Using Sonication for In-Well Softening of Semivolatile Compounds

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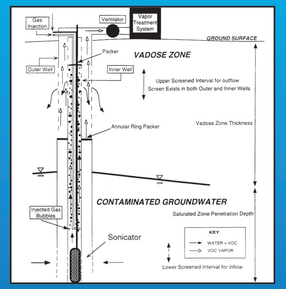
Technology Description

- Sound transmitted through liquid as wave of alternating positive- and negative-pressure cavitation cycles.
  - Compression (positive pressure) cycles push molecules together while expansion (negative pressure) cycles pull molecules apart.
  - Acoustic cavitation affects chemical reactions.
  - During expansion cycle, also called rarefaction, separated molecules form tiny microbubbles.
  - The microbubbles grow to a critical size and implode, releasing a large amount of energy.
  - Pressures from 500 to 1,000 atmospheres and temperature around 5,000°K have been observed or calculated in the implosions, while the bulk solution stays near ambient conditions.
  - The collapsing bubble interface results in hydroxyl (•OH) and hydrogen (H•) radicals. These radicals destroy chlorinated organic compounds very effectively.



In-well sonication of halogenated organic contaminants in groundwater. Process uses
- *in-well sonication*
- *in-well vapor stripping*
- *in-situ biodegradation*

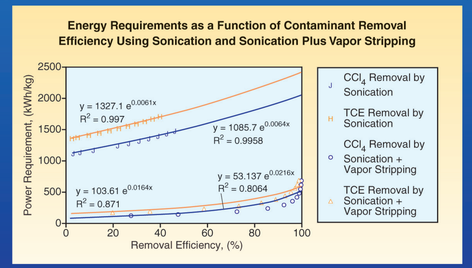
- The formation of •OH and H• radicals is enhanced through addition of chemical oxidants such as ozone (O_3) and hydrogen peroxide (H_2O_2).

Electrical Power Requirements

Calculation of electrical energy required per unit mass (of chlorinated organic) removed (kWh/kg):

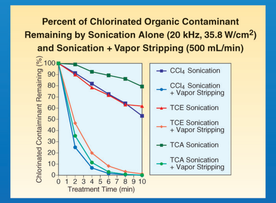
$$\frac{\text{Electrical Energy}}{\text{Mass}} = \frac{P \times t \times 10^6}{V \times 60 \times (C_i - C_f)}$$

Sonication power capacity = 600 W
Power intensity = 35.8 W/cm² (~17%)
P = 600 x 0.17 = 102 W (0.102 kW)
t = Treatment time, (min)
V = Total volume of solution, (L) = 0.5 L
C_i = Initial contaminant concentration ~ 50 mg/L
C_f = Final contaminant concentration = (mg/L)

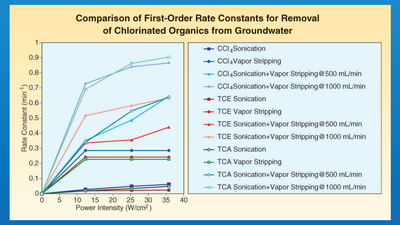


Results, Summary, and Conclusions

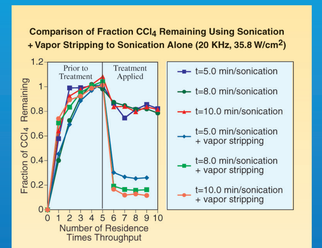
- Sonication removed 26% to 47% CCl_4 after 10-minute treatment while the combined sonication plus vapor stripping system exceeded 99% for power intensities ranging from 12.3 to 35.8 W/cm²; after 6-minute treatment, the combined system removed 88% to 98%.
- Sonication removed 19% to 38% of TCE after 10-minute treatment while the combined sonication plus vapor stripping system exceeded 96%; after 6-minute treatment, the combined system removed 87% to 93%.

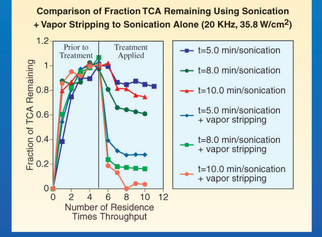


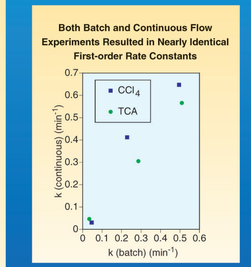
- The combined sonication plus vapor stripping system operates synergistically. The rate constant for the combined sonication plus vapor stripping system lies in the range of 0.44 to 0.65 min⁻¹, with first-order rate constants via sonication and vapor stripping (@500 mL/min) in the range of 0.02 to 0.06 min⁻¹ and 0.23 to 0.29 min⁻¹, respectively.
- First-order rate constants for removal of chlorinated organic contaminants from groundwater vary linearly with the applied power intensity.



- From continuous flow treatment for residence times from 5 to 10 minutes, sonication removed 17% to 18% CCl_4, while the combined sonication plus vapor stripping removed from 74% to 88%.
- Similarly for TCA, treatment by sonication resulted in 14% to 37% removal; sonication plus vapor stripping removed 72% to 97% in a single pass.







- Chemical degradation intermediates of CCl_4 include C_2Cl_4 and C_2Cl_6; <0.04% and <0.0125% of the CCl_4 appeared as chemical intermediates. Chemical degradation intermediates resulting from acoustic cavitation constitute a negligible quantity of the original parent compound.
- Bacterial growth (biodegradation) was higher in sonicated samples when compared to unsonicated samples, demonstrating some softening (partial degradation) of CCl_4 due to sonication.

Contaminants Studied

- Carbon tetrachloride (CCl_4)
- Trichloroethylene (TCE)
- 1,1,1-Trichloroethane (TCA)
- 1,1,2,2-Tetrachloroethylene (PCE)
- Ethylenedibromide (EDB)

Benefits

- Remediation performed *in-situ*.
- Minimizes exposure to hazardous chemicals.
- Minimal degradation intermediates are formed.
- Complementary treatment systems can drastically reduce or remove semivolatile or volatile organic compounds from groundwater.
- Converts hard-to-degrade organics into more volatile organic compounds.
- Eliminates handling or disposal of water.
- Improved efficiency shortens site remediation time and reduces costs.

Future Efforts

- Enhance performance through addition of O_3, H_2O_2, higher frequencies and power intensities, etc.
- Extend treatment concept to remediate groundwater contaminated with petroleum hydrocarbons (e.g., benzene, toluene, xylenes, etc.), polyaromatic hydrocarbons, methyl tert-butyl ether, etc.
- Scale up system for pilot-scale test capable of handling ~200 gallons.
- Field demonstration of technology at one or more selected Department of Energy facilities.

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