EVALUATION OF INDUSTRIAL PROCESS MODIFICATIONS TO REDUCE HAZARDOUS WASTES IN THE ARMED SERVICES

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INTRODUCTION

At the 1984 annual meeting of the Water Pollution Control Federation, Abel Wolman proposed a three-pronged attack on the hazardous waste problem:

1. Industry should reduce the production and use of hazardous materials to a minimum.
2. The reduced waste volume produced by industry should be treated to the greatest extent possible so that a minimum quantity of hazardous waste is discharged to the environment.
3. The water supply industry should provide final protection of public health and welfare in removing whatever hazardous substances that remain.

In making this appeal, Dr. Wolman stressed that these three efforts should be undertaken in sequence, and that each should be performed thoroughly before moving on to the next. Just as it has often proved more effective to protect a watershed through prior wastewater treatment than through extensive water treatment, reducing the quantities of industrial waste produced can simplify hazardous waste disposal and wastewater treatment.

Frequently, when we refer to reducing industrial waste discharges, we think of end-of-pipe treatment facilities. Dr. Wolman emphasized that treatment should occur as a last resort, after every effort has been made to eliminate the hazardous waste produced from the process itself.

Since 1980, it has been Department of Defense (DOD) policy to limit the generation of hazardous waste through alternative procurement policies and operational procedures that are both environmentally attractive and economically competitive. The Army, Navy, and Air Force were directed by DOD to reduce quantities of hazardous waste, when feasible, through resource recovery and reclamation, recycling, source separation, and raw material conservation. In carrying out the intent of these policies, many studies have been performed that recommended industrial process modifications which, if successful, had the potential to significantly reduce the generation of hazardous wastes at the source, rather than require treatment at end-of-pipe facilities. Several have been successfully implemented, and many others either were not implemented or failed to meet their goals.

CH2M HILL was contracted by the DOD Environmental Leadership Project and the U.S. Army Corps of Engineers to evaluate 40 cases of industrial process modifications attempted by the three armed services. Our task was to determine why some of these modifications have been successful and others have not. We were to evaluate not just technical factors, but also institutional and motivational factors that contributed to success or lack of it. The ultimate goal of the project was to encourage the development and implementation of industrial process modifications that will reduce the amount of hazardous waste generated by the armed services.

While there are specific circumstances and reasons behind the success or lack of success of each modification attempted, two factors were found to characterize each of the successful process modifications: (1) the end users were sufficiently motivated to make the change and (2) the technologies themselves were "elegant in their simplicity." Factors that have contributed to motivating personnel include improved production rate or quality, a reduction in overall costs, decreased manpower requirements, and a decrease in the quantity of hazardous wastes to be disposed of. Technologies that were "elegant in their simplicity" were easy to operate and maintain, reliable, and cost effective. In short, successfully implemented process modifications combined effective technology and motivated personnel to significantly reduce hazardous waste production by substantially changing the industrial process, substituting raw materials, or recovering and reusing waste by-products.

DOD operates industrial facilities to repair and recondition planes, helicopters, ships, tanks, and other vehicles and equipment. Metal finishing operations, which are performed at over 100 DOD industrial facilities, produce most of DOD's hazardous wastes. Metal finishing operations include: paint stripping, solvent cleaning (i.e., removal of dirt, oils, greases, and corrosion products), metal plating, and painting. This paper examines process modification case studies from each of these four metal finishing categories.

PAINT STRIPPING

Paint stripping, in preparation for reconditioning and recoating, is performed at virtually every DOD industrial facility. Complete stripping is often necessary for new paint and electrocoatings to properly adhere to existing surfaces. In typical military paint stripping, sprays or baths containing acidic methylene chloride, phenolic, or hot alkaline sodium hydroxide solutions are employed to dissolve and loosen old paint. After scraping, the resulting solvent-paint mixture is washed away with large volumes of water, resulting in significant quantities of hazardous waste (ten's of thousands of gallons per plane). In addition, hard-to-remove paint is machine sanded, often resulting in some damage to the metal substrate. Wet paint stripping is labor-intensive, dirty, and contributes a significant load to waste treatment facilities.

