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Wastewater Management for the Metal Finishing Industry in the 21st Century

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Abstract

Many factors will shape the metal finishing industry's approach to wastewater management in the next decade. Conventional treatment usually entails minimally segregated, end-of-pipe metal hydroxide precipitation systems. The current trend is to "leap frog" 40 to 50 years of technology evolution in favor of zero discharge (a misused term) systems. By applying the concept of continuous process improvement to wastewater management, 90 percent reductions in water use and toxic waste can be integrated into a metal finishing facility to position it for the difficult transition to zero discharge.

Introduction

The future of wastewater management in the metal finishing industry is sometimes predicted to be zero discharge. Unfortunately for most discussions, zero discharge can be defined many ways. Zero discharge can mean no effluent wastewater, no regulated constituents in effluent wastewater, no measurable contaminants in effluent wastewater, no environmental impact from effluent wastewater discharge, or that no material ever leaves the process except as product or byproduct. This paper considers zero discharge to mean no effluent wastewater and will try to illustrate how zero discharge can either be avoided or optimized in its implementation.

Many of us predict a future of zero discharge from an incomplete understanding of the status of the metal finishing industry, the forces driving change in the status quo, the available options, and how to optimize change. Today's metal finishing practices, which are often based on an unsophisticated process understanding, can generally be characterized by treatment and discharge of wastewaters and disposal of often hazardous residual materials. Evolving requirements include discharge restrictions, waste regulations, new management philosophies, and restricted economics. Continuous and step-wise process improvement:

- Provides a methodical approach to minimize the disruptions associated with change
- Improves the efficiency and effectiveness of the existing systems left unchanged
- May eventually overcome the forces that are perceived as requiring zero discharge
- Will minimize the investment in zero discharge technology if that alternative cannot be avoided entirely

Current Industrial Practice

Most of the metal finishing processes used today were developed 10 or more years ago. These long-established process operations are routinely followed without a clear understanding of the theories on which they are based. Accepted practices are ingrained to the point that modifications are rare and difficult to implement. Attention to both operator education and wastewater management practices could result in more efficient and cost-effective operations.

Operator Education

Perhaps the greatest hindrance in planning and preparing for the future is that metal finishing operators are provided with only a limited understanding of the processes they use. This situation is exacerbated by two factors: chemical formulations are most often proprietary and chemical suppliers guard their specialized

knowledge about metal finishing. The result is that operators serve simply as technicians, following established procedures and adding the chemicals recommended by the chemical suppliers. Because their knowledge base is limited, operators tend to run one job like the previous one, making random changes if the results fall short of requirements and eventually arriving at an acceptable result by trial and error. The metal finishing industry must begin to take a more scientific approach that disseminates the knowledge now protected by the chemical suppliers so that operators can become knowledgeable of the processes they work with and can make suggestions for process improvements.

Wastewater Management Practices

The wastewater management practices of the metal finishing industry today can be broadly characterized as end-of-pipe treatment, discharge, and disposal. Conventional treatment technologies are used to lower contaminant concentrations in the wastewater from the metal finishing processes. Discharge of treated wastewaters to a publicly owned treatment works (POTW) or receiving waters is much more common than recycle or reuse. The predominant wastewater management approach is to accept process wastewaters as inevitable, remove contaminants to meet some discharge concentration limits, dispose of typically hazardous sludges, and not push back on the metal finishing process operators and engineers to reduce wastewater flows.

High water usage has historically been the easy answer for a wealth of metal finishing challenges. It is encouraged by concentration-based discharge limits and by the simple rinse configurations in some older facilities. High water usage has become an extravagant misuse of resources that is accepted as an unavoidable part of the cost of doing business. Poor housekeeping practices resulting in spills and overflows constitute a double expense in the replacement of lost material and the treatment and disposal of the material that is sent to the wastewater treatment system.

