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The goal of the program is to conduct an R&D effort which will improve and demonstrate a combination of technologies intended to make VOC treatment both effective and affordable. The U.S. Marine Corps, the other services and industry will each benefit.

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AIR POLLUTION CONTROL SYSTEM RESEARCH

AN ITERATIVE APPROACH

TO DEVELOPING AFFORDABLE SYSTEMS

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INTRODUCTION

The Marine Corps has taken the lead in R&D for air pollution control systems (APCS) for paint booths, and cleaning/degreasing facilities. The Marine Corps Multi-Commodity Maintenance Centers $(MC)^3$ have teamed with the Air & Energy Engineering Research Lab (AEERL) of the U. S. Environmental Protection Agency, and the Applied Research Laboratory at The Pennsylvania State University (ARL Penn State) to conduct the R&D. Funding has been secured from the Strategic Environmental R&D Program (SERDP). This paper will describe the roles of the team members, the technologies involved, the lab facilities which will be developed, and the iterative approach which will be followed in the execution of the research. Potential benefits to the $(MC)^3$ depots, lower level Marine Corps maintenance activities, other DoD facilities, and to industry will be addressed.

The technologies which will be researched, separately and in combination, include: Paint booth air recirculation; UV oxidation of volatile organic compounds (VOC); ozonated water treatment of VOCs; and carbon bed regeneration. Whenever possible, promising lab results will be quickly duplicated on the full-scale field system. This iterative approach will allow for rapid dissemination of the technology improvements as they are developed.

Each team member will play a key role and each stands to benefit from the research effort. The USMC will purchase a commercial hybrid APCS and the depot at Barstow, CA will be the first host facility for the full-scale elements of the research; the depot will be the first to benefit as the cost and effectiveness of the system are iteratively improved. AEERL has done significant research on paint booth recirculation (Darvin, 1993), but at smaller scales than the Barstow depot offers; the program will provide the opportunity to prove their technology at full scale in a production environment. ARL Penn State has

made research contributions in UV oxidation (Heinsohn, 1993) and carbon bed regeneration (Cannon, et al., 1993); this program will enhance their facilities and build on their expertise in State College, and provide full-scale applications.

The goal of the program is to conduct an R&D effort which will improve and demonstrate a combination of technologies intended to make VOC treatment both effective and affordable. The U.S. Marine Corps, the other services and industry will each benefit.

FUNDING

The primary funding for the research described in this paper will be provided by the Strategic Environmental Research and Development Program, which states as one of its purposes: "address environmental matters of concern to the DoD and the DoE through support for basic and applied research and development of technologies that can enhance the capabilities of the departments to meet their environmental obligations." The contributions of each of the four participating agencies will also be substantial, and will be discussed later in the paper. The research will build on paint booth recirculation work accomplished by the Air & Energy Engineering Research Laboratory (AEERL) of the U. S. Environmental Protection Agency, much of which has been funded by the U.S. Air Force, and on UV oxidation research conducted at Penn State which was funded by the Air Emissions Reduction Center (AERC), a consortium of pharmaceutical companies.

CONCEPT OF RESEARCH

The research will be accomplished on lab scale, pilot scale, and production air pollution control systems (APCS). The production system, to be installed at Marine Corps Logistics Base (MCLB), Barstow, CA, will treat the exhaust from three paint booths which will be modified to recirculate a large percentage of their exhaust. These recirculation systems are, themselves, a critical element in the overall R&D effort. Areas of research relating to the APCS which are thought to hold substantial promise are now, and will continue to be studied on lab scale equipment. Results are being published, presented, and made available to the equipment manufacturer who will provide the full scale system to MCLB Barstow and the pilot scale system to ARL Penn State. The ongoing research has already resulted in design changes relating to UV light selection and spacing and to oxidant generation method. As the acquisition process proceeds, research results will impact the configuration, and ultimately, the performance of the APCS. The pilot scale system will be delivered well prior to the full scale system, permitting trials of promising modifications in time to influence final configuration. Once the Barstow system has been installed, and is operating in concert with the paint booth recirculation systems, problems encountered can be investigated on all three scales. Additionally, new coating materials and equipment can be tested for treatability and functionality before committing them to the production environment. Numerous cycles of R&D, triggered at any of the three scales of equipment are expected. Results will continue to be published throughout the program, with a goal of improving the cost and performance of systems for both DoD and the private sector. The program was designed to provide the most efficient technology transfer possible in a complex technical environment.

