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ENVIRONMENTAL RESEARCH BRIEF

Waste Minimization Assessment for a Manufacturer of Permanent-Magnet DC Electric Motors

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Abstract

The U.S. Environmental Protection Agency (EPA) has funded a pilot project to assist small- and medium-size manufacturers who want to minimize their generation of waste but who lack the expertise to do so. Waste Minimization Assessment Centers (WMACs) were established at selected universities and procedures were adapted from the EPA *Waste Minimization Opportunity Assessment Manual* (EPA/625/7-88/003, July 1988). The WMAC team at the University of Tennessee performed an assessment at a plant manufacturing permanent-magnet DC electric motors—approximately 12 million motors and repair parts per yr. The armatures and stators are manufactured separately and then assembled into complete motor units. After assembly, the motors are appropriately masked and painted according to customer specifications. The team's report, detailing findings and recommendations, indicated that the majority of waste was generated in the armature assembly line but that the greatest savings could be obtained by installing an electrostatic powder coating system to reduce the generation of waste paint solids (93%) and to eliminate the generation of waste paint liquids.

This Research Brief was developed by the principal investigators and EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of an ongoing research project that is fully documented in a separate report of the same title, which is available from the authors.

Introduction

The amount of waste generated by industrial plants has become an increasingly costly problem for manufacturers and an additional stress on the environment. One solution to the problem of waste is to reduce or eliminate the waste at its source.

University City Science Center (Philadelphia, PA) has begun a pilot project to assist small- and medium-size manufacturers who want to minimize their formation of waste but who lack the in-house expertise to do so. Under agreement with EPA's Risk Reduction Engineering Laboratory, the Science Center has established three WMACs. This assessment was done by engineering faculty and students at the University of Tennessee's (Knoxville) WMAC. The assessment teams have considerable direct experience with process operations in manufacturing plants and also have the knowledge and skills needed to minimize waste generation.

The waste minimization assessments are done for small- and medium-size manufacturers at no out-of-pocket cost to the client. To qualify for the assessment, each client must fall within Standard Industrial Classification Code 20-39, have gross annual sales not exceeding $50 million, employ no more than 500 persons, and lack in-house expertise in waste minimization.

The potential benefits of the pilot project include minimization of the amount of waste generated by manufacturers, reduced waste treatment and disposal costs for participating plants, valuable experience for graduate and undergraduate students who participate in the program, and a cleaner environment without more regulations and higher costs for manufacturers.

Methodology of Assessments

The waste minimization assessments require several site visits to each client served. In general, the WMACs follow the procedures outlined in the EPA *Waste Minimization Opportunity Assessment Manual* (EPA/625/7-88/003, July 1988). The WMAC

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staff locates the sources of waste in the plant and identifies the current disposal or treatment methods and their associated costs. They then identify and analyze a variety of ways to reduce or eliminate the waste. Specific measures to achieve that goal are recommended and the essential supporting technological and economic information is developed. Finally, a confidential report detailing the WMAC's findings and recommendations (including cost savings, implementation costs, and payback times) is prepared for each client.

Plant Background

The plant produces permanent-magnet DC electric motors for general use. The plant operates 6,860 hr/yr to produce approximately 13 million motors and parts.

Manufacturing Process

Raw materials for the manufacture of the motors and parts include iron and aluminum castings, steel tubing and shafting, copper wire, copper commutators, steel laminations, purchased fans, poles, epoxy coating, varnish, adhesive, and cleaning chemicals. The two separate parts of the product (the armature and the stator) are manufactured separately and then assembled into complete motor units. An abbreviated process flow diagram is illustrated in Figure 1.

The following steps are involved in making the motors:

Armature Assembly

Assembly of the armatures begins with the cutting and machining of steel shafts. A semi-synthetic metal working fluid or coolant is used in the machining area to cool the grinders and lathes; spent coolant is disposed of offsite as hazardous waste. Metal scrap is hauled offsite by a metal reclaimer.

Approximately 2% of the shafts are then taken to the painting area to be coated with a "black oxide" paint while the remaining 98% receive no coating. The painting process is described in detail. Next, all shafts are transported to a subassembly area where steel laminations are stacked (the height will vary according to motor design) and pressed onto a shaft. Assembled armatures are then preheated in a laminating oven. After preheating, each part is manually dipped into a 200-gal epoxy powder dip tank and allowed to cool. An exhaust hood collects released epoxy dust that is ducted to a collection bag filter for periodic disposal offsite as hazardous waste. This powder becomes waste after collecting moisture from the atmosphere.