Precipitation Processes

Precipitation is by far the most common metal finishing wastewater treatment technology. Chemicals such as sodium or calcium are added to wastewaters to raise the pH and precipitate metals based on the low solubility of those metal ions in the presence of the metal hydroxide forms at high pH. Iron coprecipitation is sometimes used as an enhancement of the chemical precipitation process when the influent concentrations of the target ions are low and causing the formation of large quantities of iron hydroxide sludge for disposal. Sulfide precipitation is another enhancement of the chemical precipitation process sometimes used when the effluent concentrations of the target ions must be extremely low; however, sulfide precipitation carries with it the risk of releasing hydrogen sulfide gas. The pretreatment process used for chromium is chemical reduction, which converts the form of chromium commonly used in metal finishing to the form required for the precipitation processes. The pretreatment process for cyanide is destructive oxidation, which converts the cyanide to much less troublesome compounds.

Ion-specific Discharge Limits

Ion-specific discharge limits have been broadly applied to the regulation of wastewater discharges from metal finishing operations based on federal guidelines. Ion-specific limits define the concentration of ions that must not be exceeded in the discharged wastewater. The regulatory mechanism behind ion-specific limits frequently refers to what is called "best available control technology" (BACT). This approach is not actually technology driven; any technology that achieves the numerical concentration limits is acceptable, and BACT is only important when the limits are not achievable.

Ion-specific discharge limits are not based on quantifiable impacts of the wastewater discharged from the metal finishing operation. The only consideration of wastewater discharge impact is implicit in the process for setting the concentration limits. The agency responsible for regulating the wastewater discharged from the metal finisher may consider the regulatory guidelines and evaluate the wastewater receiver to decide if concentration limits lower than those in the guidelines are appropriate.

Dilution

"Dilution is the solution to pollution" sums up the simplest response to concentration-based wastewater discharge limits. A high volume of rinsewater dilutes the modest quantity of contaminants dragged from the metal finishing baths and results in a low concentration of contaminants. Unfortunately, dilution is an ineffective pollution control measure because it does nothing to minimize the impact of discharged wastewater contaminants that either accumulate in sediment or enter the food chain.

Hydroxide Sludge Disposal

Hydroxide sludges from precipitation processes are the greatest environmental burden created by the metal finishing industry. These sludges are either hazardous by definition or by some characteristic such as a high concentration of regulated contaminants in water that has been in contact with the sludge (leachate). Metal finishing sludges can be dewatered to decrease their mass and volume, and additional processing may reduce the ion mobility of the metals. However, the processed sludge must be disposed of in a well designed landfill that is permanently maintained to minimize the possibility of the metals contaminating the environment.

No Water Recycle or Reuse

Recycle and reuse are not part of the end-of-pipe treatment philosophy common in the metal finishing industry today. Fresh water or deionized water are used in whatever process requires water. The end-of-pipe treatment technologies are designed to produce wastewater suitable for discharge without consideration of conforming to recycle or reuse requirements. Generally, the toxic contaminants from the metal finishing processes are purged in the sludge from the treatment processes while the other contaminants from the metal finishing processes are purged in the discharged wastewater.

Evolving Requirements

Discharge Restrictions

Evolving discharge restrictions are replacing categorical limits with lower ion concentration limits, mass-load limits, aquatic toxicity assessment criteria, and lower pre-treatment concentration requirements.

Lower Ion Concentrations Limits

Lower ion concentration limits increase the performance requirements of the existing wastewater treatment systems and may require a change in wastewater treatment technology. The lower concentration limits may be based on an increased concern for the receiving water resources, particularly those water bodies that are also used as drinking water supplies. Lower concentration limits are also being used to protect fishery resources from materials that have been demonstrated to travel up the food chain.

Mass-Load Limits

Mass-load limits are replacing concentration-based discharge limits. The effect of mass-load limits will be to eliminate dilution as a wastewater discharge requirement conformance tool. Mass-load limits are based on a knowledge that some contaminants are not destroyed but linger in the environment and can accumulate to high concentrations in water or sediment despite coming from a low concentration discharge source.

