Aqueous degreasing is being implemented at Boeing as one approach to the elimination of vapor degreasing operations. Vapor degreaser replacement work was initiated in 1987 and is presently an active, evolving program. Aqueous degreasing has been the initial focus of the program, because of simplicity and utility. Candidate aqueous degreasers have been evaluated for cleaning effectiveness, toxicity, corrosion effects, effects on subsequent processing, waste disposal, and manufacturing feasibility. The implementation of qualified processes has been underway for two years and continues. This report is a summary of the cooperative efforts conducted by Boeing at several sites, and across divisional lines and disciplines.

**Vapor degreasing is a most effective process for cleaning metals, and will be difficult to replace.** It offers the ability to continuously flush surfaces with fresh, non-flammable solvent in a relatively small working volume, with minimal concern for corrosive effects, producing degreased and dry parts. The initial implementation efforts at Boeing have involved the use of aqueous degreasers, process solutions that are mostly water. The degreasers investigated fall into three general categories, which will be defined as solvent emulsion (semi-aqueous) degreasers, alkaline emulsion degreasers, and surfactant degreasers.

The solvent emulsions are similar to those that have been used in the past, but contain solvents such as terpenes rather than naphtha. The alkaline emulsions are mostly alkaline cleaners, but they generally employ some emulsified solvent to boost cleaning effectiveness. The solvent emulsions also contain surfactants as part of the degreaser package. The surfactant degreasers, however, rely exclusively on a blend of surfactants to affect degreasing. The use of any of these aqueous degreasers will require rinsing to remove residues, and drying when wet chemical processing does not follow.

### 50 Degreaser Candidates Have Been Evaluated

An initial list of 10 degreasers was developed by contacting suppliers, using the selection criteria of indicated degreasing capacity, low toxicity, and regeneration capability. As this program progressed, many more contacts were made within the aerospace industry and with other chemical suppliers. These contacts lead to the evaluation of more than 50 degreaser candidates.

**Degreasing Effectiveness Testing**

Vapor degreasers in a large manufacturing operation are often used as general degreasing stations, degreasing hardware after many different operations, removing a variety of soils from a number of substrate materials. For this reason, it was initially expected that the aqueous degreasers would be required to perform similarly. Many specifications require only that a degreaser “leave no visible residue.”

For our evaluation, a comparative method was used, in which degreasing effectiveness was observed with respect to operating time and temperature, using several types of contamination, and then compared to the observations made for other degreasers. The principal target was to obtain broad spectrum soils removal, but not necessarily to achieve a water-break-free surface. Most degreasing effectiveness screening was done by immersion with minimal agitation, to maintain temperature control. The intent was to compare the chemical activity of the degreasers, recognizing that agitation would accelerate their effectiveness in actual use.

Degreasing effectiveness testing was also-and is continuing to be conducted—using spray and ultrasonic configurations. Evaluations were conducted similarly to that used during immersion testing, but for shorter time periods. The objective again was broad spectrum soils removal for general degreasing uses.

**Corrosion Testing**

Corrosion testing was conducted on the most active materials identified in degreasing effectiveness screening, to ensure that the aqueous degreasers did not cause any adverse affects of substrate materials.

- **Etch testing** was conducted according to Boeing specifications. Representative test metals were immersed in the degreasers at operating concentration and temperature for 24 hours, measuring the weight change of the specimens as indications of uniform dimensional changes. Cleaners that would not pass this test had generally been removed from consideration during degreasing effectiveness testing, because of the staining and gassing observed.

- **Intergranular attack and end-grain pitting tests** were conducted according to Boeing specifications. Polished metal test specimens were immersed in the degreasers at operating concentration and temperature for 30 or 40 min (alloy-dependent). Specimens were then cross-sectioned to determine that intergranular attack in excess of 0.0002 in. and end-grain pitting in excess of 0.001 in. had not occurred.
. Sandwich corrosion testing was conducted according to Boeing specifications in a manner very similar to ASTM F1110. The intent was to determine whether cleaners could be used on assemblies or other parts where entrainment of degreaser might occur.

. Hydrogen embrittlement testing of high-strength steels was performed in accordance with ASTM F519, using both cadmium-plated and unplated, notched tensile rods (Type IA specimens). The specimens were subjected to 45 percent of their ultimate tensile strength, while being immersed in the room temperature test degreaser. The specimens must not break for a minimum of 150 hours.

. Stress corrosion testing of titanium alloys was conducted in accordance with ASTM F945.

. Hydrogen pickup testing of titanium alloys was also performed, to ensure that hydrogen content had not increased more than 20 ppm (measured instrumentally) with exposure to test degreasers.

Effects on Subsequent Processing
Substituting the aqueous degreasing process for vapor degreasing must not adversely affect the production processes that follow. The first requirement of this type involves sulfur content. Sulfur concentration, in any chemical form, at the operating concentration of the degreaser, must not exceed 100 ppm, so as not to risk heat-treat blistering of aluminum alloys from degreaser residues inadvertently remaining on part surfaces. In addition, degreasers should not be operated in excess of 140°F to avoid flash drying of degreaser residues onto part surfaces.

