**Beaver EcoWorks and It's Novel Advanced Oxidation Process Technology**

Sanjeev Jakhete is a serial entrepreneur. Throughout his many technology patents one theme unites them all—electrochemistry, i.e., electrochemistry to treat wastewater. The technology underlying his latest venture, Beaver EcoWorks, is advanced oxidation processes (AOP). You name it—organic compounds, pathogens, heavy metals, BOD and dissolved gases. AOP oxidizes and destroys it.

AOP technology has been around for about two decades. Most wastewater AOP systems are based on the creation of the all-powerful OH radical. That is typically done by UV radiation of a hydrogen peroxide solution or ozone. Electro-oxidation is a technique that inserts two electrodes that impose a high voltage current between them. The chemistry that occurs at the anode and cathode creates species that oxidize organic compounds, sulfur compounds and metals.

The Beaver EcoWorks process is a unique AOP process based on electro-oxidation. There are three oxidizing species that arise in the EcoWorks AOP system:

The first oxidizing agent is chlorine. Since wastewater almost always contains salts, the anode oxidizes chloride ($Cl^-$) to chlorine ($Cl_2$):

$$2\,\mathrm{Cl}^- \rightarrow \mathrm{Cl_2(g)} + 2\,\mathrm{e}^-$$

When chlorine dissolves in water it forms hypochlorous acid:

$$\mathrm{Cl_2} + \mathrm{H_2O} \rightarrow \mathrm{HCl} + \mathrm{HOCl}\ ;\ \mathrm{HOCl} \leftrightarrow \mathrm{H}^+ + \mathrm{OCl}^-$$

The reaction on the right-hand side simply reflects the conversion of HOCl into hypochlorite ($OCl^-$) at basic (>7) pH levels.

The second oxidizing species is the hydroxyl radical (OH•) discussed in the white paper of Fife Chemical. The hydroxyl radicals are not to be confused with hydroxide anion ($OH^-$), which "wears" two paired electrons on its electron "topcoat" and is negatively charged. By contrast the hydroxyl radical is neutral (uncharged) by virtue of its single unpaired electron. It is desperate to become a hydroxide anion and, therefore, readily "steals" an electron from a molecule that can be oxidized, e.g., most organic compounds. In the atmosphere, the hydroxyl radical is nature's oxidizing agent but, like any radical, it is rarely found in water, which, by virtue of the polar water molecule, prefers to keep the company of charged ions. Electro-oxidation and UV light both generate hydroxyl radicals. The electro-oxidation reaction at the anode requires only water:

$$\mathrm{H_2O} \rightarrow \mathrm{OH}\bullet + \mathrm{H}^+ + \mathrm{e}^- \ \mathit{or}\ \mathrm{OH}^- \rightarrow \mathrm{OH}\bullet + \mathrm{e}^-$$

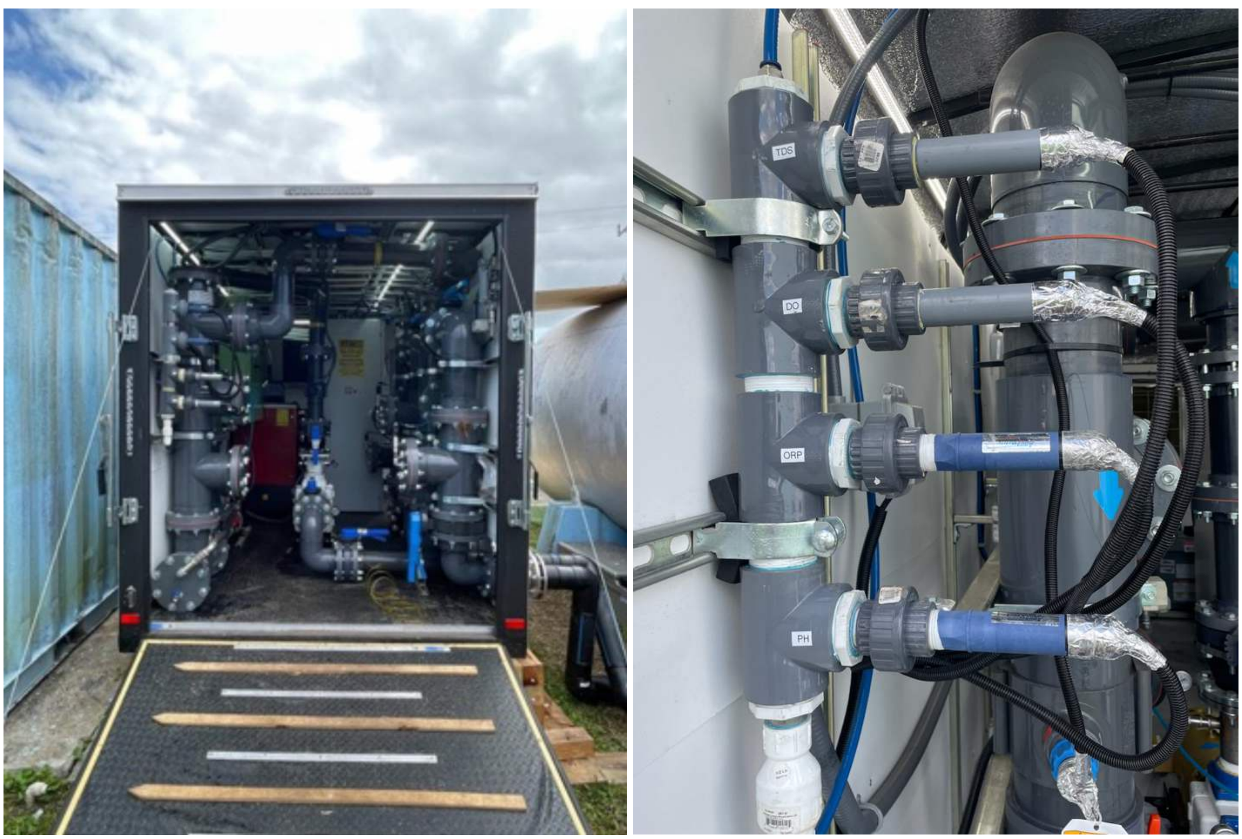
The proprietary electrodes in the EcoWorks AOP system creates a third oxidant—ozone:

