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NONTHERMAL PLASMA TECHNOLOGY FOR ORGANIC DESTRUCTION

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Nonthermal Plasma Technology for Organic Destruction

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Pacific Northwest Laboratory (PNL) is investigating the use of nonthermal, electrically driven plasmas for destroying organic contaminants near ambient temperatures and pressures. Three different plasma systems have been developed to treat organics in air, water, and soil. These systems are the Gas-Phase Corona Reactor (GPCR)[1] for treating air, the Liquid-Phase Corona Reactor[2] for treating water, and In Situ Corona[2],[3] for treating soils. This presentation focuses on recent technical developments, commercial status, and project costs of GPCR as a cost-effective alternative to other air-purification technologies that are now in use to treat off-gases from site-remediation efforts as well as industrial emissions.

Gas-Phase Corona Reactor

The GPCR process uses high-voltage ac fields developed in a packed bed of dielectric pellets to form a nonequilibrium plasma in the void spaces between the pellets. The pellets perform at least three critical functions. First, they refract high-voltage electric fields so that the local fields between pellets are stronger than the applied field by a factor of 10 to 250 times, depending on the shape, porosity, and dielectric constant of the pellet material. Second, the pellet surfaces catalyze chemical reactions. Third, physical sorption of contaminants on the pellet surfaces can significantly influence the residence time of contaminants in the reactor. While many reactor geometries are conceivable, present GPCR devices are shaped like coaxial cylinders with an inner metal electrode and an outer tube made of glass. The dielectric pellets are placed in the annular gap. A metal screen in contact with the outside surface of the tube serves as the ground electrode. The inner electrode is connected to a high-voltage (15 to 30 kV) ac power supply operated at fixed (60 Hz) or variable frequencies. The glass tube serves as the reaction vessel and as a dielectric barrier to inhibit direct charge transfer between electrodes. The gas to be treated is simply pulled through the packed bed where reactant species are produced and subsequent chemical reactions occur. Figure 1 is a photograph of a GPCR device capable of treating between 20 and 60 acfm of air depending on the contaminant and the required level of destruction.

FIGURE 1. Photograph of Commercial Reactor Prototype (95010602-9CN)

Contaminants Tested

The GPCR process has been effective in destroying a wide range of hazardous air pollutants as well as chemical[4] and biological[5] warfare agents. The following specific compounds have been tested, with destruction efficiencies noted in parentheses:

- trichloroethylene (>99.9%)
- perchloroethylene (>99.9%)
- benzene (97.85%)
- naphthalene (>99.9%)
- GD nerve agent (>99.8%)
- hydrogen cyanide (>99.4%)
- cyanogen (>99.8%)
- methyl cyanide (98%)
- phosgene (>99.84%)
- methane (>97%)
- Freon 14 (70%)

- phosphonofluoridic acid (>99.8%)
- dimethyl methyl phosphonate (>99%)

Tests are underway with carbon tetrachloride, toluene, trichlorethane and acetone.

Initial Field Test of GPCR

The GPCR process was field-tested[6] on a pilot scale in 1993 for treating humid air contaminated with trichloroethylene (TCE) at a concentration of 130 ppmv and perchloroethylene (PCE) at 720 ppmv. The contaminated air stream was produced by a soil-vapor extraction vent at the U.S. Department of Energy's (DOE's) Savannah River Site. The field system used 21 small reactors, each capable of treating 0.1 to 2.0 acfm, corresponding to reactor residence times of 15.7 to 0.8 s. By connecting the small reactors in parallel, the field tests were performed at inlet flowrates up to 42 cfm, corresponding to a 0.8-s residence time. Results are summarized in Table 1, based on a fit of the test data. Figure 2 is a photograph showing 14 of the 21 field reactors in operation.

