Pollution Prevention in Mass-Finishing Operations

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A result of any mass-finishing operation is the generation of waste in the form of wastewater and sludge. Traditionally, waste streams from mass-finishing operations have been chemically treated to meet sewer discharge requirements. In most instances, and prior to chemical treatment, mass-finishing wastewater is mixed with other metal-bearing waste streams originating from very different manufacturing operations.

A new, preferred approach toward minimizing the generation of waste from mass-finishing operations is called *pollution prevention.* Pollution prevention or source reduction means that waste should be reduced or eliminated at the source as opposed to end-of-pipe treatment. For the mass-finishing operation, pollution-prevention measures include process modification and in-process recycling. Input materials such as the metal type, finishing media, and soap should be studied for possible modification to prevent potential waste. The type of mass-finishing equipment employed in the process can also influence the amount of waste generated. In some cases, hazardous or toxic cleaning chemicals can be replaced by the aqueous-based tubbing or vibratory operation. Once all possible process modifications are made and waste streams segregated, the finishing solution can be recycled to further minimize waste leaving the operation. In some applications, the same soap solution can be reused for up to one year.

Soap purchases, water/sewer fees, and environmental liabilities may all be reduced. In most cases, a reasonable payback is achieved on equipment purchases. Many companies have already successfully implemented pollution prevention into their mass-finishing operations with excellent results.

BACKGROUND

Mass finishing is a mechanical process used to deburr, polish, and/or clean a variety of manufactured parts and can be found in industries such as jewelry and machine tool manufacturing. Vibratory and tumbling machines are two very common types of mass-finishing equipment. The waste effluent, whether from a batch or continuous process, consists of soapy water, pulverized media, and both soluble and insoluble metals of the type found in the metal parts being processed.

Figure 1 describes the flow scheme of a typical mass-finishing operation. Depending on the finishing operation, the waste solution generated can vary. Analytical tests were carried out on used solutions at different companies. Although the results vary, some general consistencies are observed. Most of the solids found in the waste stream consist of plastic or ceramic media. Because the hardness of the metal parts is much higher than that of most plastics and ceramics, the plastic and ceramic media tend to erode faster than the metal; however, significant metal levels of the metal type used in the finishing operation are still observed. For example, one company manufactures zinc alloy fasteners; the vibratory operation used to clean and polish these fasteners produces a waste stream that contains 320 mg/L of zinc and 1,770 mg/L of total suspended solids (TSS). In all of these cases, the solution cannot be discharged to the sewer without treatment because of high levels of metals, suspended solids, and sometimes oil and grease. Traditional treatment has included end-of-pipe chemical addition to remove metals and solids prior to discharge.

