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Real-Time Cleaning Performance Feedback

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REAL-TIME CLEANING PERFORMANCE FEEDBACK

by

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Abstract

Monitoring contamination levels on parts during cleaning operations will provide feedback that can be useful in reducing waste generation and air emissions caused by over- or under-cleaning. Such real-time process controls can help eliminate pollution in a wide variety of industries, including aerospace, electronics, and metal finishing.

Introduction

One of the biggest sources of hazardous waste and VOC air emissions throughout American industry, as well as throughout the DOE complex, is parts and equipment cleaning operations. Processes common to the Department of Energy (DOE) complex include cleaning related to metal machining and electroplating, electronic fabrication activities such as printed circuit board manufacturing and assembly, and composites molding and machining. In some of these processes, cleaning operations generate most of the waste volume (see Figure 1).

Parts and equipment cleaning is an integral part of many major industries such as aerospace, automotive manufacturing, electronics equipment and computer manufacturing, medical equipment manufacturing, and chemical fabrication. In all of these industries, large quantities of hazardous solvents (both halogenated and nonhalogenated) are routinely used and eventually find their way into a waste stream or are emitted into the air. In 1991, the U.S. demand for four commonly used halogenated cleaning solvents (trichloroethylene, perchloroethylene, methylene chloride, and 1,1,1 trichloroethane) totaled nearly 200,000 metric tons; of this, one gallon in three was used for parts and equipment cleaning.

A common and effective way to reduce hazardous solvent waste and emissions has been to substitute environmentally benign materials whenever possible. While this excellent approach is responsible for significant pollution prevention, many cleaning applications still require chlorinated or other hazardous and volatile solvents. In these cases, it is essential to use the chemicals in as *efficient* and *conservative* a manner as possible. Waste caused by unnecessary cleaning of parts or by having to reclean parts that were improperly cleaned the first time should be avoided through accurate process controls and contamination analysis procedures.

Unfortunately, these procedures are not taken in most industries. While many U.S. manufacturing processes are now state of the art and highly efficient, parts and equipment cleaning lags sorely behind, especially in the area of real-time process controls. In preparing for the current project, LLNL staff interviewed engineers in various industries. In aircraft manufacturing, one of the most common methods for determining when a wing or fuselage section is clean enough is the water-break test. This highly variable, nonquantitative approach determines that a part is clean when water runs off the surface in a sheet rather than beading up.

In our interviews, one aerospace engineer referred to this method as a "nineteenth century approach" that gave varied results depending on the cleaners (for instance, detergent on a part surface causes water to sheet off and makes the surface appear clean even when considerable soil is present). Laboratory analyses of surface contamination is another method to spot check cleaning performance, but these analyses have turnaround times of several days or longer and often do not identify a problem until many parts have been improperly cleaned.

All of the aerospace personnel interviewed emphatically supported the development of real-time feedback mechanisms for determining when a part is clean enough. Electronics companies were also interested in process control technology. One company that manufactures printed circuit board assemblies for satellites and Space Shuttle experiments minimizes cleaning problems by overcleaning most parts, hoping to adequately clean all of them. This overcleaning generates unnecessary waste and emissions. Also, because of the lack of real-time performance feedback, improperly cleaned parts may not be detected until later in the production process when it is more expensive to reclean them.

Lawrence Livermore National Laboratory (LLNL) is developing portable contamination analysis units (CAUs) that can provide real-time cleaning verification feedback in industrial production lines. LLNL plans to make this technology robust enough to use in a wide range of DOE and industrial applications. The CAUs will be easily held by hand so that they can quickly be moved from one part of an assembly line to another. They will generate highly precise data. In bench-scale testing of the CAU, hydrocarbon residues the thicknesses of the order of one nanometer (corresponding to contamination one or two monolayers thick) were routinely measured (see Figure 2). The CAU also identifies the type of contamination and can distinguish between hydrocarbon species and other common contaminants such as silicone oils. Finally, the components of the CAU are inexpensive so that once the technology is commercialized, it will be affordable to medium- and small-sized shops as well as to larger plants.

Project Tasks

The CAU offers the real-time process controls needed to design more environmentally friendly cleaning processes. We have already assembled and tested a bench-scale proof-of-concept CAU. Now, we are working to design and fabricate a more sensitive and portable version that can demonstrate its usefulness in both industry and DOE processes. Developing a commercially viable prototype CAU will entail the following tasks:

A. Design and Fabricate Portable CAU

This task includes three milestones:

- Sensor fabrication and testing
- Interface development
- Electronics support package development.

The contamination sensor package, which uses mass spectrometry technology, must be light enough to be easily hand-held yet accurate enough to measure extremely small amounts of contamination on parts surfaces. It will be combined with a probe designed to interface with parts surfaces and use vacuum and thermal means to desorb contamination from the surface. Laser desorption and sputtering may also be used in situations where contamination is difficult to desorb. Finally, the package will be connected to an electronics package that includes a data processing unit and contaminant library for identifying the amount and type of surface contamination.