The other area of effects on subsequent processing involves degreasing at the head of a chemical processing line. Because of the lack of adequate measurement techniques for and established limits on residues following degreasing, the most straightforward (and laborious) method of looking for adverse effects was judged to be the quality of subsequent finishes. Many subsequent processes, such as alodizing, anodizing, painting, bonding and platting, were performed after degreasing with candidate materials. These final finishes were then evaluated per specification performance requirements.

Toxicological & Industrial Hygiene Evaluation
Candidate degreasers were initially selected to be low-toxicity materials, based on supplier information. Degreasers that seemed to be performing well in the aforementioned evaluations were then forwarded to industrial hygiene specialists for their analysis of acceptability for use.

Results & Lessons Learned
Completion of the outlined test program resulted in the identification of several active degreasers that could meet some or all of the performance criteria listed for use on aluminum, magnesium, ferrous, nickel, titanium, and copper alloy parts. Boeing specification coverage has been issued, describing the limitations of these degreasers to various classes and grades of processing.

. The alkaline emulsion degreasers evaluated thus far, for example, have had difficulty with sandwich corrosion, and therefore are not permitted for use on parts that can entrap solution where rinsing might not remove all degreaser from surfaces.

. The alkaline emulsion degreasers have also failed hydrogen embrittlement with cadmium-plated specimens, because of cadmium re-embrittlement, and so have limitations in this regard.

. Finally, the affects on subsequent processes testing was not informative. Very few failures of final finishes were observed and none was attributable to the aqueous degreasers under test. The quality of the final finishes are so far removed from the degreasing step that this test requirement has been largely discontinued.

The next step in the process involves manufacturing feasibility. This phase of the process has illuminated shortcomings in the bench-scale test program. The worst of these is discovering shop soils that are not readily removed by all the approved degreasers, although many aqueous degreasers will remove soils that were not removed by vapor degreasing. The initial test program was oriented toward broad-spectrum soils removal. But once firm intent to implement occurs, a more complete accounting of the soils expected to be encountered for each specific degreasing site inevitably follows. The lesson is that the better the soils load is identified, the better the job of degreaser candidate selection can be performed, operations which have the uncommon flexibility to change both the degreasing method and the manufacturing soils coming in for removal by degreasing are a source of envy.

Mechanical Action
Bench-scale screening of degreasers in immersion and spray configurations illustrated the strong impact that mechanical action has on aqueous degreasers, not exactly a startling observation to most. But where part configuration and shop circumstances permit, the spray application of non-foaming aqueous degreasers markedly decreases degreasing time. Light oils removed in less than 10 minutes by immersion are removed in less than 30 seconds by spray. Choosing a degreaser compatible with spraycleaning would preclude the use of most solvent emulsions without fire protection, because of air-stripping of the solvent fraction. The effect of mechanical action is also apparent during implementation of immersion degreasing. A vigorous and uniform agitation helps to remove soils affected by the chemical activity of the degreaser. But again, the form and intensity of agitation is limited by the type of degreaser to be used.

Regeneration
The current generation of aqueous degreasers differs from those used in the past in that they contain surfactant packages that do not permit complete emulsification or saponification of organic contaminants. The end result is that organics removed from hardware will float to the degreaser surface when the degreaser cools or stands quiescent. The ability to regenerate such degreasers should significantly extend degreaser life, reducing the volume of hazardous waste disposal.

All aqueous degreasers currently being implemented at Boeing have provisions to take advantage of regeneration through physical separation of organic soils. However, initial implementation of aqueous degreasers will be strictly to replace the vapor degreasing process, meaning that alkaline cleaning to produce a water-break-free surface prior to chemical processing will still be performed. It is believed that with experience and adequate control of regeneration, the degreasing and final cleaning steps can be combined into one.
Galvanic Effects
An additional lesson learned through implementation has involved adverse galvanic effects. The potential for problems in this area was recognized in preparing specification coverage, through provisions against processing mixed metal loads. But agitation in an immersion degreaser can force parts and parts baskets up against the wall of the tank. The area ratio of a large stainless steel tank to small aluminum details creates a situation that has been observed to result in pitting of freshly machined surfaces. Provision must be made to circumvent this potential problem, through tank lining or the use of non-conductive materials for baskets or sideboards, to avoid a conductive pathway to parts.

Aqueous Degreasing is Workable...
The replacement of vapor degreasing with aqueous systems will not be without difficulties. The increased ‘footprint’ of aqueous degreasing on the factory floor makes retrofitting complicated and potentially expensive. There are many choices of degreasers and the form of equipment to apply the degreasers, so feasibility testing with the specific soils and systems of interest is a must. In some cases, this will require more degreasing stations, tailored to the needs of a limited site, than was the case with vapor degreasing. But aqueous degreasing is workable, and the reduction in hazards to shop personnel and the environment are being realized.

About the Author
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AESF SUR/FIN ‘92’s Session U:
“Hazardous Waste Reduction in the Aerospace Industry”
In addition to the complete texts of Dr. Golden’s and the Graham/Patry paper on waste minimization efforts at Tinker AFB (edited and included in this issue), the SUR/FIN proceedings contains the following papers:
The Importance of Water-Based Cleaners in a Cleaning Operation
Corrosion Control Performance Evaluations of Environmentally Acceptable Alternatives for Cadmium Plating
Boeing’s Evaluation of a Replacement for Chromium Plating: Ni-W-Sic Composite Electroplating
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