Aquatic Toxicity

Aquatic toxicity limits go beyond either discharge concentration or mass-load limits and require assessment of the biological impacts associated with discharges. These limits assess the response of certain species to concentrations of contaminants in effluent and characterize the waste impact on an acute (short-term) and chronic (long-term) basis.

Pretreatment Standards

Pretreatment standards being imposed by POTWs are intended to enlist dischargers in helping the POTWs increase conformance with their external sludge and discharge requirements. Depending on the POTW's external requirements, the pretreatment limits may be established to control wastewater contaminants that pass through untreated or that contaminate the sludge and compromise the sludge disposal process.

Waste Regulations

Waste regulations are affecting wastewater management decisions by forcing consideration of the secondary impact of wastewater management.

Sludge Disposal Restrictions

Sludge disposal restrictions eliminate the disposal of specified sludges or require specific sludge treatment processes before disposal. The landfill ban under the Resource Conservation and Recovery Act (RCRA) identifies specific waste types that may not be landfilled unless treated as well as the required waste treatment technologies for those wastes.

Toxic Use and Toxic Waste Reduction

Toxic use and toxic waste reduction requirements place responsibility on the material users and waste generators to reduce their reliance on materials with toxic impacts. Ozone-depleting solvents are being eliminated from production and use in most industrialized countries of the world. Cadmium, chromium, cyanide, lead, and phosphorus have already been eliminated from use in many areas. Toxic waste reduction concerns have become a market driver, leading many companies to develop new technologies. It should be recognized that toxic use reduction may not translate to an equivalent reduction in waste as alternative processes may create alternative waste disposal challenges. Sometimes a toxic waste reduction project merely exchanges a high-profile toxic waste for a low-profile toxic waste that may be no less toxic than the replaced material.

Clean Air Act

The Clean Air Act Amendments (CAAA) are requiring more stringent controls on atmospheric emissions, particularly for air toxics and ozone-depleting compounds. The CAAA-required reductions in ozone-depleting compounds are driving the development of aqueous-based degreasing, which will create new challenges for wastewater management. The CAAA is also causing metal finishers to consider improved wet scrubber technologies for controlling atmospheric emissions, which will in turn increase wastewater management loads that should be considered in an alternatives evaluation.

Process Phaseout

Process phaseout may result in exchanging one waste type for another, thus necessitating completely revamped waste management techniques. For instance, the replacement of ozone-depleting chlorofluorocarbon solvents with aqueous cleaners creates new wastewater management challenges, and the replacement of cadmium plating with zinc-based plating or ion vapor deposition eliminates cadmium usage but introduces completely different waste management requirements.

Management

New management approaches are modernizing and changing the data inputs to the decisionmaking process.

Total Quality Management

Total quality management (TQM), which is being widely embraced, is changing the way in which decisions are made. TQM focuses on customer requirements, evaluates process effectiveness, places a premium on prevention of problems, empowers workers to improve processes, and encourages customer feedback as a means of evaluating conformance with requirements.

"Green" Public Relations

Public relations considerations encourage selection of environmentally benign alternatives. Management is marketing environmental sensitivity to customers who are increasingly more environmentally conscious. Similarly, customers are requiring their suppliers to select environmentally benign alternatives, particularly for raw materials that are to be incorporated into products marketed under a "green" label.

Zero Discharge Mandates

Zero discharge is being mandated as a long-term goal of some managements that are becoming overwhelmed with the increasing regulatory burden. Zero discharge of any wastes is also attractive to managements concerned with the lessons of Superfund that large financial liabilities associated with stored wastes are never eliminated despite the best of intentions, conformance with all existing and coming regulations, and application of the best waste management technology known at the time.

Total Cost Accounting

Total cost accounting uses the entire process life-cycle "cradle-to-grave" to assess costs and value of alternatives. Environmental management costs must be added to the costs for raw materials and the production process in order to determine the true cost of bringing a product to market.