THE TEAM MEMBERS

Four organizations are key to the conduct of the program. Each will make substantial contributions and each will gain from participation. The Maintenance Directorate of the Marine Corps Multi- Commodity Maintenance Centers $(MC)^3$ has lead the way in establishing this program. Marine Corps funds initiated the program and Marine Corps funds will purchase the full scale APCS for installation at Barstow. MCLB Barstow will be the beta site throughout the program. The $(MC)^3$ personnel at Barstow are already making the compromises between production and research necessary to assure program success. Participation in the program ensures that the $(MC)^3$ paint facilities will remain compliant with air quality regulations. Participation places the Maintenance Directorate in an R&D leadership position, assuring them their share of both responsibility and voice among the DoD depots.

The AEERL has also provided early funding to start the program prior to SERDP funding release. AEERL brings substantial paint booth recirculation technology to bear. Mr. Charles H. Darvin, who has made major contributions to recirculation development, is AEERL's principle investigator on this project. Participation ensures continuing development of this important technology, giving AEERL a most productive avenue on which to fulfill their mission. AEERL is committed to the technology transfer process; they see paint booth recirculation, as well as the APCS development, as excellent candidates.

ARL Penn State has also provided kick-off funding and has assembled a very strong team of researchers to advance the work, some of which was ongoing under other programs. New, totally dedicated lab space is being provided and appropriately equipped. ARL will grow their expertise during the program, and will enhance their laboratory facilities, improving the likelihood of attracting additional research funding.

Terr-Aqua Enviro Systems (TAES) is providing the pilot scale APCS and a wealth of engineering experience to accelerate the programs. TAES will gain considerable market place exposure, and has the option to take full advantage of research results to improve their systems. While all research results will move rapidly to the public domain, TAES will be in a position to react most quickly. The program has, with this mechanism, enhanced the likelihood of continuous, successful technology transfer.

Each team member will have made a substantial contribution to make this program a success, and each stand to gain in proportion to its input. The balance achieved in creating this win-win situation may become a model for multi-agency programs in the future.

THE TECHNOLOGIES

The marriage of paint booth recirculation and a hybrid APCS is driven by cost and by the needs of DoD depots to use a variety of coating materials. APCS cost is a direct function of volumetric exhaust flowrate, and, within limits, is independent of the concentration of volatile organic compounds in the exhaust stream.

Recirculation/Partitioning

The flow reduction technique defined by recirculation and partitioning is a unique concept that modifies the exhaust stream to permit the lowest possible discharge volume. Recirculation/partitioning makes air emission control more economically feasible by reducing the exhaust volume that must be controlled.

A reduction of volumetric exhaust flowrate will result in a corresponding reduction of emissions control equipment acquisition and operating cost.

The concept of air recirculation is used in a number of applications particularly in paint baking ovens (Darvin, 1993). However, the technique of flow partitioning is a new booth design concept which when demonstrated in an operating booth will eliminate the concern of recirculating booth air to a manned spray booth. This issue is unique to the OSHA requirements for manned spray booth operation which defines the level of air flow and pollutant concentration within a booth. The present operating codes have prevented the use of flow reduction schemes in booths which could reduce emissions control cost for spray painting operations. Recirculation and partitioning will allow compliance with the air flow requirements within the booth while achieving a 50 percent and greater reduction in booth exhaust flow rate. (See Figure 1).