$$\mathrm{O_2} + \mathrm{H_2O} \rightarrow O_3 + 2\,\mathrm{H}^+ + 2\,\mathrm{e}^-$$

To be complete we can include minor oxidants that are created, such as chlorine dioxide ($ClO_2$) and hydrogen peroxide ($H_2O_2$). Let us also not forget that the surface of the anode itself is an oxidizing agent.

A properly designed electrolytic cell in an AOP system produces a rich broth of oxidants that is more than up to the job of breaking down organic compounds, oxidizing metals and sulfides and disinfecting pathogens. The key to any AOP pretreatment system is to control the voltage applied to the electrodes so that the generation of oxidizing species occurs at a constant level.

Oxidizing agents are the most common tools in the AOP toolbox. Beaver EcoWorks goes beyond traditional AOP. It adds an additional weapon to it oxidant arsenal—ultrafine bubbles, aka "nanobubbles." Nanobubbles are a minor miracle. They are defined as a bubble that is less than 200 nm in diameter—about 5000 times smaller than a typical bubble. For a given D.O. concentration nanobubbles give a surface area that is about 25,000 times that of typical bubbles. That's a lot of chemical activity, and that activity is the result of their internal pressure being about 10,000 greater than a regular bubble. So, when they implode the release enough energy to generate more OH• radicals and break down organic compounds. Better yet, they have a negative surface charge, so they avoid one another and stay in suspension much longer than conventional bubbles. As a bonus, nanobubbles increase dissolved oxygen concentrations, which is nature's most common oxidizing agent in water. The EcoWorks system incorporates its own proprietary nanobubble generator that maintains a D.O. concentration of 8 ppm in wastewater and 20 ppm in drinking water, the latter being 150% saturation. Nanobubbles in this system are on the order of 10 nm.




*Left: Trailer containing the Beaver EcoWorks AOP pretreatment system for the Indiantown, Florida. Right: AquaMetrix differential pH, differential ORP and conductivity sensors for monitoring the AOP system.*

Any number of electrolytic cells can comprise an AOP system to treat anywhere from 50 to 1000 gallons per minute. A PLC controls all three processes. The PLC adjusts the power to the reactor to optimize the current water chemistry. This modular system can treat wastewater from oil and gas production, mining, environmental contamination, manufacturing and municipal waste, and drinking water. The efficacy of the EcoWorks AOP system was demonstrated as pretreatment at the Indiantown, Florida drinking water treatment facility in collaboration with the USEPA. The system is neatly packaged into a trailer and processes 400-500 gal/min. After 30 days in operation the plant confirmed several improvements in water quality following pretreatment that enabled operators to eliminate ammonia injection and pre-chlorination. Disinfection byproduct concentrations practically vanished, oxidized heavy metals, reduced water hardness and improved taste and odor of the drinking water.

Controlling an AOP process requires monitoring it. Although a chlorine analyzer is the obvious choice for measuring free chlorine levels, ORP measurements are simpler, easier to maintain, and more representative of the total oxidizing potential of the mix of oxidizing agents. Sanjeev's team performs spot measurements of free chlorine concentration using a handheld meter to ensure that those levels are maintained at approximately 0.5 ppm. Interestingly, ORP values of this powerful oxidation machinery are only in the range of 250 to 300 mV rather than 700 to 800 mV expected for 0.5 ppm free chlorine alone. This surprisingly low ORP value is due to the large concentration of oxidizable content of the raw water (mainly organic compounds) that consumes chlorine and the other oxidizing agents as fast as they can be produced.

Since oxidation efficacy, or ORP, is dependent on pH, measurement of pH levels is also essential. Lastly, conductivity serves as a real-time indicator of water quality, so its measurement is highly advised. The photo on the right-hand side shows this trio of sensors.

Measuring pH, ORP and conductivity in wastewater requires sensors designed to operate in harsh conditions. Furthermore, introducing a high voltage into wastewater can overwhelm the high-impedance electrical circuit that comprises a typical pH or ORP probe. Sanjeev was familiar with the AquaMetrix differential probe from his previous wastewater processing companies and had developed a very high comfort level that the AquaMetrix probe worked reliably in this challenging environment. He also used the AquaMetrix AM-2300 to process the signals of the three sensors and send the finished signals to his SCADA system. Since installing them in his Beaver EcoWorks AOP systems they have worked without failure. The differential circuit of the pH and ORP sensors minimize stray voltages that work their way into the sensing environment and allow replenishment of the reference solutions when they invariable become contaminated. The AM-2300 makes it easy for the user to set-up, calibrate and monitor the three probes and any other analog sensors.