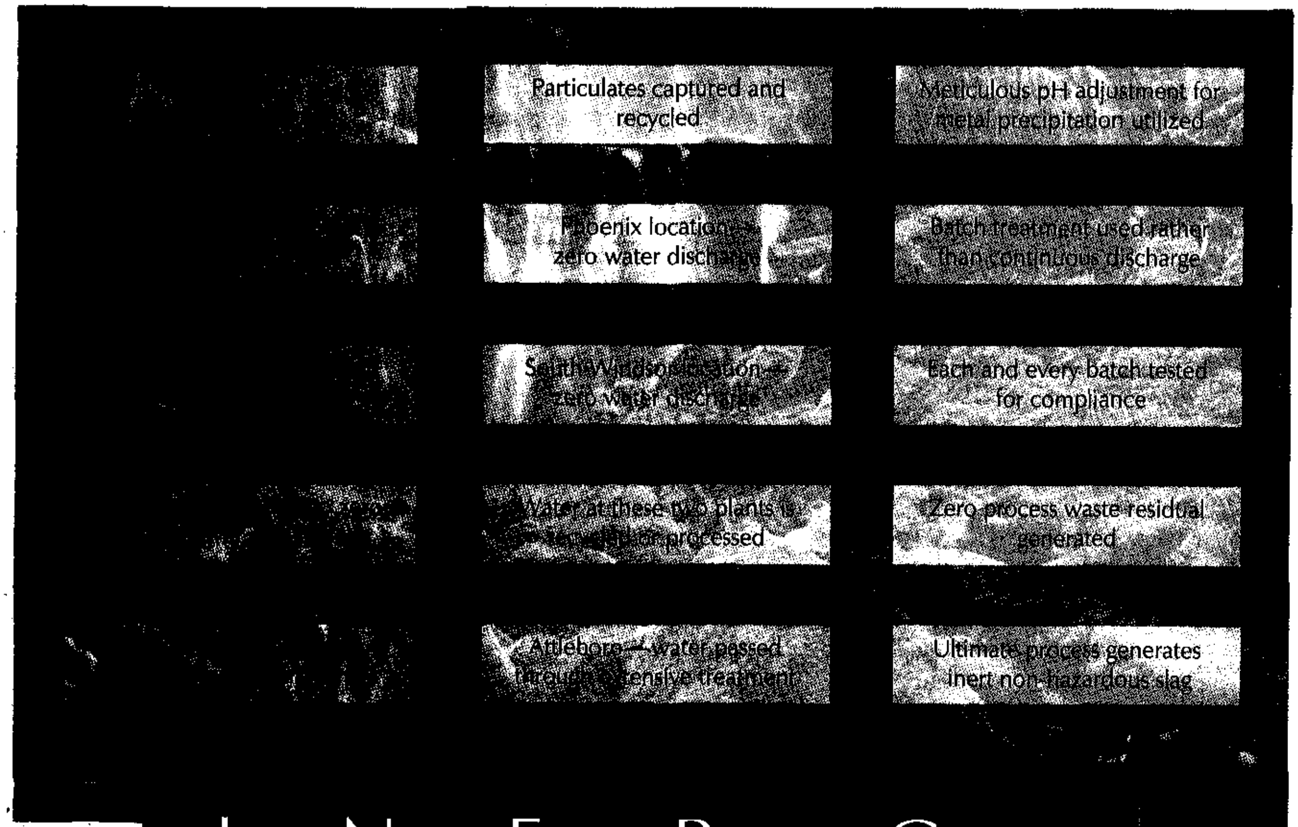
TRADITIONAL TREATMENT TECHNOLOGIES

Chemical-treatment technologies have been used by many companies to produce water clean enough for sewer discharge. In most cases, different chemicals are used for pH adjustment and metal flocculation. The end result is metal-free water and precipitated metal sludge that is usually dewatered with a filter press prior to off-site disposal as waste and sometimes even hazardous waste. In companies that rely on other waste-generating processes such as electroplating, the tubbing/vibratory waste is sometimes mixed with these other streams prior to end-of-pipe treatment. Depending on the capacity of the finishing operation and any other wastewater-producing process in the plant, the costs of these chemical-treatment systems vary.

Capital and operating costs can vary widely for different waste streams and flow capacities. The major capital costs include tanks, controls, pumps, and mixers. The major operating costs include chemical costs, labor, and sludge disposal. If the sludge is hazardous, the operating costs increase significantly due to higher disposal and labor costs. Liabilities are also much greater. Sound pollution prevention or source reduction measures can result in substantial reductions in costs and liabilities.

POLLUTION PREVENTION

Pollution Prevention is now the preferred method for environmental protection. In contrast to the end-of-pipe waste treatment approach, pollution prevention is defined by the U.S. Environmental Protection Agency as "the use of materials, processes or practices that reduce or eliminate the creation of pollutants at their source." *Source reduction,* the defining theme of pollution prevention, can be carried out in many ways. Where source reduction is successfully used, the need for treatment and disposal is often dramatically reduced. Most of the technical-based solutions are process engineering modifications that require varying amounts of development research and testing. As described in more detail later in this article, many effective technical solutions have been developed by different organizations; this information can be readily shared with other companies. Examples of



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process modifications include replacing waste-generating input materials with other materials that do not produce as much waste. *In-process recycling* of spent materials is also considered a viable source reduction measure since the amount of waste leaving the process is reduced. Off-site recycling, such as the reclamation of waste materials at a commercial treatment facility, is considered to be a secondary option to source reduction. End-of-pipe treatment and disposal are considered the last resort, to be used only when source reduction and recycling are impractical (see Table I).

Management commitment is critical to the success of any pollution-prevention program. Unless managers are willing to ensure that process modifications are implemented, changes will not take place and waste will not be reduced. Better housekeeping on the manufacturing floor will inevitably lead to less waste. Careful monitoring of process input materials (e.g., eliminating excess chemical usage) will also prevent some waste generation. The success of any pollution-prevention program, then, is the result of a cooperative working approach that involves management and worker commitment and a well thought out plan. Even where effective processes have been developed to reduce pollution, success can be limited when proper implementation and supervision are lacking.

Process inputs and waste solutions vary from operation to operation. Changing one variable may result in significant pollution reductions; changing more than one variable may prove to be even more effective. The recommendations presented here are intended to provide the manufacturer with practical options for reducing mass-finishing waste.