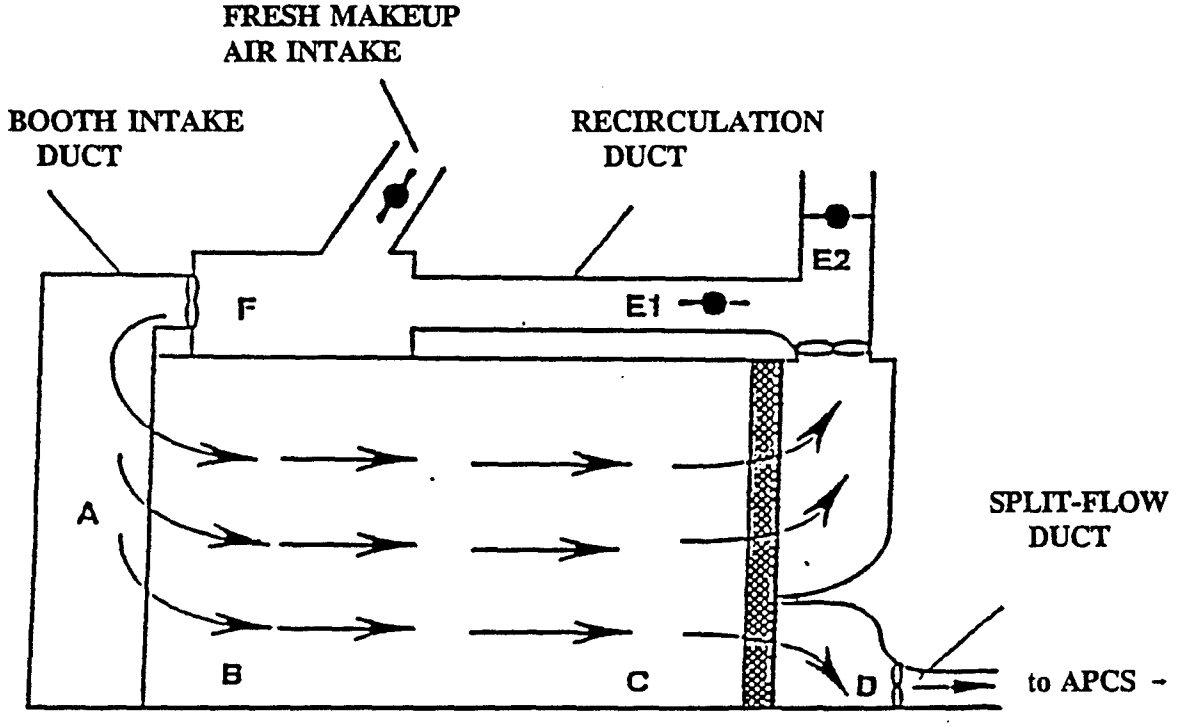

Figure 1. Recirculating/Partitioned Spray Booth

The TAES APCS

The TAES APCS which will be installed at MCLB Barstow (and pilot scale at ARL Penn State) uses a self-contained, self-regenerative multi-stage process. The design captures and oxidizes a broad range of Volatile Organic Compounds (VOCs), including chlorinated and halogenated VOCs. The APCS will reduce VOC emissions in exhaust air streams from paint spray booths, ovens, mixing rooms, conformal coating operations, solvent cleaning and paint removal facilities to below air quality regulation levels while producing no secondary hazardous pollutants.

The APCS consists of the following stages:

- A collection system which will capture and deliver the contaminated air stream to the APCS.
- Pre-filters and secondary filters which remove any airborne particulates which are entrained in the air stream down to approximately one micron. Typical high efficiency particulate arrestor (HEPA) filters are used for this.
- Photolytic-Reactors which initiate photo dissociation and radical oxidation processes. (This device houses special UV lights to initiate oxidation of VOCs).
- Mist Air Dispersion Unit which will "wet" the air stream. This is done so that any sub-micron particulate has the opportunity to go into aqueous phase.
- An Aqua-Reactor which is a counter flow packed bed scrubber with highly oxidant rich water circulating throughout.
- Carbon Beds which capture and treat remaining VOCs are the final step in the treatment train. These carbon beds are regenerated with oxidants for onsite destruction of the VOCs.

THE RESEARCH

While not necessarily separated in the execution, the research is most clearly described in four areas: Recirculation/Partitioning; UV-Radical Oxidation; Carbon Bed Regeneration; and Miscellaneous.

Recirculation/Partitioning

The recirculation/partitioning portion of the program will include studies to develop, demonstrate and evaluate the emission flow reduction potential of the concept while remaining within the criteria established by OSHA and consensus code organizations. Specific research will be conducted to: (a) define the level of pollutant buildup in the recirculating air stream; (b) to develop booth design, modification specifications, and models; (c) define control cost projections based on flow reduction potential; and (d) predict resulting energy requirements to control the modified booth. The diagram of the recirculation partitioned spray booth concept is represented in Figure 1.

Past EPA studies suggest that pollutants in a horizontal flow spray booth are divided into two concentration regions in which the lower region of the booth exhibits an average concentration for all pollutant species greater than in the upper region of the booth. The result is that the greatest portion of the pollutant generated during painting remains in the lower level of the booth. Based on this finding, separate exhaust streams might be directed from the two regions of the booth: one a pollutant-rich lower stream directed to a control system and the second, a lean upper stream recirculated to the spray booth.

Booth pollutant concentration analysis and booth flow modeling studies are required to evaluate and validate the potential of the recirculation/partitioning concept for Marine Corps painting facilities. The results of these studies will confirm the capability of the design concept to remain within the booth concentration limits established by OSHA and other consensus organizations. Specific analysis of metals, isocyanates and total organic volatiles will be conducted. Both pre- and post-booth modification studies

will be completed during more than 100 individual experiments completed during each stage of the program. Each experiment will give data points that indicate how and where pollutants accumulate within the flow patterns of the test booths. Modeling of the concentration zones for various pollutants and the flow patterns within the test booths and under varying painting scenarios will be completed. These data and resulting models will allow development of criteria for booth design, modification and operation.

UV-Radical Oxidation

The UV-radical oxidation system manufactured by Terra-Aqua Enviro Systems (TAES) has been permitted and in operation for several years in the South Coast Air District of California. This district is known to have the most stringent air emissions standards in the U.S. The UV-radical oxidation system has rapid transient characteristics, but little has been published describing the chemical reactions that occur in each component and how the chemical kinetics is coupled with the velocity field in the reactor (Heinsohn, 1993). Thus, it is not known what percent destruction occurs in each of the TAES components, or perhaps whether one of the system components can be eliminated.