Several alternative paint stripping processes have been studied by private industry and the military. Among these are: dry media blasting, laser stripping, flash lamp stripping, water jet stripping, CO_2 pellet blasting, and cryogenics. The most promising technique is dry media blasting using a soft recoverable plastic media.

Conventional sand and glass bead blasting techniques have been used in many settings for paint and rust removal from metal surfaces. However, these paint removal techniques cannot be used in many military applications, because the hard abrasive media can damage aluminum and fiberglass surfaces and delicate steel parts. In addition, sand and glass bead blasting produces a silicate dust that can cause respiratory ailments, such as silicosis. Soft vegetable media, such as walnut shells and rice hulls, have successfully been used to strip paint from metal surfaces. However, these materials are susceptible to biological growth during storage, are difficult to recycle, and rapidly degrade, producing large amounts of dust that can create an explosion hazard. The used media is mixed with the removed paint and must be disposed of as a hazardous waste.

In plastic media stripping, small, angular plastic beads are air blasted directly onto the painted surface, causing the coating to dislodge. The key parameter for successful use of plastic media blasting is hardness--the paint must be softer than the plastic media, which in turn must be softer than the underlying substrate. By carefully controlling the size of the beads and the conditions of the process, operators can separate the plastic media from the loosened paint particles and then recycle the media. Generation of wet hazardous waste (solvents and paint sludge in water) is completely eliminated. A small volume of dry hazardous waste is produced as a result of stripping the zinc chromate primer.

Hill Air Force Base (AFB) in Ogden, Utah, has been the lead military facility in the development and testing of plastic media blasting technology. The development of this process modification is a clear example of the key elements contributing to the successful implementation of a modification: the process itself is simple, and operators were motivated to use it. Conventional sand blasting equipment was adapted to include media recovery and separation from the waste paint chips and dust. This modification was spearheaded by Mr. Robert Roberts, a staff member at Hill AFB who recognized the environmental constraints of the existing methods used for stripping planes. He tried many methods before discovering, developing, implementing, and promoting the dry plastic media method.

Initially, the motivation was to develop a process to replace the existing wet solvent process, which was environmentally objectionable and occupationally hazardous. Following extensive testing on aircraft components to demonstrate the process's effectiveness and safety, personnel at Hill AFB completely stripped an F-4 fighter plane in July of 1984. This test demonstrated that the process was much less labor-intensive and less occupationally hazardous than solvent stripping. The aircraft was completely stripped in 1/8 the manhours required for wet paint stripping. In addition, greater control in stripping was achieved, compared with wet paint stripping and sanding, resulting in reduced damage to underlying surfaces. A full-scale plastic bead blasting hanger is currently being constructed based on the prospects of reduced manpower requirements and favorable environmental impact. The hanger incorporates a live floor vacuum recovery system to provide ventilation and dust removal, and a separation system for bead recovery and reuse.

The new hanger will cost approximately $650,000. Annual savings are anticipated to be $800,000, resulting in a payback period of less than one year. DOD estimated that over $100 million could be saved annually and that the generation of millions of gallons of hazardous wastewaters per day could be avoided by switching to plastic media paint stripping at all facilities.

Another installation at which plastic media stripping has succeeded is the Naval Air Rework Facility (NARF) in Pensacola, Florida, where the technology has been used to strip paint from aircraft and helicopter parts. The operation is currently being done in enclosed glove boxes and walk-in blast rooms. Pensacola's long-range plans involve converting two helicopter hangers to accommodate dry media stripping.

There are two major disadvantages of plastic media stripping. First, successful stripping requires that the plastic media be harder than the coat of paint. Aluminum surfaces coated with epoxy and urethane paints must therefore be presoftened with a stripping solvent, such as methylene chloride, and then allowed to dry prior to blasting. Secondly, stripping of thin-skin aluminum and fiberglass surfaces require skilled operators, who must carefully set and control a myriad of variables (i.e., bead hardness, roughness, and size; motive air pressure; standoff distance; application angle; nozzle size; feed rate; etc.) so that surfaces are not damaged during stripping.