Table I. Pollution Prevention Hierarchy

Source reduction	Process modification to eliminate or reduce pollutants at the source, e.g., solvent elimination, better housekeeping, in-process recycling of spent materials
Recycling	Off-site processing of waste materials for reuse, e.g., sludge reclamation for metal recovery
Treatment and disposal	End-of-pipe treatment of waste prior to disposal, e.g., chemical treatment system that treats several waste streams prior to sewer discharge with hazardous sludge generation

MASS-FINISHING PROCESS MODIFICATIONS

As shown in Figure 1, there are four basic input materials in the mass-finishing operation: metal parts, media, soap, and water. The type and amount (or flow rate) of each input material are considered in the overall analysis of the process. Replacement or modification of process material types and quantities may reduce or increase the amounts of pollutants generated. The type of mass-finishing machine must also be considered. While process modifications are considered to be true source reduction, much of the following discussion concerns varying parameters that may not at first seem changeable. The most important aspect of mass finishing, final product quality, cannot be compromised. It is suggested that companies investigate any possible process modification that may reduce waste. Once all possible process modifications have been made, in-process recycling and off-site recycling should then be considered.

Metal Parts

Metal composition and part finish are usually dictated by the customer, so the entire operation is designed around customer specifications. Nevertheless, opportunities may exist to modify alloy compositions to reduce or eliminate the generation of pollutants and/or hazardous waste. Sludge from mass-finishing operations would be characterized as hazardous if it fails the Toxicity Characteristic Leaching Procedure (TCLP) test for any of the eight listed heavy metals. The metals that are listed as potentially hazardous include cadmium, chromium, lead, silver, mercury, beryllium, barium, and arsenic.

The costs of generating hazardous waste are significant. Hazardous waste creates more paperwork, exposes companies to liabilities, costs more to treat or dispose of than nonhazardous waste, and may require a special permit for on-site management. Reducing the use of hazardous materials may lead to considerable cost savings.

If potential hazardous metal constituents can be eliminated, source reduction is successfully applied. A manufacturer may have to modify its operation. Investigation into the use of the finished product may provide some helpful insight. Is it possible for alternative metal alloys to be used? Careful consideration into all the possibilities should be taken. Meetings with manufacturing personnel as well as customers may be necessary. In most cases, a test program is required to determine feasibility. At least one metal manufacturer has recently developed a "lead-free" casting metal substitute, which offers a potential material substitute to many costume jewelry companies. The incentive for successful metal replacement is reduced liabilities and waste management/disposal costs.

Finishing Media

Selection of the proper media plays an important role in the minimization of potential sludge generation. Two critical parameters are the shape and hardness of the finishing media. Media are selected on the basis of metal part type, shape, and desired finish. As part of the mass-finishing operation, mechanical erosion of both media and metal occurs continuously, causing the formation of metal and media particles

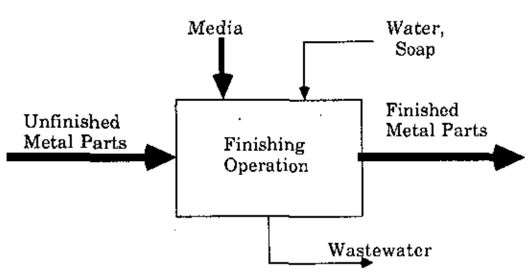

Figure 1. Process flow diagram.

in the soap solution. In addition, some metal is dissolved into solution. The resultant "dirty" solution contains potential pollutants that have been traditionally treated with chemicals to remove metals and suspended solids prior to discharge. While product quality may be satisfactory, some companies may be using media that is too soft and wears down quickly, thus creating excess waste and high media purchase costs. Consultation with the media supplier may open up opportunities to change the media to another type that still provides for the same product quality but does not wear down as fast.

Testing at various Rhode Island facilities indicates that solids from the waste solutions are predominantly made up of finishing media when plastic and/or ceramic media are used. Solids analyses carried out at different companies revealed that over 80% (by weight) of the waste solids collected were nonmetallic. If traditional chemical treatment is used to clean the waste solution prior to discharge, the total volume of sludge generated can actually increase by 100% due to the addition of precipitating chemicals. The more waste sludge generated, the higher the costs and potential liabilities of disposal, especially if the sludge is considered to be hazardous waste.

A carefully designed test program can provide insight into the best possible media that not only provides the best part finish but also allows for effective pollution-prevention options. For any waste sludge that is produced, off-site reclamation possibilities should be investigated. Many impurities, including the eroded metal itself, are present in the waste solids. Although in some cases metal can be recovered, media recovery options are limited. Most finishing equipment suppliers will work with the manufacturer to find the best media and soap to minimize waste.

