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Electron Beam Treatment for the Removal of Benzene and Toulene from Aqueous Streams and Sludge

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Technology Description: The electron accelerator utilized in this treatment process has a potential of 1.5 MeV, rated from 0 to 50 mA, providing radiation doses of 0-850 krad (0-8.5 kGy). The horizontal electron beam is scanned at 200 Hz and impacts the waste stream as it flows over a weir approximately 1.2 m (48") wide. The influent streams (460 L min^{-1}, 120 gal min^{-1} which can be easily scaled up for larger applications) connected to the accelerator are potable (drinking) water, secondary wastewater effluent, and anaerobically digested sewage sludge.

High energy electron beam irradiation of aqueous solutions results in the following:

$$H_2O \text{ -/ \/ -> } 2.7\ OH\bullet + 2.6\ e^-_{aq} + 0.6\ H\bullet + 2.6\ H_3O^+ + 0.45\ H_2 + 0.7\ H_2O_2$$

This process is unique, in comparison to other advanced oxidation processes (AOP), in that it generates equal concentrations of highly oxidizing (OH•) and highly reducing (e^-_{aq}) species. The reactive transients initiate thousands of chemical reactions capable of destroying hazardous compounds in aqueous solution, in most cases, mineralizing them to carbon dioxide, water, and salt. The process is essentially pH independent in the range 3-11. No residual sludge is formed and no pretreatment is necessary. The reaction by-products are formed at relatively low concentration and are non-toxic. This process, therefore, represents a new ultimate disposal technology for the remediation of contaminated water, soils, and sludge.

Waste Applicability: This process has demonstrated the ability to treat complex mixtures of hazardous chemicals in drinking water, groundwater, wastewater, sludge, and water containing up to 5% w/w suspended solids. It has been shown to be effective in removing chloroform, bromodichloromethane, dibromochloromethane, bromoform, 1,1,1-trichloroethane, 1,1,2,2-tetrachloroethane, carbon tetrachloride, TCE, PCE, *trans*-1,2-dichloroethene, *cis*-1,2-dichloroethene, 1,1-dichloroethene, hexachloro-1,3-butadiene, hexachloroethane, methylene chloride, benzene, toluene, phenol, *o*-, *m*-, *p*-xylene, *o*-, *m*-, *p*-dichlorobenzene, chlorobenzene, nitrobenzene, 4-nitrophenol, pentachlorophenol, ethylbenzene, dieldrin, dimethylmethylphosphonate (DMMP), diethylmethylphosphonate (DEMP), diisopropylmethylphosphonate (DIMP), acetone, glyoxal, methylglyoxal, acetaldehyde, formaldehyde, methylphosphonic acid, acetic acid, *o*-, *m*-, *p*-dihydroxyphenol, *o*-cresol, and formic acid.

Test Results: The removal of benzene and toluene from aqueous solution has been evaluated as a function of solute concentration, absorbed dose, pH, and total solids content. Table 1 summarizes the doses required to remove 99% ($D_{0.99}$) of benzene and toluene from solution (a dose of 418 krad raises the temperature of the water 1°C). The removal efficiency, $D_{0.99}$, for benzene and toluene does not appear to be affected by solution pH. In addition, 3% w/w Kaolin clay did not appear to significantly affect the removal efficiency of either benzene or toluene at pH 7 and 5, compared with the absence of Kaolin under similar experimental conditions. Most likely this indicates that the solution containing 3% w/w solids is essentially transparent to the electron beam.

Reaction by-products identified for benzene include phenol, 1,2-, 1,3-, and 1,4-dihydroxybenzene, formaldehyde, acetaldehyde, and glyoxal. The reaction by-products for toluene include, *o*-cresol, formaldehyde, acetaldehyde, glyoxal, and methylglyoxal. In all cases, the sum of the reaction by-products identified, as well as any unreacted solute, accounted for less than 9% of the total carbon mass balance for benzene and less than 2% of the total carbon mass balance for toluene at an absorbed dose of 200

Table 1. *Variation of $D_{0.99}$ versus Concentration, pH and Clay Content for Experiments with Benzene and Toluene*

pH	*init conc mg L^{-1}*	*$D_{0.99}$ krad*	*init conc mg L^{-1}*	*$D_{0.99}$ krad*	*init conc mg L^{-1}*	*$D_{0.99}$ krad*
			Benzene			
5	*0.13*	*62*	*1.50*	*86*	*6.79*	*210*
	0.10	*63*	*1.88*	*83*	*1.82*	*166*
7	*0.14*	*48*	*1.17*	*39*	*6.58*	*211*
	0.16	*47*	*1.17*	*39*	*1.91*	*184*
9	*0.15*	*51*	*1.67*	*87*	*2.22*	*199*
	0.09	*65*	*1.32*	*95*	*2.84*	*231*
5[a]	*0.10*	*48*	*1.47*	*94*	*1.94*	*142*
7[a]	*0.09*	*50*	*1.22*	*98*	*5.96*	*220*
			Toluene			
5	*0.03*	*59*	*0.68*	*44*	*3.76*	*167*
	0.04	*55*	*0.63*	*44*	*4.86*	*166*
7	*0.03*	*57*	*0.69*	*95*	*5.61*	*166*
	0.05	*54*	*0.55*	*44*	*6.06*	*170*
9	*0.04*	*55*	*0.83*	*74*	*6.11*	*178*
	0.04	*58*	*0.74*	*89*	*4.39*	*165*
5[a]	*0.07*	*67*	*0.33*	*44*	*3.56*	*150*
7[a]	*0.07*	*52*	*0.42*	*45*	*4.28*	*165*

[a]addition of 3% w/w Kaolin (EPK) clay.

krad. Presumably the remaining organic carbon is mineralized to CO_2 and water or to as yet unidentified reaction by-products.

Two papers are available (1 published, 1 submitted for publication) detailing all experimental results.

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