B. Calibrate CAU and Develop Library of Contaminant Signatures

The CAU will be calibrated to measure contaminant layer thickness and other standard metrics such as micrograms of contamination per square centimeter of part surface. Calibration procedures will employ various research-grade, bench-scale equipment, including Fourier Transform Infrared Spectroscopy, Electron Spectroscopy Chemical Analysis, and other technologies.

C. Field Test CAU within LLNL Cleaning Processes

Test milestones will include successful operation in the following LLNL cleaning processes:

- Printed circuit board cleaning
- Electronic component cleaning
- Machined parts cleaning
- Electroplated parts cleaning
- Lasers component and target chamber cleaning
- Plastics cleaning.

D. Field Test CAU at Other DOE Sites

Testing at other national laboratories and DOE production facilities is being arranged.

E. Field Test CAU on Industry Production Lines

Field testing is being arranged at aerospace, electronics, and metal finishing production facilities. The City of Los Angeles' Hazardous and Toxic Materials Program is helping to identify these test sites.

F. Using Feedback from Field Tests, Prepare CAU Equipment Package for Commercialization

The CAU package will be modified in response to the needs of industries field testing it.

Conclusions

The CAU project is demonstrating that real-time cleaning process performance feedback is a valuable technology for many industries and one that LLNL is well-positioned to develop. The future of the CAU sensor appears to be promising; however, testing needs to be extended to many surface contaminants, substrates, and geometries. A major goal of the project is to initiate partnerships with many industry segments and use the LLNL technology to improve manufacturing cleaning operations and reduce pollution generation.

Developing "Just Enough Cleaning" technologies is consistent with LLNL's and the U.S. Department of Energy's new mission, which is to use national laboratory resources to benefit American industry (see Figure 3) and to provide links between DOE research and development and the needs and requirements of manufacturing.

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Figure 1.

In some processes, the cleaning steps dominate waste generation. In this zinc plating operation, for instance, 13 of the 15 steps are related to cleaning, and all of them contribute to waste generation.