Mass-Finishing Compounds

The type of soap in the finishing operation is an important variable that is dependent on the metal part and media used. As previously mentioned, many different compounds exist. Some soaps are best for polishing, whereas others are better suited for deburring, and the pH varies from chemical to chemical. Because an in-process recycling program is ultimately desired after all finishing process modifications have been implemented, it is critical to minimize the number of different soaps that are used. If many different soaps are used, in-process recycling becomes more difficult and expensive because a separate recycling system would be required for each soap. Many companies use a different soap for each type of part that is manufactured. While certain compounds are more effective than others for certain metal parts, many soaps have a much broader range of applicability than often is realized. Because the traditional approach has been end-of-pipe treatment and discharge, there was little concern about the number of different soaps used; everything would eventually end up in the sewer. J & L Finishing (Providence, R.I.), a mass-finishing job shop that accepts parts of all types and shapes, was able to reduce their number of soaps from four to two. After having eliminated their chemical treatment process, the company installed a large (500 gal/day) membrane filtration system for one soap and a small membrane system for another compound. The company has thus been able to recycle soap and water much more economically. (For further discussion on this topic, see In-Process Recycling below.)

In some cases, the mass-finishing operation presents opportunities to eliminate hazardous chemicals. For example, Miniature Casting Corp. (Cranston, R.I.) uses an alkaline compound in its vibratory operation and had originally discharged to sewer. Due to local sewer requirements, the pH of the solution could not be above 10. Because the alkaline compound was not strong enough, some heavily contaminated parts required precleaning with mineral spirits, a hazardous solvent, prior to the vibratory step. Although a stronger concentration of the alkaline soap could successfully clean all the parts, the pH of the solution would be raised to 11 and would not meet discharge requirements. Recycling the solution, on the other hand, relieves the company from all discharge requirements as the solution is no longer being discharged. By employing an in-process recycling scheme, higher pH solution can be used, and the mineral spirits cleaning is eliminated.

Machine Modification

Two basic mass-finishing machine designs are vibratory and tumbling. Many variations exist depending on the application. More elaborate designs may prove to be more cost-effective and prevent more pollution by increasing efficiency. Process cycle times and, hence, waste generation are reduced. There are now available new types of mass-finishing equipment that have been designed to be more efficient in material use and pollution prevention. For example, in applications where large quantities of identical parts are manufactured, a machine is available that cleans each part individually and quickly with relatively little waste. A company can work with the machine supplier to determine which design is best for its operation. One company switched the majority of its mass finishing from barrel tumblers to small vibratory units, which resulted in less soap/water use and less waste generation.

Water and Soap Conservation

In continuous-feed operations where a continuous flow of solution is fed into the basin, the amount of finishing solution and water used may be reduced. Pilot tests at various companies have indicated that satisfactory part finishes can be obtained even when flow rates are reduced. Lower flow rates lead to decreased volumes of waste solution, which in turn results in lower equipment/operating costs. In addition, shorter cycle times can reduce water consumption. Some parts may not have to be run as long as previously believed for proper surface finish. Reductions in cycle time not only reduce water and soap use, but also reduce the amount of sludge generated. Because each application is different, on-site testing needs to be carried out to determine optimal flows and cycle times.

In-Process Recycling

In-process recycling, or recycling at the source, is another pollution-prevention approach that can be implemented once all of the other possible process modifications described above have been made. The following discussion describes several techniques that have proven to be successful in many appli-

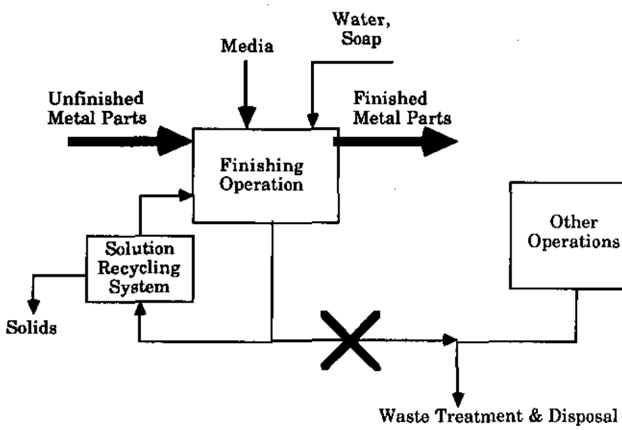

Figure 2. Stream segregation.

cations. Some recycling programs are more costly than others and each company should test all available options to determine the most cost-effective program.

Waste Stream Segregation

Before any recycling program is implemented, it is important to ensure that specific operations are separated in such a way that prevents solution mixing. If the waste stream from the original finishing operation is mixed with other waste streams prior to end-of-pipe treatment, the finishing solution must be captured prior to mixing with the other waste streams (see Fig. 2). Similarly, if more than one finishing solution is used, each of these streams must be separated and will require individual recycling systems. It is important that soaps not be mixed as the original soap solution is desired for reuse.

