The Reactive Bed Plasma System for Contamination Control
by Joseph G. Birmingham, Robert R. Moore and Tony R. Ferr-v

Introduction

In August 1987, NASA provided the Plasma Group at the Chemical Research, Development and Engineering Center (CRDEC) a list of chemicals including liquids, vapors, and particulates that are anticipated to cause contamination problems aboard the Space Station II. CRDEC has selected several of these compounds to test an invention described as the Reactive Bed Plasma reactor. The objective of this paper is to summarize the contamination control capabilities of the Reactive Bed Plasma (RBP) system by delineating the results of toxic chemical decomposition studies, aerosol filtration work, and other testing.

Description of Reactive Bed Plasma

The Reactive Bed Plasma (RBP) was invented at the Chemical Research, Development and Engineering Center (CRDEC) to provide breathable air in chemical and biological warfare environments. The RBP is a synergistic combination of a plasma (or ionized gas) and catalytic technologies to produce an air purification system. The catalytic packing material's main function is to facilitate an increased amount of time in the active plasma region for contaminant molecules in a flowing air stream. The plasma generated high energy electrons and subsequently produced species decompose toxic materials. In addition, the RBP can perform as a highly efficient electrostatic precipitator to collect and eventually deactivate hazardous particulate material. Since, the RBP can handle toxic chemicals as well as hazardous aerosols, it can be described as an universal filter.

It is understood that trade-offs exist for any new technology. Some disadvantages of the RBP concept include the emission of electromagnetic noise (necessitating the shielding of the device), high voltage hazards and the treatment of reaction products. The advantages of the RBP include the potential for operating as an efficient, low temperature, long-lived, minimal energy-consumption, universal contamination control device.

Toxic Chemical Decomposition Studies

The list of chemicals provided by NASA included liquids and gases such as chlorinated compounds (such as hydrochloric acid, trichloroethane and chlorine), organics (such as benzene), and others. The RBP system has been tested against several compounds including cyanogen chloride (2), phosgene (3) and benzene (4). These test gases allow the contamination control capability of the RBP to be extrapolated to many chemical groups. Each gas's decomposition results reveal an important attribute of the RBP system. The efficient decomposition of cyanogen chloride demonstrated that the RBP did not exhibit the
characteristic poisoning mechanisms of catalysts. Additionally, the phosgene results indicated that the RBP utilizes low temperatures (around 150 degrees C) and its performance does not drop quickly. Also, any hydrochloric acid formed was converted to chlorine (as expected from a low temperature process). Finally, the benzene testing showed that the RBP can easily decompose organics flowing in an air stream. The main reaction products from these decomposition studies include carbon dioxide and water, salts, and small amounts of acid gases (including halogens from the parent compounds and nitrogen dioxide from the air stream). The RBP has demonstrated the potential as a low temperature, efficient universal decomposition system for hazardous compounds in a flowing air stream.

Aerosol Processing in RBP

Particulate materials on NASA's Contamination Control list include Polystyrene Latex Spheres, microbes (which might include Bacillus Globigii spores and T-2 mycotoxin), and semiconductor processing aerosols. The Reactive Bed Plasma (RBP) reactor combines electrostatic precipitation with a packed bed to form a new aerosol filtration device. The testing of the RBP with Polystyrene Latex spheres revealed that the RBP was a more efficient filter than for the empty plasma reactor (electrostatic precipitator) or a single packed bed (5). The biological aerosol challenges of the RBP including Bacillus Globigii spores (a heat resistant simulant for pathogenic species) and T-2 mycotoxin demonstrated efficient deactivation and decomposition, respectively (6). The RBP could become an ultrafiltration device with the incorporation of a ceramic High Efficiency Particulate Aerosol (HEPA) filter. Therefore, the RBP has the potential to become an aerosol filtration device for many applications.

Post-treatment of RBP Effluent

The requirement to neutralize any products found in the reactor effluent will be undertaken in the post-treatment section of the RBP system. Two approaches of removing the reaction products are packed beds and gas separation membranes. First, packed beds consisting of reactive material coated onto alumina support spheres has demonstrated the efficient removal of nitrogen dioxide and chlorine. This packed bed system will undergo additional testing. Next, some contamination control applications would allow a gas separation membrane to separate products to undergo further treatment in a scrubber solution. Since post-treatment burdens for contamination control are minimal, the solutions suggested may be adequate.

Contamination Control Approach Utilizing an RBP

The Reactive Bed Plasma (RBP) system has demonstrated the capability of efficiently processing many of the chemicals suggested by NASA. The ability to process liquids will require vaporization of the contaminate materials. This phase change may require the use of heat and air to introduce the hazardous
material into the RBP. Alternately, waste gases can be processed directly. Additional work is required to meet the stringent size, weight and volume constraints of the Space Station. Nevertheless, it is believed that the Reactive Bed Plasma system can provide contamination control for many applications.