Next, the epoxied shafts with lamination are put onto a coil-winding machine on which copper wire is manually wound onto the epoxy-coated unit and fitted between the "fins" of the lamination. Wood or paper insulators are manually tapped between each "fin" and then copper commutators are applied to the end of each shaft and wire terminators are connected to the copper commutators. The armatures are then manually loaded into an oven in which varnish is applied over wires at both ends of the lamination and drying occurs. Surface varnish and epoxy along with some lamination metal is then ground off to meet specifications. Small amounts of this waste varnish/epoxy powder are disposed of in the municipal trash. In addition, varnish that becomes too thick for proper application is shipped offsite as a hazardous waste.

Finally, pre-purchased fan components are preheated in an electric oven and manually dropped down onto shafts. The part is allowed to air cool to produce a tight fit. From the subassembly area, finished armatures are transported to the finished goods stock room to await final assembly.

Stator Assembly

Stator assembly begins with machining of steel tubing. After machining, parts are transferred to the cleaning area where they are manually conveyed and dipped in a series of five tanks to prepare the surface for adhesive fastening of magnetic poles. The first tank is a caustic-solution bath. Secondly, the parts are dipped in a rinse tank after which they are immersed in a phosphating tank. Another rinse tank follows the phosphating tank and finally the parts are dipped in a sealing tank that contains sodium nitrate. Solutions from tanks #1 and #3 are dumped every 6 wk. Sludge from those tanks is shoveled out of the tank bottoms and shipped offsite as hazardous waste; wastewater from the tanks flows to the septic tank where the acidic water from tank #3 neutralizes the caustic water from tank #1. The water streams from rinse tanks #2 and #4 are combined for neutralization and pumped to the sewer. From the septic tank, the wastewater is pumped to the sewer.

The machined and cleaned tubing lengths are then transported to the adjacent pole area where they are manually wiped clean with an acetone-wetted cloth. On an annual basis, 75% of these cloths are shipped offsite, washed, and brought back to the plant for reuse. The remaining 25% of the rags are too torn or thin for reuse and are shipped offsite for incineration. Next, the pole pieces with adhesive applied are manually applied to the inside surface of each unit and held in place with clamps. The adhesive is cured by baking the stator units in one of four curing ovens. Next, the stator units are taken to another subassembly area where the poles are magnetized and then the units are transferred to final assembly.

In final assembly, armatures are placed inside the stators and iron castings with bearings are positioned on the end of the stators to form the complete motors. Units may then be transported to the painting area, if required.

Painting

About 2% of this plant's products are painted black for cosmetic purposes. Parts to be painted are manually removed from final assembly and placed on a conveyor system. These parts are conveyed through a water curtain spray paint booth and are manually spray-painted with solvent-based flat black paint. Paint overspray is captured in the water curtain and is precipitated out with the use of a chelating agent. Waste paint sludge from this operation is periodically removed from the booth and shipped offsite as hazardous waste. In addition, some paint is skimmed off the top of the water and added to the paint sludge. Water from the water curtain sump that has become too contaminated with paint is shipped offsite as waste paint liquids.

Approximately 3% of the painted products are conveyed through an "air-dry" spray paint booth to which gloss black paint is added. Used air filters are removed from this booth and added to the paint solids waste barrels.

Each paint booth has one spray gun in use. The guns are cleaned periodically with solvent; spent solvent is shipped offsite as a hazardous waste.

Finally the product pieces are air-dried, packaged, and shipped.