Solution Recycling Options

As shown in Figure 2, a properly designed material recovery system prevents waste solution from entering the treatment and disposal stream. Table II describes how significant savings in process waste can be achieved with recycling. The more times a solution is recycled, the less wastewater is generated. For example, if a company generates 1,000 gal/day of waste finishing solution, reusing the 1,000 gallons just once will reduce actual waste solution generation down to 50% of the original waste volume. Because mass-finishing operations vary from company to company, several types of solution recycling systems have been developed to suit almost any application. The following techniques are based on actual tests and case studies at several different companies.

Table II. Effect of Reuse on Waste Reduction

Number of Times Solution Reused	*% Volume Reduction of Original Waste Solution*
1	50
2	67
3	75
4	80
5	83
10	91

Simple Recycle

As the solution is used and leaves the tubbing or vibratory machine, it is usually considered "waste" and no longer suitable for reuse. The solution may be reused more than once with little or no filtration. Although the solution may appear spent or visibly dirty, in some cases companies have captured the machine effluent and simply reused the solution after simple settling (see Fig. 3). Final part quality is not affected, and the volume of waste solution is minimized. Table II shows how reusing the solution even once can cause a 50% reduction in the volume of waste solution that has to be treated or disposed of. Since 1992, Miniature Casting has utilized a simple recycling program. The company reuses the same solution for many weeks with simple settling. After two to three months, the parts cannot be cleaned adequately and more advanced filtration technologies are used to "recharge" the recycled solution. A discussion of these other filtration techniques is presented below. The equipment costs for the simple recycle system include tank, pump, and piping costs. A small operation (less than several hundred gallons per day) can use drums, whereas larger operations (thousands of gallons per day) would require the installation of holding tanks. Anticipated costs range from several hundred dollars to several thousand dollars. The solids that are periodically removed from the settling tank consist mostly of media and some metal. Depending on the nature of these solids, some off-site reclamation opportunities may exist. But because chemical treatment is not used, the volume of removed solids is much smaller than what would be obtained with chemical flocculation.

Coarse Filtration

Many companies have utilized cartridge or bag filtration to clean the used finishing solution. Since most companies who recycle their solution ultimately use membrane filtration (discussed later), some type of coarse prefiltration is usually required. "Coarse" filtration can be defined as removing particles that are larger than 30–200 µm in size. Although settling is often considered to be one type of coarse particle removal, separation is not always well defined. Different mass-finishing media have different settling characteristics, which are not

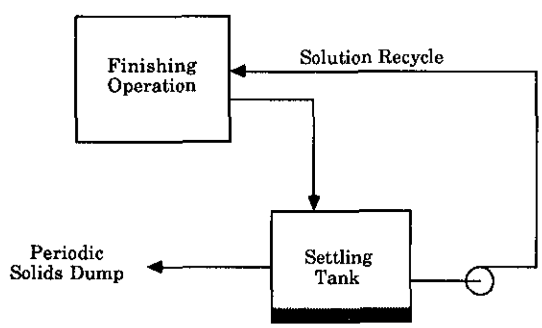

Figure 3. Simple solution recycle.

Table III. Approximate Costs for Complete Membrane Recycling System

Flow Rate, gal/day	Initial Capital, $	Annual Operating, $
50	4,000	500
150	7,000	1,000
500	18,000	2,500
1,000	34,000	4,000
10,000	80,000	10,000

relevant if a bag or cartridge filter is used. A filter separates particles of a specified size regardless of settling characteristic. Usually, settling is used prior to any filtration to remove the large particles and extend the lifetime of the filters (see Fig. 4).

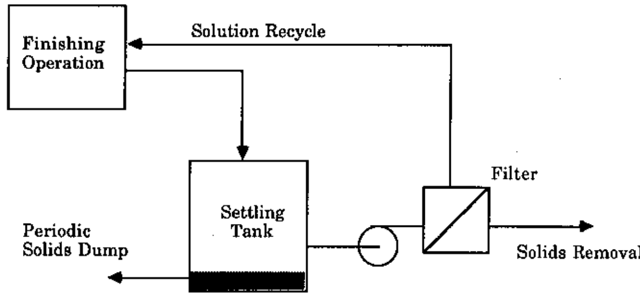

Figure 4. Solution recycle with coarse filtration.

Membrane Filtration

Membrane filtration is the best means of mechanically separating different constituents. Membranes can separate µm-size particles (microfiltration), particles <0.1 µm in size or large molecules (ultrafiltration), and small molecules and dissolved metal (nanofiltration and reverse osmosis). For the most part, companies have relied on microfiltration and ultrafiltration for cleaning and reusing finishing solution. Because one of the primary objectives is to recover as much soap as possible, it is usually not necessary to make use of nanofiltration or reverse osmosis technologies, which would separate out most of the soaps and are much more costly to operate. A typical process schematic for a recycling system using membrane technology is shown in Figure 5.