Electroplating Line

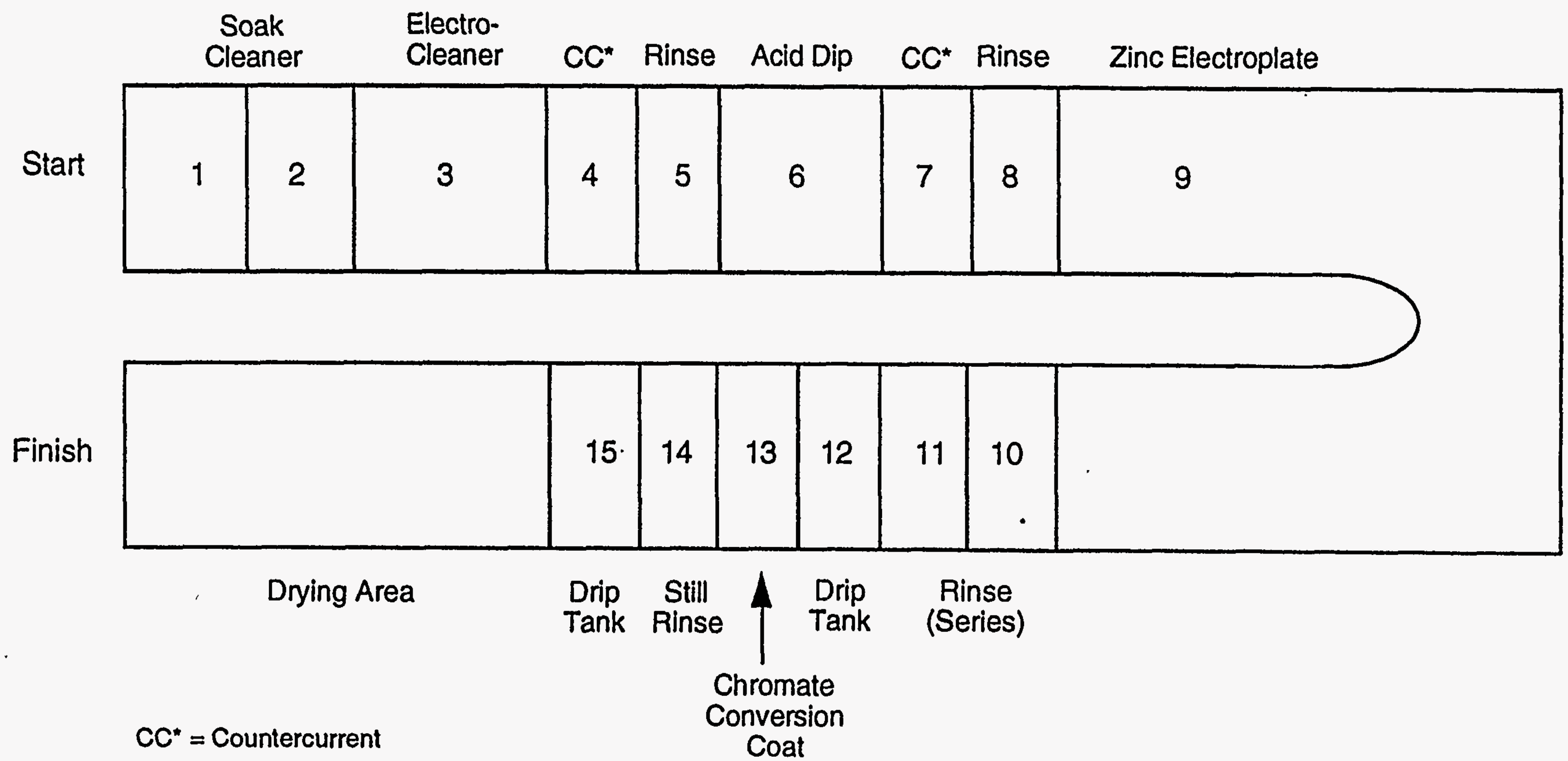

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Figure 2.

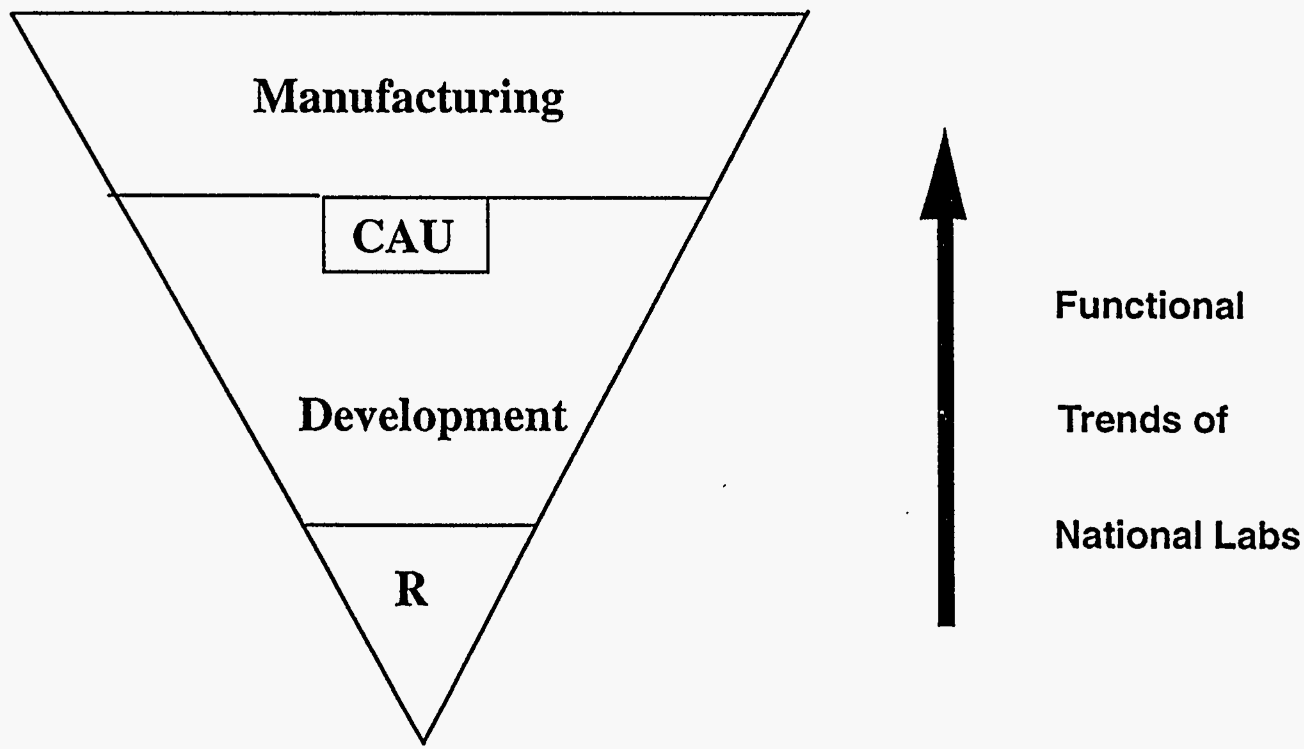
The prototype CAU has already been able to detect very small amounts of trace contaminants on precision-cleaned surfaces.

Cleaner/Solvent	Average Residue Thickness (nm)
NC300	1.2
815GD	1.2
MP1793	1.4
JALSAC	1.4
1990GD	1.6
CITRASAFE	2.8
Acetone	4.2

Substrate: aluminum

Figure 3.

The proposed research project is consistent with the DOE's mandate for the national laboratories to create necessary links between research and development and manufacturing.



The CAU device offers an innovative and beneficial quality control device with applications across several manufacturing segments.