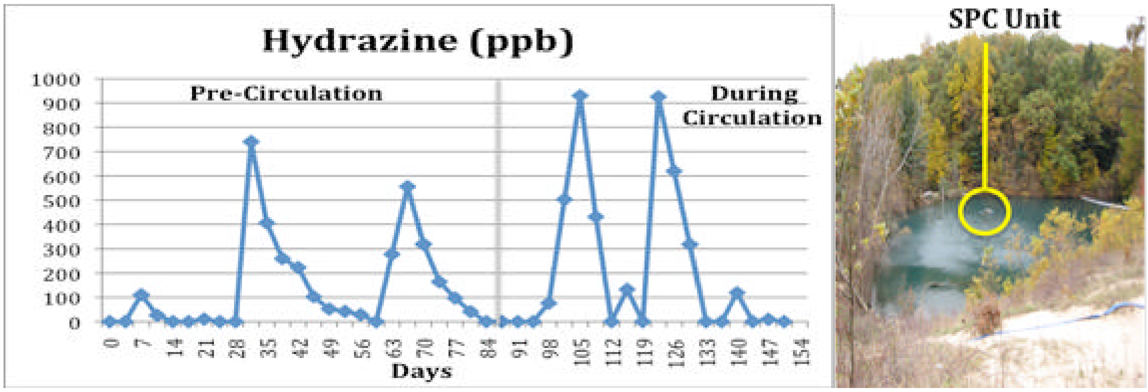
Similar "odor events" occurred yearly at the Final Waste Evaporation Pond of *Tri-State Generation & Transmission Association, Inc*., Craig, CO. The 0.20 km^2 (50 ac) pond is 9.14 m (30 ft) deep in the north end, inclining to ground level at the south end. The pond water contains 22,000 mg/L sulfate, creating a chemical oxygen demand of 700 mg/L. The utility considered adding an aeration system to the pond, but sought alternative solutions due to the estimated monthly expense of $2,000-3,000 for grid power. The utility chose SPC because one unit typically displaces 20-40 hp of grid energy required for aeration. At an average aeration displacement of 30 hp, one unit displaces about 25,000 watts of electricity. Two SPC units were deployed in the deeper north end of the pond during 2005. The units' intakes were set at 7.01-8.53 m (23-28 ft) to continually oxidize and de-gas the lower depths of the pond, thereby preventing buildup of the sulfur compounds below the thermocline. "Odor events" have not occurred since SPC deployment.


Left, location of two SPC units (yellow triangles) in the Pawnee Plant reservoir. Middle, installation of an SPC unit in the Tri-State utility. Right, location of two SPC units (yellow triangles) in the Final Waste Evaporation Pond at Tri-State.

Enhance degradation of the anticorrosive compounds, hydrazine and ethanolamine (ETA) in wastewater

Nuclear power utilities periodically supplement water with pH control compounds to prevent corrosion and passivate oxidized areas of iron pipes servicing steam generators. Hydrazine (N_2H_4) reacts with oxidized piping to form protective layers of magnetite, and increases pH through ammonia production. Ammonia is a preferred nutrient source for HAB organisms. Ethanolamine (ETA; C_2H_2NO) also raises pH, but increases biological and chemical oxygen demand, as well as N concentrations in wastewater. Both hydrazine and ETA are toxic to humans and aquatic organisms. Wastewater containing hydrazine and ETA must be treated prior to release because of NPDES and other environmental discharge standards concerning toxicity of the compounds, oxygen demand and N concentrations.

Both hydrazine and ETA are used at *American Electric's Cook Nuclear Power Plant*, Bridgeman, MI. The wastewater is retained in a 0.005 km^2 (1.2 ac), 1.83 m (6 ft) deep pond until discharge limits can be met. The treated water is injected into the ground where it travels to Lake Michigan through a direct vent. The long detention times required to meet discharge limits occasionally caused wastewater quantity to exceed pond capacity. The utility installed a small SPC unit in the pond during 2002. Measurements of hydrazine and ETA concentrations in the wastewater showed that degradation rates of the compounds increased during circulation. The state dropped the requirements to measure hydrazine and ETA concentrations in 2006 because of the enhanced degradation rates. Blair Zordell, an environmental specialist at the utility, reported that the state was impressed because: 1) the utility initiated circulation without a requirement to do so; 2) the circulator was solar powered, and; 3) the compound concentrations when released were well below those desired by the state. Mr. Zordell further reported that SPC enabled the utility to avoid potential regulation of the compound discharge levels, and that the utility commonly refers to SPC treatment when seeking changes in their permit.



SPC shortened the time period needed to degrade hydrazine in American Electric's wastewater pond.

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