Personnel at Hill AFB and Pensacola NARF initially implemented the process modification because of a desire to improve working conditions and to reduce the generation of hazardous waste. They found that plastic media stripping improved product quality and decreased production costs as a result of reduced manpower requirements. This combination of benefits has now replaced environmental and occupational health and safety benefits as the primary incentives to expand application of this new technology; the elimination of wastewater discharges has become a secondary benefit. The process is successfully being applied at both facilities because of strong support from management, engineering, and maintenance personnel, as well as the fact that the technology selected is appropriate to the skill levels of operating personnel at military industrial facilities.

SOLVENT CLEANING

Following paint stripping, metal surfaces are often cleaned with solvents to remove accumulated dirt, oils, greases, and corrosion products. Trichloroethylene, 1,1,1-trichloroethane, and perchloroethylene are used in vapor degreasers at DOD facilities. Mineral spirits, such as Stoddard solvent and Varsol, are used in cold cleaning baths. Alcohols and Freon are commonly used for metal preparation and precision cleaning of electronics equipment. Solvents are also used in painting operations. As previously noted, methylene chloride is commonly used to strip paint and carbon from metal surfaces. Toluene is commonly used to thin solvent-based paints. Volatile solvents, such as methyl ethyl ketone and xylene, are used to clean painting equipment.

Disposal costs for waste solvents can exceed $100 per drum. This cost is expected to increase substantially in the future because RCRA regulations are scheduled to ban the land disposal of liquid hazardous wastes. When waste solvents are disposed of, fresh solvents must be purchased at a cost that usually exceeds the cost of waste disposal. Therefore, recycling of waste solvents can result in a savings of hundreds of dollars per drum.

There is great potential to reduce the quantities of solvents and related by-products generated at DOD industrial facilities. Solvents and other organic fluids are most frequently reclaimed by batch non-fractionating distillation. Batch distillation systems typically consist of a still pot, a heat source, and a condenser. The waste organic mixture is loaded into the still pot, heat is applied to the contents, causing the mixture to boil, and organic vapors separate from the waste mixture and pass overhead to the condenser. Cleaned organic fluid is then collected for reuse, and still bottoms are disposed of as hazardous waste.

An atmospheric still can reclaim organic solvents that have boiling points less than 325°F. By adding vacuum, a distillation unit can be used to recover organic fluids which have atmospheric boiling points up to 500°F, while a 300°F limit is maintained in the still's pot.

Waste solvents can either be collected and transported to a centralized distillation facility for recovery or recycled at the point of use. DOD facilities have been successful with both approaches. Regardless of where the distillation occurs, it is critical that waste solvents be properly segregated and stored so that mixing of various solvents and impurities does not occur.

The main advantage of operating a large centralized facility is that capital costs can be recovered quickly due to economies of scale. A centralized facility can redistill large quantities of various types of solvents. Since many different types of solvents are recycled, great care must be taken with waste segregation and sample analysis. Centralized reclamation also requires that solvents be transported to and from the point of use.

Local facilities are sometimes preferable because the waste generator has total control over the recycling operation. Since only a few types of solvents are being redistilled at the small facilities, laboratory analysis of waste solvents is often not required. Labor-intensive transportation and segregation activities are also eliminated.

Successful centralized facilities depend on a fully dedicated individual to initiate and supervise operation of the system and an enthusiastic staff dedicated solely to solvent collection, analysis, recycling, and distribution. Decentralized facilities require the reassignment of more personnel (foreman and operators) to adopt solvent recovery as part as their routine.

Warner Robins AFB, located in Macon, Georgia, has operated a centralized batch, atmospheric still since August of 1982. The solvent recovery system consists of a single-stage batch still, a water separator, and an electrically powered steam generator. The still, which can operate up to a temperature of 300°F in the pot and can reclaim solvents at a rate of 55 gallons per hour, is used to reclaim trichloroethane, Freon-113, and isopropanol at recovery rates of 70 to 99 percent. Through 1984, savings due to the reduced need for virgin material and reduced hazardous waste disposal costs have been estimated at more than $230,000. Reclaiming the used chemicals costs only $13 per drum, whereas disposal of the chemicals and repurchase of new materials would have cost from $250 to $500 per drum.

