

## UNDERWATER PLASMA: A NEW REMEDIATION TECHNOLOGY FOR MTBE and BTEX

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**Abstract:** Concurrent Technologies Corporation (CTC), Keramida Environmental, Inc./Teknicon, LLC, TechSavants, Inc., and Furness-Newburge, Inc. are involved in the Casting Emissions Reduction Program (CERP) at McClellan Airpark in Sacramento, CA. CERP is a full-scale research and development foundry facility funded and run jointly by the U.S. government, U.S. automobile manufacturing companies and private industry. CERP's goal is to identify lower emission processes within the metal castings industry. This research is important to ensure that the U.S. remains competitive in automobile manufacturing and that the U.S. Department of Defense capabilities (as a major consumer of castings) are not compromised.

As part of CERP, proprietary advanced oxidation (AO) technologies are being used to treat effluent cooling water from the castings processes. Maximizing opportunities provided by the CERP research foundry, Teknicon, LLC and CTC have begun working with the policy-makers in the Sacramento Area to create an environmental technology campus centered on CERP. This technology campus provides opportunities to address other media contamination issues facing the nation, while identifying, testing, and deploying next-generation technologies.

Conducting research to utilize one of the AO technologies to address groundwater issues, this coalition of companies is providing for management and recycling of water resources into the future.

### **Technology Background**

TechSavants, Inc. and Furness-Newburge, Inc. have investigated the use of laboratory-scale underwater plasma (UWAP) technology integrated with advanced oxidation and vapor stripping to remediate methyl-tert-butyl ether (MTBE) and benzene, toluene, ethylbenzene, and xylene (BTEX) compounds in groundwater simulants. Vapor stripping was used with and without ozone and hydrogen peroxide. The goal of these tests was to evaluate the synergistic effects of combining the underwater plasma technology with vapor stripping. Vapor stripping, by itself, does not destroy MTBE or BTEX. However, by integrating underwater plasma, advanced oxidation, and vapor stripping, the compounds can be rapidly and effectively destroyed.

The underwater plasma (UWAP) technology is actuated by setting off an electrical discharge in a liquid medium by pulsing a sparking device. In the laboratory skid-mounted system, a capacitor stores up to ~6,000 volts of electricity, then discharges it in a 4 microsecond pulse. As a result of this discharge, the water attempts to expand ~1800x by converting liquid water into steam in a microsecond. This attempted expansion creates a tremendous shock wave that travels rapidly through the liquid. Additionally, the shock waves create hydroxyl radicals ( $\bullet\text{OH}$ ) and hydrogen radicals ( $\text{H}\bullet$ ), which are

very effective for destroying organic compounds. The radicals are formed through the dissociation of water molecules ( $\text{H}_2\text{O}$ ) into the hydroxyl and hydrogen radicals:  $\text{H}_2\text{O} \rightarrow \bullet\text{OH} + \bullet\text{H}$ . The formation and combustion of hydrogen ions results in secondary shock waves that form immediately after the primary shock wave is released, producing additional radicals.

The UWAP technology degrades organic compounds through chemical and physical effects. Chemical effects come via the implosion of microbubbles that generate free radicals which react easily with organic compounds. In addition, when ozone ( $\text{O}_3$ ) and hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) are added, additional radicals are produced, resulting in even greater rates for organic contaminants to be oxidized underwater. Physical effects are caused by shock waves formed during symmetric cavitation or by microjets formed during asymmetric cavitation. This technology has been shown to be extremely effective for destroying organic contaminants such as chlorinated solvents and petroleum hydrocarbons.

A high voltage, high current pulsed power supply is being developed for downhole application of the UWAP technology. Although controllable and adjustable, the UWAP technology will require carefully designed power level experiments to be carried out in a laboratory setting before going to the field.

### **Approach**

Laboratory experiments were performed using UWAP alone, vapor stripping alone (operated at an air injection rate of  $\sim 1,000\text{-mL/min}$ ), and the combined UWAP/vapor stripping system (performed with and without addition of  $\text{O}_3$  and  $\text{H}_2\text{O}_2$ ). The UWAP power ranged from 4000-5700 volts, discharged from 50-80 times per minute. Ozone was added at  $\sim 200$  ppm at 30 psi and hydrogen peroxide at  $\sim 30$  ppm. The benzene concentration ranged from 50 to 850 ppm; the concentration of toluene, ethylbenzene, and xylenes were in the range of 15 to 100 ppm. Various concentrations of MTBE were studied, ranging in concentration from  $\sim 15$  ppb to  $\sim 300$  ppm.