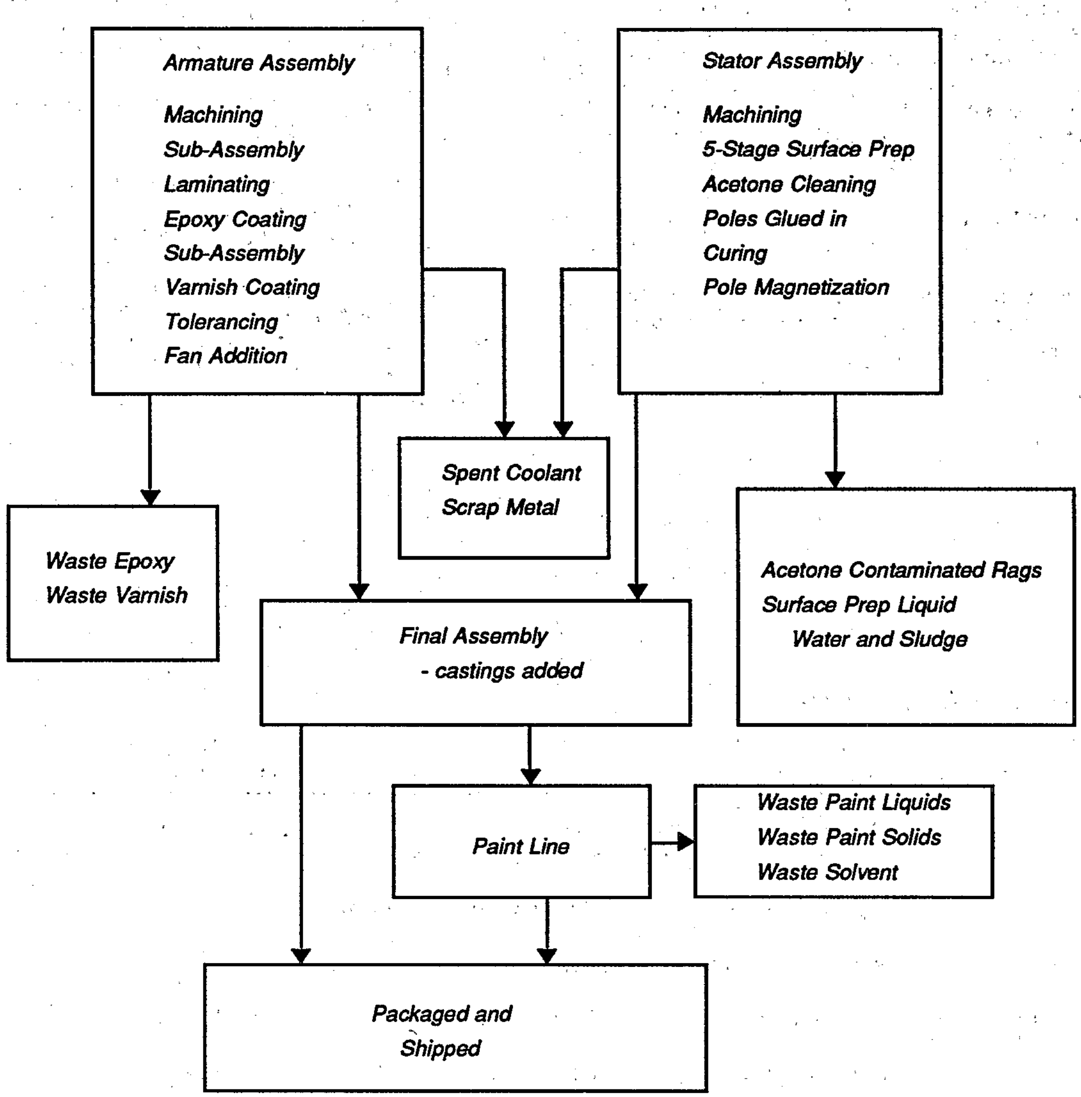

***Figure 1.** Abbreviated Process Flow Diagram.*

Existing Waste Management Practices

- A coolant recovery system recovers almost all of the coolant for reuse in the machining tools.

Waste Minimization Opportunities

The waste currently generated by the plant, the source of the waste, the quantity of the waste, and the annual treatment and disposal costs are given in Table 1.

Table 2 shows the opportunities for waste minimization that the WMAC recommended for the plant. The minimization opportunity, the waste in question, the possible waste reduction and associated savings, and the implementation cost along with the payback time are also shown in Table 2. The quantities of waste currently generated by the plant and possible waste reduction depend upon the production level of the plant. All values should be considered in that context.

It should be noted that the economic savings of the WMOs usually address only the raw material cost avoidance and reduction of present and future costs associated with waste treatment and disposal. Other savings not quantifiable by this study include a wide variety of possible future costs related to changing emissions standards, liability, and employee health. It should also be noted that the savings given for each WMO reflect the savings achievable when implementing each WMO independently and do not reflect duplication of savings that will result when WMOs are implemented in a package.