Robins AFB has been able to successfully recycle solvents in a large-scale operation because of careful waste segregation, storage, and transportation. Site managers are responsible for segregation and labeling of waste drums at 30 different collections areas. Before solvents are reclaimed, samples are analyzed to confirm the labeling. Samples are also analyzed after distillation to ensure that they meet appropriate specifications.

Solvent recycling has been successful at Robins AFB because of a strong commitment from management to reduce the quantities of waste solvents that must be disposed of. Of equal importance, production personnel have cooperated with the recycling team so that waste solvents can be segregated, labeled, analyzed, transported, and redistilled in an orderly and systematic fashion. In addition, proven distillation equipment was available and was relatively easy to operate and maintain. One major factor in the success of the Robins solvent recovery program has been the commitment of Mr. O. H. Carstarphen, the Solvent Reclamation Engineer. Through his perseverance, colleagues and management were convinced to supply equipment and manpower to set up and run the program.

In contrast to Robins, with its centralized facility, Norfolk Naval Ship Yard (NSY) in Norfolk, Virginia, has installed a $10,000 nonfractionating batch still to recover waste solvents generated in the paint shop during cleaning operations. This small still, which has a capacity of 2 gal/hr, is used to recover methyl isobutyl ketone, methyl ethyl ketone, epoxy thinners, and mineral spirits. Operators have the option to operate the still with or without a vacuum system depending upon the distillation temperature required. After a 15-minute startup period, the still runs without operator attention. Over 50 percent of waste solvent is recovered at a cost of about $0.16 per gallon.

The solvent recovery operation was successful because of the personal dedication of Mr. Jake Coulter, the Paint Shop Foreman, and the straightforward, uncomplicated operation of a technically innovative system.

Anniston Army Depot, located in Anniston, Alabama, uses small distillation units that are individually attached to 15 vapor degreasers for the reclamation of trichloroethylene (TCE). The stills operate continuously when the vapor degreasers are in operation, normally 40 hr/week. Dirty solvent is fed from a degreaser boiling sump through a water separator to the recovery still. The steam-heated stills have the capacity to recycle 20 gal/hr of TCE. The still bottoms, which contain TCE, oils, greases, and dirt, are automatically discharged to holding drums and then disposed of as a hazardous waste. Because of the recycling operation, vapor degreaser baths never have to be dumped and disposed of. Losses of TCE result only from drag-out, evaporation, and waste still bottoms. Twice a year during shutdown, the vapor degreasers and stills are taken out of service for cleaning and general maintenance.

Production personnel have been receptive to the stills because TCE baths are kept clean and consequently product quality is improved. The distillation units are also simple to operate and maintain.

METAL PLATING

"Plating" is defined as the deposition of a thin layer of metal on the surface of a basis metal for the purpose of changing the properties of the basis metal. These modifications may be to improve the basis metal's appearance (decorative plating), to increase resistance to corrosion, or to improve engineering properties (hardness, wearability, solderability, or frictional characteristics). The principal metals plated at military facilities are chromium and cadmium.

Chromium is used principally in the remanufacturing of worn parts for which replacement with new parts would be infeasible because of their unique design. Remanufacturing consists of stripping a portion of the old plate, overplating with a thick layer of chromium (hard chrome plating), and machining back to original specifications. Parts are typically plated for longer than 24 hours to achieve the required chromium thickness.

Sacrificial cadmium coatings are usually applied to protect the basis metal, typically iron or steel. A thin surface coating is normally applied for decorative purposes or to provide corrosion protection, improve resistance to wear or erosion, or reduce friction. These coatings are significantly thinner than hard chrome plating and are applied in minutes rather than hours or days, as required for hard chrome plating.

The major discharges of hazardous waste from typical metal plating facilities consist of rinsewaters contaminated by drag-out from various cleaning and plating baths, cleanup of spills, disposal of acid and alkaline cleaners, and occasional plating bath dumps.

The most common process modifications that have been implemented at DOD plating shops to reduce generation of hazardous wastes involve reduction of drag-out from processing baths, reduction of rinsewater flows, improved rinsing efficiencies, recovery of metals from rinsewaters, and material substitutions.