### **Results**

Target contaminant concentrations were analyzed using gas chromatography techniques to determine the residual concentrations as a function of treatment time. After 60 minutes of treatment time, BTEX compounds and MTBE were reduced by more than an order of magnitude ( $>95\%$ ); see results presented in Table 1. Vapor stripping systems by themselves transfer the organic contaminant from the liquid phase into the gaseous phase, whereas combining UWAP with a vapor stripping system results in significant or total destruction/conversion of the organic contaminant into environmentally benign compounds (carbon dioxide and water). Employing the UWAP system coupled with vapor stripping resulted in greater than 95% removal within 90 minutes for MTBE initial concentrations ranging from the ppb range to the hundreds of ppm range. Figure 1 shows the fraction of MTBE remaining as a function of treatment time using underwater plasma combined with vapor stripping containing low levels of ozone. The curves for an initial

MTBE concentration of ~160 and ~15 ppm were virtually identical indicating the treatment performance was not concentration dependent. After treatment at the ppb level, residual MTBE concentrations below 1 ppb were obtained. Figure 2 shows the fraction of MTBE and benzene remaining as a function of treatment time using underwater plasma combined with vapor stripping containing low levels of ozone. Both MTBE and benzene are very effectively removed from solution. Over 90% of the benzene was removed within 10 minutes treatment time. This figure indicates that the presence of other contaminants (BTEX compounds in the groundwater simulant system) had little effect on the removal of MTBE.

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Table 1. Removal of Organics Using Underwater Plasma

Chemical	Phase	Initial Concentration, (ppm)		Average Concentration Reduction, (%)	Time Required to Reach this Level of Reduction, (minutes)
		Maximum	Average		
Benzene	Dissolved	850	50	94	60
				88-92	10
Toluene	Dissolved	30	15	90	30
Ethylbenzene	Dissolved	100	30	90	60
Xylenes	Dissolved	100	30	95	60
MTBE	Dissolved	300	10-20	>95	60
	Dissolved	75 ppb	40 ppb	>95	90

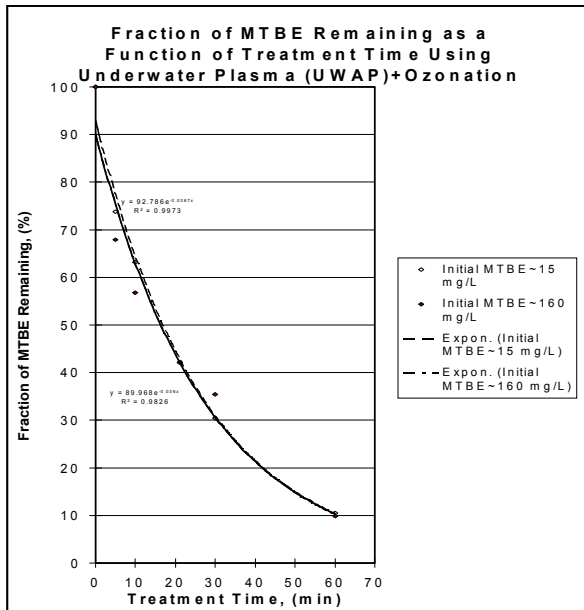


Figure 1. Fraction of MTBE Remaining as a Function of Treatment Time Using Underwater Plasma (UWAP) with Ozone Addition.

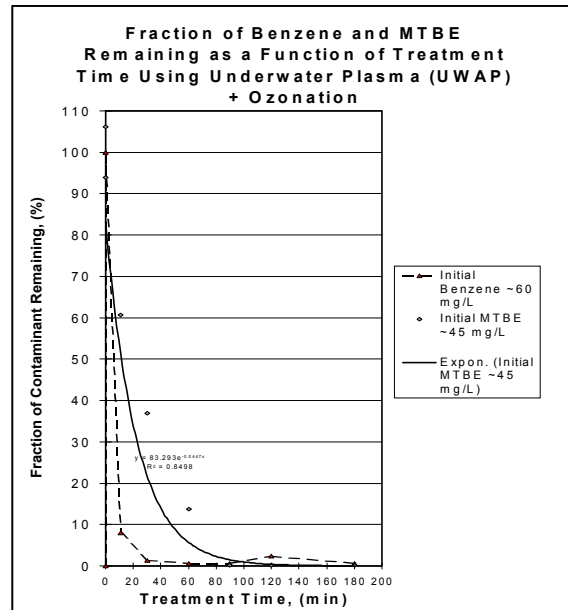


Figure 2. Fraction of Benzene and MTBE Remaining as a Function of Treatment Time Using Underwater Plasma (UWAP) with Ozone Addition.