This area of the research will focus on the photolytic reactor component of the UV-radical oxidation system. The research will:

- Determine the destruction efficiency and exhaust products for a variety of military coatings; and
- Describe how UV-radical oxidation processes destroy VOCs and hazardous air pollutants (HAPs) so that the system's performance can be improved and its cost and size reduced.

Carbon Bed Regeneration

The Terr-Aqua system employs carbon beds as the final step in the treatment train. Granular activated carbon (GAC) adsorption of VOCs has been documented (Cannon, et al., 1993), and GAC adsorption offers a best available technology for capturing VOCs and HAPs. While in service, the GAC will eventually become exhausted (spent) in its capacity to adsorb organic compounds, at which point it can either be regenerated and reused, or landfilled and replaced.

The TAES system employs frequent cycles of VOC loading onto GAC followed by in-situ oxidant regeneration. The frequent cycling precludes the buildup of VOCs on GAC to levels that cause the effluent VOC concentration to exceed standards. The GAC thus serves as a collector for VOCs, which facilitates the necessarily long reaction times for oxidation of the retained VOCs. Thus, although typical air residence times through the activated carbon system may be measured in seconds, the VOC retention and destruction time on the activated carbon surface may be measured in hours. VOCs and HAPs are not the only organic materials affected by oxidation, however: the activated carbon surface itself may also become oxidized, which could potentially cause either favorable or detrimental effects. The intent of the research is to develop the fundamental science that characterizes regeneration so that the process can be enhanced. The technical objectives of this research area are:

- Determine the extent to which oxidants regenerate an activated carbon that has become loaded with volatile organic compounds.

- Determine whether this oxidation adversely or favorable alters the adsorptive properties and pore structure of activated carbon.

- Monitor the influence of several variables on regeneration effectiveness, including regeneration times, oxidant intensity and spacing, temperature, and nature of VOCs that have been adsorbed.

- Provide fundamental insight on techniques for enhancing the oxidation method of regenerating GAC.

Miscellaneous

This is by no means the least important area of the research. As experience is gained on lab scale, pilot scale, and ultimately the production APCS, promising areas of research, offering rapid and/or high return on research effort will become apparent. These opportunities, plus the investigation of problems effecting production at MCLB Barstow, will receive rapid response. Early candidates which may well get considerable attention are:

- The effect of metals contained in various coating materials on the treatment process and disposition of these metals during the process.

- The effects of water temperature and pH on the performance of the aqua reactor.

ISSUES

Treatment vs. Pollution Prevention

Both President Clinton and Ms. Browner, the Administrator of the USEPA, have issued policy statements which emphasize pollution prevention by source reduction and deemphasize the treatment and control approaches to reducing pollution. This research focuses on treatment. The justification is simply that:

- The military is years away from converting entirely to low or zero solvent based coating materials; and

- Even when these worthwhile goals are achieved, the remaining hazardous air pollutants in coating materials must still be dealt with.

All DoD facilities which paint must soon determine how they will cope with increasing regulatory pressure. Those facilities which are in non-attainment areas must react immediately. This research will serve those needs.

Competition vs. Technology Transfer

The procurement process sometimes moves at speeds which are not only non-responsive to the needs of their customers, but the process frequently insures that the equipment installed is not of the latest technology. In order to ensure that the research is conducted on current technology, and that at least one

private supplier of APCS equipment will convert research results to available product, TAES has been included as an active participant in the research. Great care will be taken to ensure that research results which belong in the public domain are made available in a timely manner.

SUMMARY AND GOALS

A unique and very capable team has been assembled to execute promising research. The marriage of paint booth recirculation technology to a hybrid ultra violet-radical oxidation air pollution control system (APCS) offers promise for an affordable system which will accommodate a wide range of coating materials. The ultimate goals of the research are to bring the cost of paint booth/APCS systems down and their effectiveness up. Success will bring costs within reach of DoD maintenance activities below the depot level, as well as, small and medium businesses which badly need such technologies.

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TABLE OF ABBREVIATIONS

AEERL	Air and Energy Engineering Research Laboratory
APCS	Air Pollution Control System
ARL	Applied Research Laboratory
HAP	Hazardous Air Pollutant
$(MC)^3$	Marine Corps Multi-Commodity Maintenance Centers
MCLB	Marine Corps Logistics Base
SERDP	Strategic Environmental Research and Development Program
TAES	TerrAqua Enviro Systems, Inc.
UV	Ultra Violet
VOC	Volatile Organic Compounds