Rinsewater modifications reduce flows that must be processed in wastewater treatment plants; however, the amount of toxic metals generally remains the same. If rinse flow rates are reduced sufficiently, it is possible to use rinsewater to make up for evaporative losses in the plating tanks, resulting in metal recovery and reduced waste discharge.

Various DOD facilities have installed flow restriction valves, timers, and conductivity controls on the rinsewater supply line to reduce wastewater quantities. Timers or conductivity controls regulate the frequency at which rinsewater is supplied to the rinse tank; the control valve opens when the conductivity of the rinsewater exceeds a selected value. Conductivity controls have not performed well in most military installations, as a result of the probes' lack of ruggedness and the need for frequent calibration and cleaning. Recovery processes, such as reverse osmosis, electrodialysis, and ion exchange, have been suggested to remove impurities from plating baths and concentrate rinsewaters so that they can be used for bath makeup.

The Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California, has implemented many of the abovementioned process modifications at Pensacola NARF to reduce wastes generated by the hard chromium plating shop. NCEL has retrofitted an existing countercurrent rinse tank with a recirculating spray rinse system, which reduces rinsewater requirements sufficiently that the rinsewater can be used for plating bath makeup. A pump recirculates rinsewater through eight high-velocity spray nozzles located around the perimeter of the rinse tank. The pump is activated by a foot pedal as parts are lowered into the empty tank, and clean rinsewater is available via a hand-held sprayer. After repeated use, a portion of the rinsewater is pumped through a cloth filter into the plating tank and added to the plating bath to replace water lost through evaporation. Plating baths are operated at elevated temperatures to increase the rate of evaporation and speed of plating. These modifications have reduced freshwater use from 350,000 gallons per month for countercurrent rinsing to about 1,200 gallons per month of makeup water for spray rinsing. Since this amount was less than the evaporation rate, all of the spray rinse was returned to the plating bath, resulting in a "zero discharge" condition. A total savings of approximately $25,000 per year per bath was projected, principally due to reduced industrial wastewater treatment costs.

Without drag-out to aid in removal of contaminants from the bath, a cleanup process was required to reduce the need for plating bath dumps. An electrolytic bath purification system was installed to continuously remove cations from the chromium plating solution. The system uses cathodes contained within membrane module anodes to oxidize trivalent chromium to hexavalent chromium and to selectively precipitate cation impurities from the plating solution. Hexavalent ions remain on the anode side of the membrane, and are returned to the plating bath. The purification system did not effectively remove contamination from the chromium plating bath during a trial run. The system was plagued by failure of the membrane module anodes, caused by a supplier's change of material. Although replacement of the membrane modules is expected to rectify the problem, further testing is required before this technology can be recommended for use at other DOD facilities.

NCEL implemented these process modifications at Pensacola as a test prototype system. Although NCEL has proved that the spray rinse system is effective in removing drag-out, plating personnel remain skeptical about the effectiveness of the spray rinse system. Despite resistance from platers, there are plans to construct a permanent spray rinse and bath purification system, given the prospects of reduced wastewater flows and treatment costs. At other military installations where the spray system was installed, the rinsewater modifications have been received more favorably because an extensive training program was provided prior to startup. Engineering and management have been very supportive of the process modifications. That these plating modifications have succeeded is due in large part to the dedication of Mr. Charles Carpenter, of NCEL, who originated the new system, diligently supervised its implementation, and remained available for ongoing consultation.

Other DOD facilities have reduced hazardous waste quantities by implementing material substitutions. Traditionally, cadmium has almost universally been plated from alkaline cyanide baths, because of the improved plate resulting from the stable cadmium cyanide complexes. Unfortunately, cadmium cyanide baths are costly and dangerous to operate and expensive to treat. Alternative baths containing fluoborate, sulfate, and chloride anions have been developed to replace cyanide baths.

