# In Situ Remediation of Pesticides, Explosives, and Chemical Weapons Using Heat-Enhanced Hydrolysis

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**Background/Objectives.** Important pesticides from a site remediation standpoint include: dieldrin*, aldrin*, toxaphene*, heptachlor*, lindane, 1,2-dibromo-3-chloropropane (DBCP), 1,2-dichloropropane, ethylene dibromide (EDB). 1,2,3-trichloropropane, DDT and degradation products*, and pentachlorophenol.
**compound on the "dirty dozen" list of persistent organic pollutants (POPs)*

Electrical resistance heating (ERH) provides two main mechanisms of contamination removal: vaporization and degradation. While ERH is primarily used to steam strip contaminants, ERH can also enhance hydrolysis. Hydrolysis is a key mechanism of contaminant degradation that breaks contaminant chemical bonds through a reaction with water. Interestingly, thermally enhanced hydrolysis is an important degradation reaction for every pesticide on the above list. Hydrolysis occurs through either a water substitution or elimination reaction pathway. Hydrolysis elimination reactions may also be referred to as "dehydrohalogenation," in which a carbon single bond becomes a double bond and hydrogen chloride is released from chlorinated compounds. While biotic and other degradation pathways exist for pesticides, this presentation will focus on abiotic hydrolysis reactions.

Depending on the compound, hydrolysis can be faster if the pH is high (alkaline or basic hydrolysis) or low (acid hydrolysis). However, other compounds undergo rapid neutral hydrolysis and the rate of neutral hydrolysis then becomes independent of pH.

**Approach/Activities.** When studying hydrolysis, researchers often measure the hydrolysis rate at elevated temperatures to speed up the reactions and then calculate the hydrolysis rate at room temperature using the Arrhenius equation.

The Arrhenius equation also indicates that the rate of hydrolysis will increase with temperature. The activation energy will determine the exact factor of temperature acceleration; however, based on the hydrolysis activation energy of other chlorinated compounds, it is estimated that pesticide hydrolysis rates will double with each 10°C increase in temperature.

When discussing hydrolysis, it is convenient to use the concept of half-life, which is how long it takes for half of the compound to be destroyed. Seven half-lives produce 99% destruction; ten half-lives results in 99.9% destruction.

**Results/Lessons Learned.** The presentation will focus on practical application of heat enhanced hydrolysis for site remediation and will provide site examples for heat-enhanced pesticide remediations. In addition, research data on the heat enhanced alkaline hydrolysis of explosive compounds will be provided. The presence of low levels of mustard gas as a co-contaminant at a mixed waste site will also be discussed.