Project ID: **54973**

Project Title: **A Novel Energy-Efficient Plasma Chemical Process for the Destruction of Volatile Toxic Compounds**

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## RESEARCH OBJECTIVE

Removal of low-concentrations (below several percent) of volatile toxic compounds (VTCs) from contaminated air streams is encountered at DOE waste sites in two instances:

(i) Off-gases resulting from air-stripping of contaminated soil and water.
(ii) Effluent from the incineration of highly-concentrated combustible hazardous wastes

The objective of our research program is to develop a novel plasma chemical process for the destruction of VTC's in low- concentration waste streams.

## RESEARCH PROGRESS AND IMPLICATIONS

Within the past two and half years,

• The basic physics/chemistry involved in the dissociative electron attachment to highly- excited molecules was unraveled in a plasma mixing apparatus (publications 1,3,4,8,9,11,13)
• An analytical methodology for the evaluation of VTC destruction in a flowing plasma apparatus was developed (publication 10).
• Basic mechanisms involved in enhanced electron attachment to Rydberg states of molecules was studied (publications 6, 7, 9, 11, 12).
• For comparison with electron attachment to Rydberg states, electron attachment measurements on ground states of benzene and methylene chloride was studied (publication 5; electron attachment to benzene was found to be negligible).
• The role of dissociative electron attachment was confirmed by monitoring enhanced negative ion formation (publications 3, 7).
• Pulsed glow discharge studies were conducted for the destruction of VTCs, and the destruction mechanisms were studied (publications 2, 7, 11, 13).
• One unanticipated positive result was that the glow discharge did not yield any gaseous byproduct other than the rare gases that were used in the gas mixtures. We observed dust particle formation. This will be advantageous since the dust particles can be filtered and disposed (publication 13).

PLANNED ACTIVITIES:

• We need to study the dust formation in detail for different hazardous gases in order to determine whether this is a general phenomenon. Dust formation has been previously observed in material processing discharges (eg. silane discharges), and it has been proposed that negative ions are the precursors for dust formation. Since our destruction mechanism is based on an enhanced electron attachment process, the dust formation can be expected to be a general phenomenon for our technique (1999-2000).
• Up to now we have studied hazardous gases mixed with rare gases (in order to clarify the destruction mechanisms). We plan introduce $N_2$, $O_2$, and water vapor systematically so that we can study the effects of these gases on the destruction process (1999-2001).
• Conduct pilot studies to illustrate the suitability of this new technique for usage in thefield (2001-2002).

**Publications**


1. L. A. Pinnaduwage, D. L. McCorkle, and W. Ding, "Enhanced electron attachment to highly excited molecules using a plasma mixing scheme", *Appl. Phys. Lett.* **71**, 3634 (1997).
2. L. A. Pinnaduwage,"Implications of Electron Attachment to Highly-Excited States in Pulsed Power Discharges",Digest of Technical Papers of the 11th IEEE Pulsed Power Conference, (Eds. G. Cooperstein and I. Vitkovitsky) IEEE Publishing Services, New York, 1997. pp. 1048-1053.
3. W. Ding, D. L. McCorkle, and L. A. Pinnaduwage, "Enhanced formation of negative ions by electron attachment to highly-excited molecules in a flowing afterglow plasma", *J. Appl. Phys*. **84**, 3051 (1998).
4. D. L. McCorkle, W. Ding, C. Y. Ma, and L. A. Pinnaduwage, "Exploratory Studies on a Plasma Remediation Process Based on Enhanced Dissociative Electron Attachment to Highly-Excited Molecules", *J. Phys. D* , **32**, 46 (1999).
5. L. A. Pinnaduwage, C. Tav, D. L. McCorkle, and W. Ding, "Temperature Dependence of Electron Attachment to Methylene Chloride",*J. Chem. Phys.*, **110**, 9011 (1999).
6. L. A. Pinnaduwage, W. Ding, D. L. McCorkle, S. H. Lin, A. M. Mebel, and A. Garscadden, "Enhanced Electron Attachment to Rydberg States in Molecular Hydrogen Volume Discharges", *J.*

*Appl. Phys.*, **85**, 7064 (1999).