Economics

Economics are also affecting waste management practices as financial resources become less readily available in these recessionary times. Industrial users are often targeted as sources of income for both private and public parties. Waste disposal fees have risen in response to increased liability concerns and dwindling landfill space. Water and sewer rates are rising steadily in many localities in response to the scarcity of water for process usage and the capacity restrictions of POTWs. Permit fees are rising as public financial resources become less available. Civil penalties associated with regulatory nonconformance are rising as a proven method to force quick conformance. This movement has greatly increased management concern regarding decisions made within the corporation that could result in high fines or time in jail.

Continuous Process Improvement

Continuous process improvement is a method of avoiding abrupt disruptions in existing processes while accommodating changing requirements. It is characterized by planning, pilot testing, measuring, institutionalizing successes, and always returning to planning. Planning starts with analyzing process flow in relation to requirements. It includes problem identification in specific and measurable terms, leads through cause-and-effect analysis, and results in identification of potential process improvements to be tested. Each potential process improvement is pilot tested on a small scale to gather the data needed to characterize the value of the change. The results of the pilot tests are measured using a predetermined method to evaluate the value of the process modification. Successful pilot tests should be institutionalized across the entire process and failures should be documented. Planning for further process improvements is the next step in continuous process improvement.

Good Operating Theory

Good operating theory allows us to optimize our decisionmaking process. We should consider the metal finishing and waste management processes as integrated and inseparable from each other. Life-cycle cost accounting is a natural outgrowth of this. Partnership arrangements allow us to work with our suppliers by making our requirements their requirements. When requirements change swiftly, process optimization is dynamic—a system must be able to respond to changing conditions. Hardware changes, a greater investment, should only follow attempts to optimize the process operations.

Good Operating Practices

Good operating practices are often small changes that altogether can lead to a significant change in our process operations and help us avoid a one-step major overhaul of our process. These techniques are relatively inexpensive modifications that reduce the need for more expensive recovery, recycle, and treatment technologies. Many good operating practices are not applicable to each process system and any change typically requires an investment, but the continuous process improvement approach is based on implementing the changes that have value and lead in the right direction. Data have shown that as much as 90 percent of the target parameter reduction, such as wastewater discharge or hazardous material disposal rate, can be achieved by a combination of some of the simplest and most easily implemented changes. In the metal finishing industry, such changes can be implemented in the areas of drag-out reduction, counter-current rinsing, recovery rinsing, rinsewater control, and tank-side process management.

Drag-out Reduction

Most drag-out reduction methods are inexpensive to implement and can be justified on the basis of savings in chemical costs alone. In addition, pollution control savings are many times the cost of the changes.

Drag-out of various processing baths into subsequent rinses is the most obvious source of pollution in a metal finishing process facility. The higher the drag-out the higher the mass loading on rinse and wastewater systems and the higher the hydraulic load due to the need for more water to dilute the solution film on the parts being processed. The amount of pollutants contributed by drag-out is a function of such factors as the design of the racks or barrels carrying the parts to be plated, the shape of the parts, plating procedures (including part withdrawal technique and rate), and several interrelated parameters of the process solution, including concentration of chemicals, temperature, viscosity, and surface tension.

Drag-out losses from process solutions with conventional rinsing techniques result in large volumes of rinsewater contaminated with relatively dilute concentrations of contaminants. Rinsewaters that follow plating solutions typically contain 5 mg/L to 100 mg/L of the metal being plated.

Many techniques are used to reduce drag-out by altering metal finishing process design parameters such as viscosity, chemical concentration, surface tension, velocity of withdrawal, and temperature.

Controlling Plating Solutions. As the chemical content of a solution is increased, its viscosity as well as its concentration increases. The result is a thickening of the film that clings to the work withdrawn from the process solution. Increased viscosity and concentration contributes to a larger mass and volume of drag-out. Higher drag-out results in a consequential need for more rinsewater, which creates additional pollution control problems. To reduce the quantity of drag-out, plating baths can usually be operated at significantly lower concentrations than those recommended by chemical manufacturers. Implementing such practices requires knowledge of the particular plating process and may require experimentation to optimize process conditions.