Many Rhode Island companies are currently using the process described in Figure 5. Although the previously mentioned techniques are certainly viable and less costly, membrane technology allows for much longer recycling periods. For example, Miniature Casting makes use of simple recycling without any filtration for several months. The water begins to become so contaminated, however, that the parts no longer are clean after finishing. At this point, all of the recycled fluid is processed through a small ultrafiltration system. The solution is "recharged" and ready to be used for another 2–3 months of simple recycling (see Fig. 6). Other companies have also implemented similar "hybrid" recycling programs where different filtration technologies are combined.

Most companies prefer to filter all of the used solution with membranes (Fig. 5) so that the soap solution is as clean as possible before reuse. Certain metal parts are subject to very strict cleaning requirements; therefore, the reused solution must be as clean as possible. Some level of on-site testing should be carried out to determine the best process.

Table III shows the approximate costs associated with the implementation of membrane technology for mass-finishing recycling. Initial capital costs include the membrane system, tanks, pumps, solids dewatering equipment, and installation. Operating costs include membrane/filter replacement, energy, and labor. Depending on the size of the operation and extent of automation in the system, costs can vary widely. If the operation is fairly small (<100 gal/day), filter bags can be used to dewater solids that are periodically removed from the operation. Companies with larger finishing operations have purchased filter presses, which can handle larger amounts of sludge and dewater at a faster rate than simple filter bags.

Regardless of the changes implemented to improve a particular mass-finishing operation, some "waste" materials will inevitably need to be dealt with; sludge will be formed (discussed below), and the solution will become unusable after a certain time period. Most companies clean and reuse the same solution for up to one year before cleaning out the system. Although membrane technologies can actually clean the water to exceed municipal drinking water standards, these membrane types (nanofiltration and reverse osmosis) are more expensive to use and do not lend themselves to the recycling process where microfiltration and ultrafiltration are best employed. Over time, salts and metals accumulate in the recycled solution to a point where the parts do not clean well. In some cases, where there are long periods of inactivity, biological growth creates an operational as well as odor problem. Small doses of hydrogen peroxide usually eliminate this problem. When the solution is ready to be replaced, companies normally do one of two things: (1) depending on the volume of recycled solution, a company may have a licensed hauler remove the

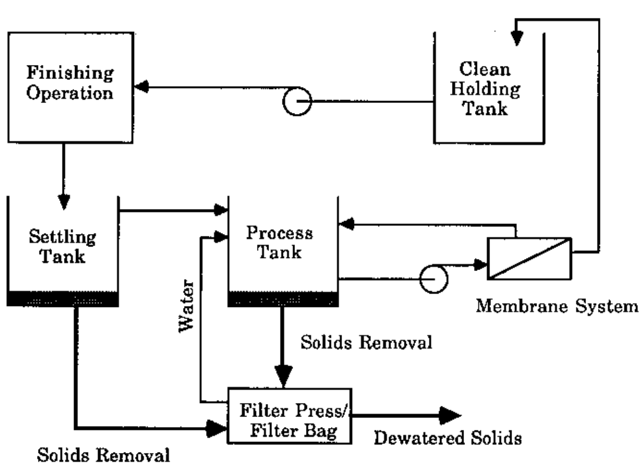

Figure 5. Solution recycle using membrane technology.

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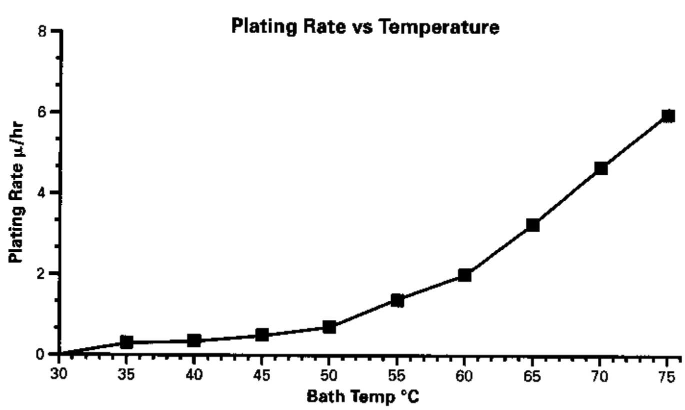