The plating shop of Air Force Plant No. 6, located in Marietta, Georgia, and operated by Lockheed-Georgia Corporation, switched from an alkaline cyanide cadmium bath to a proprietary acidic non-cyanide-containing cadmium bath. Lockheed found that product quality improved by switching from the alkaline cyanide baths to the acidic non-cyanide cadmium baths; however, more careful process control is required. Although the new plating solution, costing approximately $3 per gallon, is more expensive than the old cyanide-containing formulation, reduced waste treatment cost has resulted in a net savings for this modification. As a result of this modification, alkaline chlorination for the treatment of cyanide is no longer needed. The material substitution was implemented primarily to reduce the safety hazards associated with the operation and disposal of cyanide baths. An improvement in quality and a reduction in total costs assured the permanent adoption of this process modification.

The NARF at North Island, located in San Diego, California, has partially switched from plating steel parts with cadmium wet baths (for corrosion resistance) to coating parts with aluminum using Ion Vapor Deposition (IVD). This material substitution eliminates the environmental problems associated with cadmium and cyanide. For the past 7 years, metal parts such as landing gears, bolts, and tail hooks have been plated with the dry IVD process. Advantages of the process include safer working conditions, a higher useful temperature, improved throwing power (ability to coat complex parts uniformly), and better adhesion of the aluminum coating, compared to cadmium. However, the process is considerably more complex and requires more labor and skill than does cadmium plating. For this reason, the process has been used for few parts, and all parts are evaluated on an individual basis to determine the preferable plating technique. The process change has not significantly reduced the amount of cadmium plating performed at the facility.

PAINTING

Painting is common to virtually all DOD industrial facilities. Paint coatings are applied to surfaces of military parts, vehicles, and structures for corrosion protection, camouflage, or aesthetic appeal. In conventional spray painting, paint is thinned with solvent and applied to surfaces in a wet form. Typically, low transfer efficiencies are realized--less than 50 percent of the paint solids used end up on the parts. Paint overspray is scrubbed from paint booth exhaust air by a water spray, and solvents are used to clean painting equipment. Spray booth sludges and waste solvents are collected for disposal as hazardous waste.

Most DOD spray painting is performed on Air Force and Navy aircraft. Naval aircraft are repainted yearly, while Air Force aircraft are repainted every 5 years. With thousands of military aircraft in service, a significant volume of paint and paint solvents is consumed every year, and a large portion of it becomes hazardous waste.

Aircraft are typically coated with two layers of solvent-based paint. The primer is usually an epoxy polyamide compound, and the topcoat is usually an aliphatic polyurethane compound. The main function of the primer is to promote adhesion of the polyurethane topcoat and to protect the aluminum substrate from corrosion. The topcoat serves as an additional corrosion protection layer.

Alternatives to conventional solvent-based spray painting have been developed, involving improved painting techniques and new processes which either eliminate solvent thinners in paint or reduce their quantity. Some of the most promising developments are: waterborne coatings, dry powder coatings, wet electrostatic painting, high solids coatings, improved painting techniques, and robotics.

To meet strict volatile organic compound (VOC) air emission standards, many military (and military contractor) facilities in California have recently switched to a water-reducible, amine-cured epoxy primer which contains low concentrations of VOC compliance solvents. At application, the waterborne coating typically has a VOC concentration less than one-fourth that of conventional solvent-based primers. Another advantage of water-based paints is that cleaning can usually be performed using hot water and/or alcohol. Since solvents are not required for cleanup operations, solvent use and solvent waste production are substantially reduced or eliminated.

Recently, Pensacola and Jacksonville NARFs partially switched from conventional solvent-based primers to waterborne primers. Unlike military facilities in California which have strict VOC emission regulations, the Florida NARFs implemented the material substitution in order to improve product quality. In the past, approximately 20 percent of parts painted with solvent-based primers were rejected and had to be repainted. This rejection rate has been reduced to 2 percent with the new water-reducible primer.

The waterborne primers involve several disadvantages. For example, they are slower to dry than solvent-based paints, and there is some evidence that they provide less overall corrosion protection. In addition, water-based primers do not adhere well to oily surfaces. Nevertheless, personnel at Pensacola and Jacksonville NARFs have found that in most of their applications, water-based primers are superior overall due to ease of application, decrease in overspray, lower rejection rate, and ease of cleanup.