Summary

The Reactive Bed Plasma (RBP) system has demonstrated its unique capabilities to decompose toxic materials and process hazardous aerosols. The post-treatment requirements for the reaction products have possible solutions. Although additional work is required to meet NASA requirements, the RBP may be able to meet Contamination Control problems aboard the Space Station.

References


Reactive Bed Plasma Presentation

I. Introduction

II. Toxic Chemical Decomposition

III. Aerosol Filtration

IV. Post-Treatment of Reactor Effluent

V. Contamination Control Application
REACTIVE BED PLASMA
DEFINITION AND OBJECTIVE

- REACTIVE BED PLASMA: The synergistic coupling of plasma (or ionized gas) and catalysis

- OBJECTIVE: To develop and demonstrate Reactive Bed Plasma technology to treat pollutants released into the environment

- GOAL: Technology Transfer to industry
COLLECTIVE PROTECTION

REACTIVE BED PLASMA

- Plasma is an electrically neutral, highly ionized gas composed of electrons and ions.

STATUS:

- Laboratory investigations ongoing to establish tech database on reaction mechanisms and post-treatment scale-up.
REACTIVE BED PLASMA

OUTER ELECTRODE
OUTER DIELECTRIC TUBE
INNER DIELECTRIC TUBE
INNER ELECTRODE
ANNULUS

INFLUENT AIR
OUTER ELECTRODE
OUTER DIELECTRIC POROUS PACKING GROUND
EFFLUENT AIR
ANNULUS INNER ELECTRODE INNER DIELECTRIC

HIGH VOLTAGE TRANSFORMER VARIABLE FREQUENCY POWER SUPPLY

AO332-RB 1188-01
Reactive Bed Plasma Presentation

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Contamination Materials

- Liquids including:
  * Acids (Acetic, Nitric, Hydrochloric, Perchloric, Hydrofluoric)
  * Organics (Benzene, Xylene, Toulene, Phenol, Trimethyl Benzene)
  * Hydrocarbons (Methanol, Trichloroethylene, Acetone, Dichloromethane, Trichloroethane)
  * Others
Contamination Materials

- Gases including:
  * Air Components (Oxygen, Nitrogen, Argon, Helium, Hydrogen)
  * Light Hydrocarbons (Methane)
  * Carbon Monoxide / Carbon Dioxide
  * Freons (Freon 22, Freon 113)
  * Acid Gases (Chlorine, Fluorine)
  * Others
## RESULTS

<table>
<thead>
<tr>
<th>CHEMICAL PROCESSING</th>
<th>% DECOMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>GD (Nerve Agent)</td>
<td>&gt; 99.8 %</td>
</tr>
<tr>
<td>AC (Hydrogen Cyanide)</td>
<td>&gt; 99.4 %</td>
</tr>
<tr>
<td>*CK (Cyanogen Chloride)</td>
<td>&gt; 99.6 %</td>
</tr>
<tr>
<td>Cyanogen</td>
<td>&gt; 99.8 %</td>
</tr>
<tr>
<td>Methyl Cyanide</td>
<td>98 %</td>
</tr>
<tr>
<td>*CG (Phosgene)</td>
<td>&gt; 99.84 %</td>
</tr>
<tr>
<td>Carbon Monoxide → Dioxide</td>
<td>84 %</td>
</tr>
<tr>
<td>Methane</td>
<td>&gt; 97 %</td>
</tr>
<tr>
<td>**Benzene</td>
<td>97.85 %</td>
</tr>
</tbody>
</table>

* RBP

** Experimental RBP

"* LIMIT OF DETECTION
## CHEMICAL PROCESSING RESULTS

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>DURATION</th>
<th>CONCENTRATION</th>
<th>FLOW RATE</th>
<th>RESIDENCE</th>
<th>EFFICIENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK (Cyanogen Chloride)</td>
<td>115 min</td>
<td>1576 ppm</td>
<td>2.6 cfm</td>
<td>0.44 sec</td>
<td>&gt; 99.6 %</td>
</tr>
<tr>
<td>CG (Phosgene)</td>
<td>78 min</td>
<td>200 ppm</td>
<td>5.5 cfm</td>
<td>0.31 sec</td>
<td>&gt; 99.84 %</td>
</tr>
<tr>
<td>Benzene</td>
<td>64 min</td>
<td>177 pp</td>
<td>2.0 cfm</td>
<td>0.92 sec</td>
<td>97.85 %</td>
</tr>
</tbody>
</table>

"\(>\) LIMIT OF DETECTION
COMPARISON OF REACTIVE BED PLASMA AND THERMAL REACTORS

- PLASMA REACTOR w/p W.R.G. 3-WAY AUTO CATALYST
- THERMAL REACTOR w/p W.R.G. 3-WAY AUTO CATALYST
- THERMAL REACTOR w/p W.R.G. SUPPORT SPHERES

REACTOR EFFLUENT (µg CK/L AIR)

TIME: MINUTES (@ 4000 L 3 CK/L AIR)