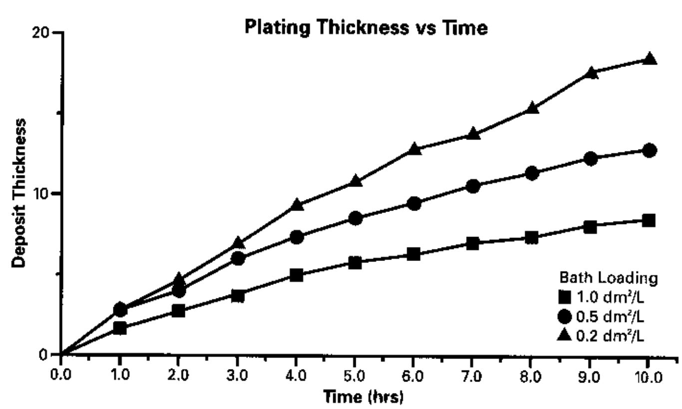

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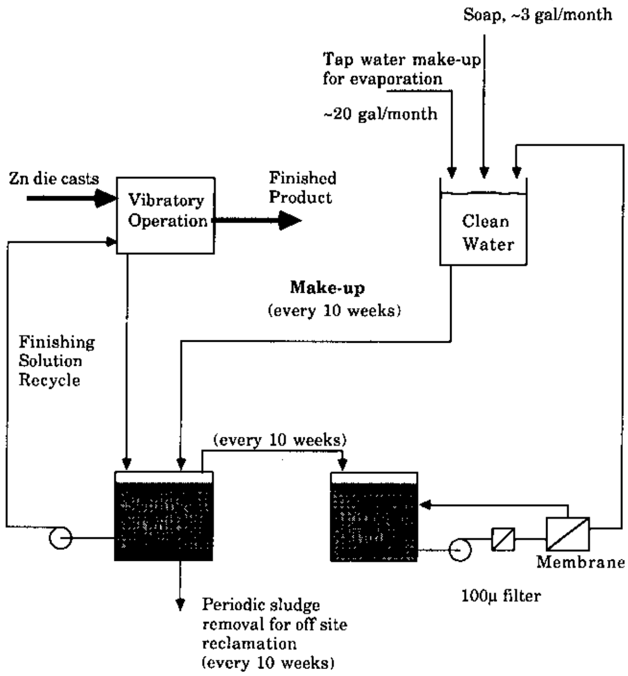

Figure 6. Present vibratory recycle operation at Miniature Casting Corp. (Cranston, R.I.).

entire working volume (some companies recycle only a couple hundred gallons of solution), or (2) dump the solution into an already existing wastewater pretreatment facility. How often the solution has to be changed varies from company to company; the average cycle appears to be about a year. In any case, the volume of waste is reduced significantly. Sludge is periodically removed from the operation and must be managed accordingly.

Sludge Handling

Although certain steps can be taken to ensure that the amount of sludge generated is minimized through process modification, some solid waste is inevitably produced. The avoidance of chemical treatment reduces potential waste, hazardous materials handling, and disposal costs. Optimizing finishing times and the type of media employed in the process will help to minimize the generation of waste sludge. The solids that are removed from in-process recycling programs consist mostly of media and some metal of the type(s) found in the parts to be cleaned. In some cases, the removed sludge can be returned to the metal supplier for reclamation. Some companies are able to return the sludge that is removed from the recycling process to their metal supplier along with scrap metal that is left over from manufacturing operations. Companies that are able to mass finish "part on part" without media (very small metal parts, usually) end up with sludge that is pure in metal, and off-site reclamation becomes even more attractive.

Off-site reclamation becomes more difficult if the metal portion of the sludge is of a mixed variety. The sludge may be a mixture of metals because many companies manufacture different metal parts that are complex alloys. For example, brass contains zinc and copper; and some "white" metals contain a mixture of lead, antimony, and tin.

Table IV. Economic Analysis of Pollution Prevention Project

	Cost Before, $	Cost After, $
Capital equipment including membrane system, tanks, pumps, and filters/housing	0	5,500
Annual operating costs (estimated)		
Soap	1,526	100
Mineral spirits	1,015	0
Cartridge filters	1,189	400
Membrane replacement	0	300
Energy	negligible	negligible
Labor	4,742	1,700
Water	161	0
Sewer fees	300	0
Analytical tests	224	20
Total	9,157	2,500

SUMMARY OF POLLUTION PREVENTION APPROACHES

Figure 7 summarizes the available pollution prevention options for mass-finishing operations. Once modifications have been made to the unit operation, in-process recycling measures can be implemented. The final waste materials (i.e., sludge and unusable finishing solution) either have to be treated and/or disposed of. In any case, the amount of waste materials generated will be reduced substantially through the implementation of pollution prevention measures.

ECONOMICS

The implementation of pollution-prevention techniques can incur costs that cover a wide range: from minimal labor costs for simple process modifications to tens of thousands of dollars for membrane filtration equipment. Most companies base equipment purchases on cost-effectiveness and payback. For example, if it is determined that a particular company's operation requires $10,000 in equipment purchases, the company would like to see annual or biannual savings of at least $10,000. These savings may come in the form of disposal cost reductions, soap/chemical purchase savings, and water/sewer fee reductions. Table IV summarizes the economic savings achieved at one company where a payback was obtained in less than one year.