Dry powder coating (or painting) is based upon the deposition of special heat-fusible plastic powders onto metallic substrates. Powder coatings are applied by powder spray guns, fluidized bed methods, electrostatic deposition, or plasma spray techniques. The advantages to all powder coating techniques are that solvent usage is eliminated, the paint spray is often minimized, and the paint can be recycled. Moreover, there is virtually no hazardous waste problem.

Air Force Plant No. 44, located in Tucson, Arizona, and operated by Hughes Aircraft, uses electrostatic dry powder painting to coat the interior of the fuselage section of the Phoenix missile. Electrostatic deposition of dry solids works by attraction between charged, dry paint particles and an electrically grounded (negative) surface to be coated. By spraying the charged coating onto an oppositely charged substrate, coatings as thin as one mil (0.001 inch) can be applied. Hughes Aircraft has found that this technique is superior to the previous wet spray application because of better coverage on hard-to-reach surfaces. In addition, fewer coatings are required, less equipment maintenance is needed, and hazardous waste generation is reduced. Consequently, significant cost reductions have been achieved. It was estimated that powder coatings could be applied for approximately one-third the cost of conventional wet paint spraying, due in large part to the reduced number of coatings required. The technique, however, requires highly skilled operators, so extensive training is necessary.

The process modification was successful because it improved both the production rate and quality, decreased manpower requirements, and consequently decreased costs. Like previously discussed case studies, an improvement in production was the primary motivation behind implementing the process modification. The subsequent reduction in hazardous waste generation became a secondary benefit.

Lockheed-Georgia has investigated various painting modifications at Air Force Plant No. 6 to reduce the quantities of paint thinner solvent (e.g., toluene) and paint used at the facility, and also to reduce the generation of solvent wastewaters and paint sludge. Solvent usage, and hence solvent waste, was reduced by increasing the amount of zinc-chromate solids in the primer during a test period. Lockheed found that it was more difficult to evenly apply the primer and control paint thickness due to rapid buildup of paint solids, especially on intricate or irregularly shaped parts. This modification was therefore abandoned in favor of the existing solvent-based, low solids (20-22 percent) primer.

Lockheed improved its painting techniques by installing a modern conveyor system in the paint line. Small aircraft parts can be plated, painted twice, and oven-cured, if necessary, without being touched by human hands. Using the conveyor system, product quality was improved and production rates were increased. Furthermore, paint overspray was reduced because operators and inspectors were trained to know the proper paint thickness that should be sprayed on parts.

Robotics was also investigated by Lockheed in an attempt to improve product quality and efficiency and to reduce paint overspray. The robot could paint an 8-foot by 6-foot rectangular area and could be used for both normal spray painting and electrostatic painting. Usage was discontinued, however, because of difficulty in spraying the irregularly shaped aircraft parts.

The use of robotics is better suited for private sector industries which use mass production for products such as vehicles and parts. Most military manufacturing and rework facilities, on the other hand, paint and strip an extremely diverse number of parts and materials. These facilities are often not amenable to robotics, since there is a wide range of variables (part sizes, shapes, materials, quantities, etc.) that can change during the course of a day.

CONCLUSIONS

In general, a number of common features distinguished successful process modifications from those that were not:

(1) Production personnel were enthusiastically and actively involved in implementing successful process modifications. In most cases, this required that some incentive be offered by the modification, such as reduced manpower requirements or simplification of plant operations. The change did not harm quality, and was most often an improvement over existing processes.

(2) A "champion," who strongly believed in the modification, ramrodded the project and overcame developmental problems and the inertia that protects existing processes (especially those that function, although they may produce undesirable wastes). Care was taken to tailor the modification to the individual facility. During

design and installation, many operations personnel were included to obtain their input and to inspire them to adopt the process change.

(3) Support was provided at a sufficiently high level in the chain of command to affect production and environmental policy decisions. Frequently, waste disposal and environmental protection had been viewed as service functions, subservient to the mission of the facility, which was usually production-oriented. Successful modifications usually required the reallocation of resources from production functions to environmental protection. Allocation of manpower slots for environmental protection was particularly difficult to obtain.

(4) Successful modifications were usually straightforward and simple to operate, thus requiring minimal training for personnel unfamiliar with the technology involved.

(5) Because process reliability was high, production was not adversely affected.

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