1 CFM @ 133 C

1 CFM @ 137 C

2.6 CFM @ 168 C
BENZENE DECOMPOSITION IN A REACTIVE BED PLASMA

Challenge: 177 ppm Benzene @ 2.0 CFM Air
Applied Power: 1000 watts
ADVANTAGES OF RBP TECHNOLOGY

- Low Temperature Process for minimal power consumption
- Highly Efficient Decomposition of most groups of toxic chemicals
- RBP does not exhibit characteristic catalyst poisoning mechanisms
DISADVANTAGES OF RBP TECHNOLOGY

- Scale-up of technology from 10 CFM to 100 CFM
- Requires post-treatment for reaction products in some applications
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Contamination Materials

- Particulates including:
  - Semiconductor Processing (Germanium, Silicon, Gallium Arsenide)
  - Latex Spheres
  - Microbes
  - Others
AEROSOL REMOVAL MECHANISMS
OF POLYSTYRENE LATEX SPHERES

COLLECTION EFFICIENCY, percent

PARTICLE SIZE, micron

MECHANISM 3

- IDEAL ELECTROSTATIC
- C PLASMA
- PACKED BED
- ACTIVE BED PLASMA
## RESULTS

<table>
<thead>
<tr>
<th>PROCESSING</th>
<th>% DEACTIVATION</th>
<th>% DECOMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIOLOGICAL PROCESSING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BG SPORES</td>
<td>&gt; 99.9999 %</td>
<td></td>
</tr>
<tr>
<td>BIOCHEMICAL PROCESSING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-2 MYCOTOXIN</td>
<td>&gt; 99.72 %</td>
<td></td>
</tr>
<tr>
<td>LIMIT OF DETECTION</td>
<td></td>
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</tbody>
</table>
CONFIGURATION OF ULTRA HIGH EFFICIENCY RBP AEROSOL COLLECTION SYSTEM

PARTICULATE LADEN AIR

CERAMIC HEPA FILTER
POROUS PACKING

CLEAN AIR

HIGH VOLTAGE TRANSFORMER

VARIABLE FREQUENCY POWER SUPPLY
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<tr>
<th>Air By-Product Formation in RBP</th>
<th>Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogenous Oxides (NO&lt;sub&gt;x&lt;/sub&gt;)</td>
<td>60</td>
</tr>
<tr>
<td>Ozone (O&lt;sub&gt;3&lt;/sub&gt;)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>&lt;1</td>
</tr>
</tbody>
</table>
REACTION PRODUCTS
CLASSES AND REMOVAL TECHNIQUES

\[ \text{CICN} + 2\text{H}_2\text{O} \rightarrow \text{NH}_4\text{Cl} + \text{CO}_2 \]

LIQUID SCRUBBER, PACKED BED, OR PARTICULATE FILTER

\[ \text{COCl}_2 + \text{O}^\cdot \rightarrow \text{Cl}_2 + \text{CO}_2 \]

LIQUID SCRUBBER OR PACKED BED

\[ \text{C}_6\text{H}_6 + 15(\text{O}^\cdot) \rightarrow 6\text{CO} + 3\text{H}_2\text{O} \]

NONE

\[ \text{N}_2 + 2\text{O} \rightarrow 2\text{NO} \]

LIQUID SCRUBBER OR PACKED BED

INORGANIC SALT: \(\text{NH}_4\text{Cl}\)

INORGANIC ACID GAS: \(\text{Cl}_2\) & \(\text{NO}_2\)
# Post-Treatment

**Packed Bed Alumina**

<table>
<thead>
<tr>
<th>Material</th>
<th>Duration</th>
<th>Concentration</th>
<th>Flow</th>
<th>Residence</th>
<th>Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorine ($\text{Cl}_2$)</td>
<td>40 min</td>
<td>140 ppm</td>
<td>28.3 lpm</td>
<td>0.15 sec</td>
<td>96%</td>
</tr>
<tr>
<td>Nitrogen Dioxide ($\text{NO}_2$)</td>
<td>35 min</td>
<td>100 ppm</td>
<td>10.1 lpm</td>
<td>0.42 sec</td>
<td>95%</td>
</tr>
</tbody>
</table>

**Gas Separation Membrane** ($\text{N}_2/\text{O}_2$ Separation)

<table>
<thead>
<tr>
<th>Nitrogen Oxides ($\text{NO}_2/\text{NO}$)</th>
<th>Duration</th>
<th>Concentration</th>
<th>Flow</th>
<th>$\text{O}_2$ Enrichment (5 lpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60 min</td>
<td>250/56 ppm</td>
<td>45/5 lpm</td>
<td>$+8% \text{ CO}_2$, $+60% \text{ NO}$</td>
</tr>
</tbody>
</table>
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RBP Contamination Control

Liquid Processing:

Heat → Liquids → Vapors → RBP → Aerosols

Gas Vapor and Particulate Handling:

Particulates → RBP

Gases → RBP