In some cases, however, because of regulatory pressure, companies are required to implement pollution-control equipment. Material recovery and the minimization of environmental discharge are the best approaches to deal-

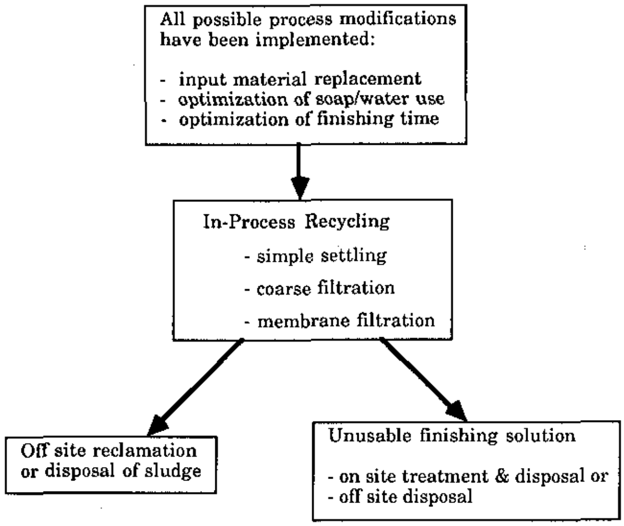

Figure 7. Summary of pollution-prevention sequence.

ing with compliance problems (in-process recycling) as liabilities can be significantly reduced immediately.

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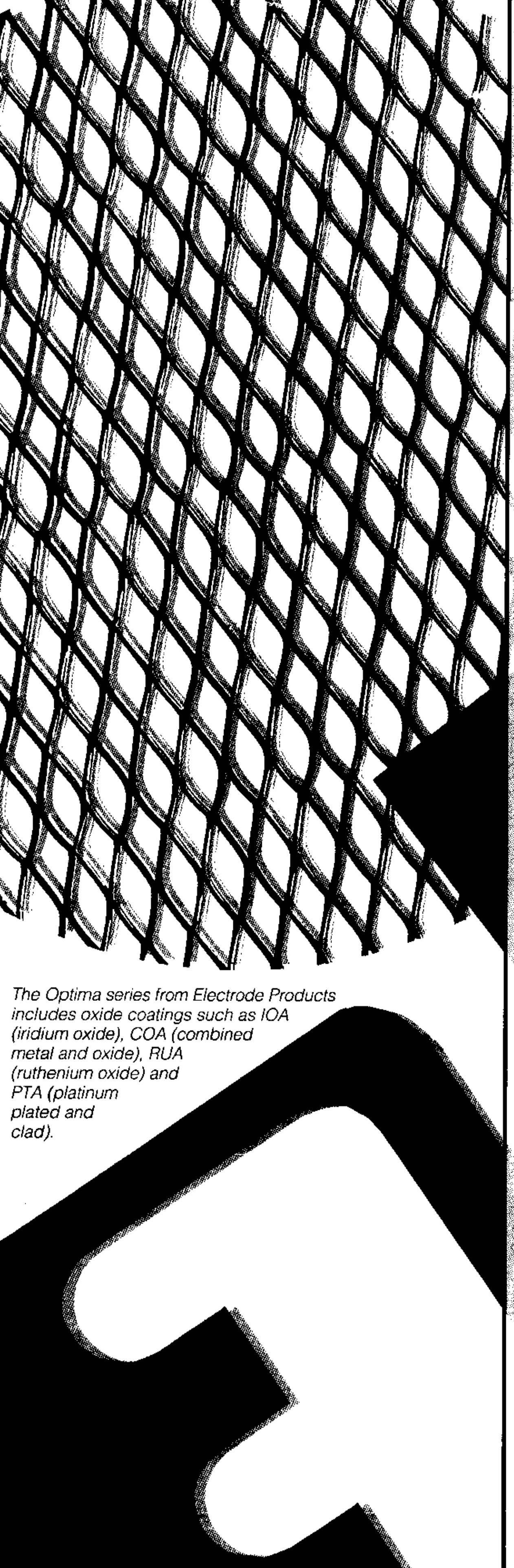
Biography

Eugene Park is currently working as a Research Professor at the Chemical Engineering Department of the University of Rhode Island (URI). His position is funded by the Pollution Prevention Program of the Rhode Island Department of Environmental Management. Since 1989, he has provided technical assistance to many R.I. companies in the area of waste reduction and pollution prevention. He received his bachelor's and master's degrees from Dartmouth College and his Ph.D. from URI. He is a member of the American Institute of Chemical Engineers. Most of his background centers around membrane filtration processes, especially for oil/water separation. He spent three years at Sanborn-Donaldson in Wrentham, Mass., as a process engineer in oil/water separation prior to coming to URI in 1989. **MF**



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