Table 1. Destruction Efficiency vs. Residence Time

	Residence Time, s		
	95%	99%	99.9%
TCE	0.8	1.2	1.8
PCE	3.3	5.1	7.7

FIGURE 2. Photograph of Pilot-Scale Field System (94010945-4CN)

The dielectric pellets used in the field-test reactors were common soda-lime glass beads having low catalytic activity and essentially nonporous. Subsequent tests with two common catalytic materials as the reactor pellets showed a decrease in residence time of 5.2, meaning the same GPCR system with different pellets would have processed air at 5.2 times greater flowrates. These residence time data provide a basis for GPCR scaleup.

Commercial Status

The GPCR device shown in Figure 1 will be used as the basis for a commercial prototype system that will use six of these reactors to treat a nominal 200 acfm of organic contaminated air. A manufacturing partner, Bionomic Industries of Mahwah, New Jersey, will perform detailed design and construction of the commercial prototype as part of a Cooperative Research and Development Agreement signed with PNL and DOE. The prototype will be field tested at multiple sites to obtain data on reliability, performance, and life-cycle costs.

Projected Costs

Based on scaleup data and quotes for major equipment components and construction materials, the capital cost of a 1200 cfm treatment system consisting of six large GPCR reactors in parallel is projected as $116K. Major components are the reactors ($7.8K each), power supply ($9.5K), process skid and instrumentation ($36.7K), and 25% contingency ($23K). The estimated power requirement for this treatment system is 38 kW. With a 5-year payback period at 8% interest, the annual equipment cost would be $34K. For a unit electrical cost of $0.075 per kW hr, the annual power cost would total $23K, for a total annual cost of $57K. Compared with quoted costs for equipment, regenerables, and energy, GPCR is projected to be about one-fourth the cost of catalytic oxidation and one-tenth the cost of carbon sorption--the two most common air purification technologies in the 1200-cfm flow range. The expected cost savings coupled with continuing amendments to the Clean Air Act are the major drivers for commercializing the GPCR technology.

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References

1. Virden, J.W., W.O. Heath, S.C. Goheen, M.C. Miller, G.M. Mong, and R.L. Richardson. 1992. "High-Energy Corona for Destruction of Volatile Organic Contaminants in Process Off-Gases", Proceedings of the International Topical Meeting on Nuclear and Hazardous Waste Management--Spectrum'92. American Nuclear Society.

2. Heath, W.O., S.C. Goheen, M.C. Miller, and R.L. Richardson. 1992. "Investigation of Electric Fields For Low-Temperature Treatment of Soils and Liquids", Proceedings of the 1992 U.S. EPA/A&WMA International Symposium on In Situ Treatment of Contaminated Soil and Water, VIP-24. Air & Waste Management Association, Pittsburgh, Pennsylvania.

3. Heath, W.O., S.M. Caley, L.M. Peurrung, B.D. Lerner, and R.W. Moss. 1994. "Feasibility of In Situ Electrical Corona for Soil Detoxification", Thirty Third Hanford Symposium on Health and the Environment, In-Situ Remediation: Scientific Basis for Current and Future Technologies. Battelle Press, Richland Washington.

4. Moore, R.R and J.G. Birmingham. 1987. "Toxic Chemical Decomposition in a Low Temperature Plasma Reactor", 1987 Conference on Chemical Defense Reseach. U.S. Army CRDEC, Aberdeen Proving Ground, Maryland.

5. Henderson, P.S., J.G. Birmingham, R.R. Moore, and W.T. Beaudry. 1987. "Biological Aerosol Decomposition in a Reactive Bed Plasma (RBP) Reactor", 1987 Conference on Chemical Defense Reseach. U.S. Army CRDEC, Aberdeen Proving Ground, Maryland.

6. Shah, R.R., R.E. Garcia, J.T. Jeffs, J.W. Virden, and W.O. Heath. 1994. Initial Field Test of High-Energy Corona Process for Treating a Contaminated Soil Off-Gas Stream. PNL-9224. Pacific Northwest Laboratory, Richland, Washington.