7. W. Ding, L. A. Pinnaduwage, C. Tav, and D. L. McCorkle, "The Role of High Rydberg States in Enhanced O- Formation in a Pulsed O2 Discharge", *Plasma Sources Sci. Technol.*. **8**, 384 (1999).
8. L. A, Pinnaduwage, P. G. Datskos, W. X. Ding, and D. L. McCorkle, "Enhanced Electron Attachment to Highly-Excited States of Molecules: Implications for Plasma Processing Discharges", Proceedings of the 1998 International Congress on Plasma Physics, (in press, 1999).
9. L. A, Pinnaduwage, W. X. Ding, and D. L. McCorkle, "Enhanced Electron Attachment to Superexcited Rydberg States of Molecular Hydrogen Using a Plasma Mixing Scheme", Proceedings of the 1998 International Congress on Plasma Physics, (in press, 1999).
10. C. Y. Ma, D. L. McCorkle, W. Ding, and L. A. Pinnaduwage, "A Methodology for Direct Sampling and Gas Chromatographic/Mass Spectral Analysis of Volatile Organic Compounds Emerging from a Low Pressure, Flow-Through Reaction Cell", *J. Chromatography* (in press, 1999).
11. D. L. McCorkle, W. X. Ding, C. Y. Ma, and L. A. Pinnaduwage, "Decomposition of Benzene in a Pulsed Glow Discharge", submitted to J. Appl. Phys. (1999).
12. C. Tav and L. A. Pinnaduwage, "Enhanced Dissociative Electron Attachment to Laser-Excited Benzene", to be submitted to J. Chem. Phys. (1999).
13. D. L. McCorkle, W. X. Ding, C. Y. Ma, and L. A. Pinnaduwage, "Decomposition of Benzene in a Pulsed Glow Discharge: Byproduct Analysis and Dust Formation", to be submitted to J. Appl. Phys. (1999).

**Conference Proceedings**

1. "Implications of Electron Attachment to Highly-Excited States in Pulsed Power Discharges", L. A. Pinnaduwage, 11th IEEE Pulsed Power Conference, Baltimore, Maryland, June 29- July 2, 1997.
2. D. L. McCorkle and L. A. Pinnaduwage,"Destruction of CH2Cl2 Using a Glow Discharge Scheme", 50th Annual Gaseous Electronics Conference, Madison, Wisconsin, October 6-9, 1997.
3. C. Y. Ma, D. L. McCorkle, W. Ding, L. A. Pinnaduwage, "A methodology for direct sampling of Volatile Organic Compounds emerging from a low-pressure, flow-through reaction cell for subsequent GC-GC/MS Analysis", presented at the 46th ASMS Conference on Mass Spectrometry and Allied Topics, Orlando, Florida, May 31-June 4, 1998.
4. W. Ding, C. Y. Ma, D. L. McCorkle, and L. A, Pinnaduwage,"Decomposition of Volatile Organic Compounds in a Positive Column Glow Discharge Plasma", presented at the 25th IEEE International Conference on Plasma Science, Raleigh, North Carolina, June 1-4, 1998.
5. W. Ding, D. L. McCorkle, and L. A, Pinnaduwage, "Enhanced Radical Formation by Electron Attachment to Highly-Excited States of Molecules in Plasmas", presented at the 25th IEEE International Conference on Plasma Science, Raleigh, North Carolina, June 1-4, 1998.
6. L. A. Pinnaduwage, C. Y. Ma, D. L. McCorkle, and W. Ding, "A Novel Energy-Efficient Plasma Chemical Process for the Destruction of Volatile Toxic Compounds", presented at the Environmental Management Science Program Workshop, Chicago, IL, July 27-30, 1998.
7. W. Ding, D. L. McCorkle, C. Y. Ma, and L. A. Pinnaduwage,"Dissociation of Benzene in a Pulsed Glow Discharge", 52nd Annual Gaseous Electronics Conference, Norfolk, Virginia, October 5-8, 1999.
8. C. Tav and L. A. Pinnaduwage, "Dissociative Electron Attachment to Laser-Excited Benzene", 52nd Annual Gaseous Electronics Conference, Norfolk, Virginia, October 5-8, 1999.
9. L. A. Pinnaduwage, W. Ding, and D. L. McCorkle, "Negative Ion Formation in Pulsed Plasmas", 52nd Annual Gaseous Electronics Conference, Norfolk, Virginia, October 5-8, 1999.

**Patents**

Two patent disclosures based on this work have been elected by the ORNL Technology Transfer Office to be filed:

1. L. A. Pinnaduwage, C. Y. Ma, D. L. McCorkle, and W. Ding, "Destruction of Low- Concentrations of Volatile Toxic Compounds using Glow Discharge"
2. L. A. Pinnaduwage, W. Ding, and D. L. McCorkle, "A Plasma Mixing Method and Device for Plasma Processing of Materials".

The following patent disclosure was recently submitted:

3. L. A. Pinnaduwage, W. Ding, and D. L. McCorkle, "Method for Suppression of Dust Formation in Material Processing Discharges".