Additional Recommendations

In addition to the opportunities recommended and analyzed by the WMAC team, five additional measures were considered. These measures were not completely analyzed because of insufficient data or minimal savings as indicated below. They were brought to the plant's attention for future reference, however, since these approaches to waste reduction may increase in attractiveness with changing plant conditions.

- Install drag-out boards on the tanks in the five-step cleaning operation to drain tank solutions back into the tanks.
- Collect the solvent used for cleaning the paint spray guns for reuse. Currently, the solvent becomes part of the liquid paint wastes.
- Use a detergent or a water-based solvent rather than the currently used solvent to clean dirty metallic raw material to reduce the costs associated with handling and removing the waste currently associated with this cleaning process.
- Convert the current varnish spray system to a more efficient robotic dip system.
- Install an automatic metering system to reduce the amount of excess adhesive used in attaching the poles to the inside surface of the stators.

This research brief summarizes a part of the work done under Cooperative Agreement No. CR-814903 by the University City Science Center under the sponsorship of the U.S. Environmental Protection Agency. The EPA Project Officer is Emma Lou George.

Table 1. Summary of Current Waste Generation

Waste Generated	*Source of Waste*	*Annual Quantity Generated*	*Annual Waste Management Cost, $*
Metal scrap	*Cutting and machining of steel shafts Metal scrap is hauled offsite by a metal reclaimer*	*1-1/2 truck loads*	*658*
Waste coolant	*Cooling of the grinders and lathes in the machining area*	*17,600 lb*	*5,504*
Thickened varnish	*Application of varnish to armature assemblies*	*920 lb*	*524*
Waste epoxy powder	*Application of epoxy powder to armature assemblies*	*5,175 lb*	*3,948*
Zinc phosphate/caustic sludge	*Five-stage washer in stator assembly line*	*3,520 lb*	*1,813*
Waste sealant	*Five-stage washer in stator assembly line*	*	*
Waste adhesive	*Adhesive application to the poles in the stator assembly line*	*30 lb*	*20*
Spent solvent	*Cleaning of paint spray guns*	*2,640 lb*	*719*
Paint solids (including plastic sheets, filters, and precipitated paint from the paint booth water curtain)	*Spray paint booth*	*7,920 lb*	*6,151*
Waste paint liquids (water from the paint booth water curtain that is too contaminated to be reused)	*Water curtain in the spray paint booth*	*8,840 lb*	*3,463*

**Quantity and cost unknown.*

Table 2. Summary of Recommended Waste Minimization Opportunities

Waste Generated	Minimization Opportunity	Annual Waste Reduction Quantity	Annual Waste Reduction Percent	Net Annual Savings	Implementation Cost	Payback Years
Paint solids Paint liquids	Install an electrostatic powder coating system to replace the water curtain spray paint booth. Retain the gloss paint booth; because of its limited use, a change is not recommended.	7,392 lb 8,840 lb	93 100	$10,230[1,2]	$78,440	7.7
Paint solids Paint liquids	Replace the compressed air paint spray guns with air-assisted airless paint spray guns. Paint overspray will be reduced as a result of increased paint adhesion to the product.	3,960 lb 4,420 lb	50 50	5,850[1]	15,440	2.6
Paint solids Paint liquids	Use the currently inactive electrostatic spray paint booth to replace the water curtain spray paint booth. Reduced raw material costs and waste generation will result from using the system. Retrain plant personnel in proper operating techniques.	3,696 lb 4,420 lb	47 50	9,970[1]	7,000	0.7
Waste epoxy powder	Recycle spent epoxy powder. Install an air-tight collection system to permit recycling.	4,658 lb	90	14,470[1]	6,480	0.5
Zinc phosphate/ caustic sludge Waste sealant Waste adhesive	Discontinue the use of the pole adhesive and utilize a mechanical means of attaching the poles to the inside surfaces of the stators. Implementation of this WMO would eliminate the need for the five-stage washer in the stator assembly line.	3,520 lb * 30 lb	100 100 100	31,760[1,2]	110,880	3.5

[1]Includes raw material cost savings.
[2]Total cost savings have been reduced by the cost of new material required.

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