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Emerging Technology Bulletin

Development of a Photothermal Detoxification Unit

Environmental Science and Engineering Group
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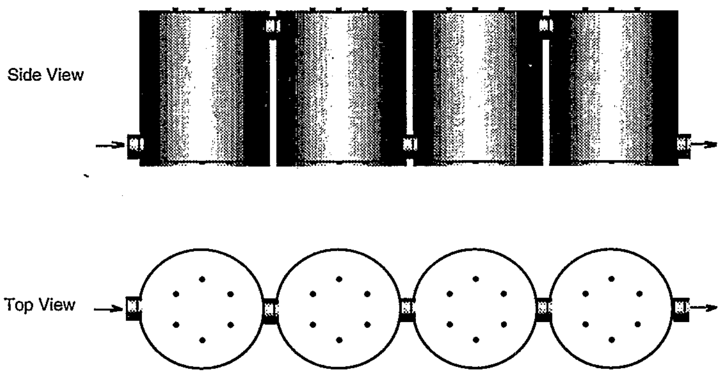
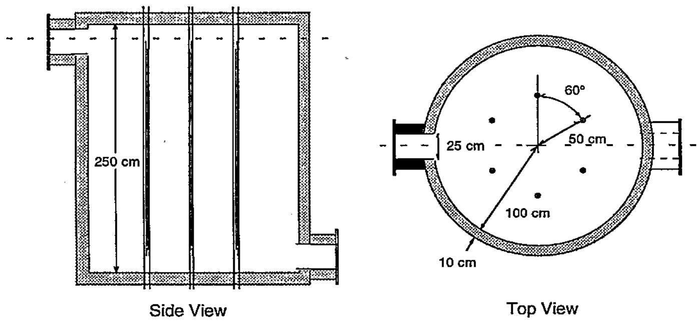
Technology Description: The University of Dayton Research Institute has developed a novel photochemical process embodied in a device called a Photothermal Detoxification Unit (PDU) which offers an efficient means of destroying hazardous organic wastes.

The PDU, which overcomes the problems of slow reaction rates and incomplete destruction of hazardous materials often associated with photochemical waste reduction, is a relatively simple device. It consists of a thermally insulated vessel (Figure 1) enclosing a set of large, medium pressure mercury vapor lamps which provide an efficient source of near-UV radiation as well as heat for the process. The PDU uses the radiation from the lamps to induce destructive photochemical reactions at moderate temperatures (200-600°C) so they proceed to completion quickly and efficiently. Since the process requires both light and heat, it is referred to as a photothermal detoxification process.



General Layout of a Four Chamber PDU



Chamber Details

Figure 1. *UDRI Photothermal Detoxification Unit (PDU)*

The process is capable of destroying organic materials at temperatures much lower than thermal processing alone and at temperatures easily achievable through non-combustion means. The specific exposure time, temperature and radiant intensity will be largely dependent on the materials of interest and the required level of destruction. In general, these aspects of the PDU design and operation are brought together through a reactor performance model such as:

$$f_r=\exp[-(k_{gnd}+k_{ab}\varnothing)t]$$

where fr is the fraction remaining in the process stream exiting the PDU, K_{gnd} is the rate of thermal reactions, K_{ab} is the rate of light absorption, ø is the efficiency of the photothermal reactions (quantum yield), and t is the mean exposure time.

To predict the performance of the PDU, it is necessary to have knowledge of the rates of thermal reactions (K_{gnd}), the photothermal quantum yields (ø), and the UV absorption rates (K_{ab}) of the system. Since none of the required high temperature spectroscopic and photochemical data is available from the literature, researchers at UDRI designed and built a special high temperature spectrophotometer and a bench-scale photothermal detoxification unit for the basic thermal and photothermal information.

Waste Applicability: Organic compounds which efficiently absorb near-UV radiation are relatively easily destroyed by the photothermal process. Toxic organic compounds whose molecular structure includes alkene or aromatic structures (i.e., chlorinated alkenes, chlorinated aromatics, chlorinated dibenzo-p-dioxins, etc.) are likely to absorb the near-UV radiation which is necessary for the photothermal detoxification process. Molecules which only weakly absorb near-UV radiation (i.e. alkanes and chloroalkanes) may require deep UV sources such as low pressure mercury lamps.

Laboratory and Bench-scale Test Results: Photothermal detoxification at elevated temperatures improves the overall efficiency of the process in three important areas: the spectroscopy,

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the rate of destruction, and the completeness of the destruction. The most important aspect of the process is whether the light absorbed by the waste feed results in the destruction of the waste feed. The Laboratory Scale-Photothermal Detoxification Unit (LS-PDU) data for trichloroethylene (TCE) exposed to 18.1 W/cm^2 of xenon arc radiation for 10 sec in air showed that the process is capable of destroying a significant portion of the TCE where no thermal destruction is occurring. For example, at 500°C the thermal decomposition has not yet begun, while the photothermal process has destroyed approximately 60% of the sample.

The last important aspect of the photothermal process is its ability to completely mineralize the waste feed. The data for 1,2,3,4-tetrachlorodibenzo-p-dioxin (TCDD) demonstrated that the process can easily destroy this type of hazardous material which has traditionally challenged conventional waste disposal techniques. For example, GC/FID chromatograms from TCDD exposed to at 600°C photothermal (17.6W/cm^2) for 10 sec in air show that not only is the parent TCDD destroyed, but nearly all the associated products of incomplete conversion (PICs) as well. Under the same thermal conditions 35% of the TCDD remained with numerous organic compounds.

A large-scale PDU should include at least four cylindrical reactor chambers operating in series, enclosing lamps mounted near the chamber centerline, and at a relatively high temperature (500-600°C). Linear, medium pressure mercury lamps are the most suitable for a large-scale PDU because of their high near-UV output, long service life, and geometry. The capacity of the system can be adjusted by selecting appropriate operating conditions, (number of lamps, operating temperature, etc.), operating chambers in series to increase efficiency and capacity, or sets of chambers in parallel.

A project summary and complete report have been submitted and will be available in the near future.

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