The concept of reduced chemical content should be extended to control of bath contaminants such as carbonates in cyanide plating solutions and metallic impurities. By limiting the concentration of impurities in the plating bath, its viscosity is minimized.

Use of Wetting Agents. For years wetting agents have been used in process solutions to aid in the plating process. These substances are used, for instance, in bright-nickel plating to promote disengagement of hydrogen bubbles at the cathode. They are also used as an aid to drag-out reduction. A wetting agent is a substance, usually a surfactant, that reduces the surface tension of a liquid, causing it to spread more readily on a solid surface. The addition of very small amounts of surfactants can reduce surface tension by two-thirds with a proportional reduction in drag-out, all other variables being equal.

Positioning Work on Racks. The metal finisher's primary consideration in the positioning of work pieces on a rack is proper exposure of the parts to the anodes for optimal coverage and uniform thickness of the electrodeposit. Drainage and rinseability are also important considerations in racking. Damage to the work piece surface can be caused by insufficient or inefficient rinsing, and succeeding process solutions can be contaminated by drag-in of unremoved chemicals from the previous solution. Several rules apply to the position of work on plating racks for drag-out minimization. The basic principle, however, is that every object can be positioned in at least one way that will produce the minimum amount of drag-out.

Work Piece Withdrawal. The velocity at which work is withdrawn from the process tank has a marked effect on drag-out volume. The faster an item is pulled out of the tank, the thicker the drag-out layer will be. The effect is so dramatic that Kushner suggests that most of the time allowed for withdrawing and draining the item should be used for withdrawal.

The velocity of withdrawal of work from the process tank usually can be adjusted with vertical hoist speed. Drainage can be controlled by the use of limit switches and timers that control the horizontal movement of the hoist. In any case, there is no substitute for operator training. Barrel plating should incorporate barrel rotation in the drainage cycle whenever possible.

Dwell time during which the parts are held over the tank may be limited by the tendency of the plated object to spot when the plating solution dries on the surface, especially for very hot processes. A fog spray that uses water from the first rinse can be effective for keeping the surface from drying, accelerating the draining process and maximizing the time available for draining.

Maintenance and Design of Racks and Barrels. Maintenance of racks, fixtures, and rack coatings has generally been poor, causing transport of chemicals inside loose-rack coatings from one process to another. Barrels should incorporate the largest hole size possible, and oversized barrels should be avoided.

Drain Board. A drain board is one of the simplest methods for drag-out recovery. The drain board can capture drips of plating solution from racks and barrels and as work pieces are transferred between tanks. Drain boards not only save chemicals and reduce rinsewater requirements, they also improve housekeeping by keeping the floor dry.

Counter-current Rinsing

Counter-current rinsing takes advantage of multiple stage counter-current process operations to improve rinse efficiency. Counter-current rinse systems can be composed of several rinse tanks alone or in combination with spray rinse stations overhead.

Counter-current Rinse Tanks. Counter-current rinsing, employing several rinse tanks connected in series, is the most powerful waste reduction and water management technique. In counter-current rinsing the plated part, after exiting the plating process bath, moves through several rinse contact stages while water flows from stage to stage in the opposite direction. Over time, the first rinse reaches a steady-state concentration of plating process drag-out contaminants which is lower than the process solution. The second rinse stabilizes at an even lower concentration, which enables less rinsewater to be used compared with only one rinse tank. The more counter-current rinse tanks, the lower the rinse rate needed for adequate removal of the process solution. This multiple-stage surface film separation technique results in great economies in required rinsewater. The challenge is to optimize the investment balance between rinse stages and rinsewater flow because the number of rinse stages rises as the rinsewater flow falls.

The rinse rate needed for adequate cleaning is governed by a logarithmic equation that depends on the concentration of plating chemicals in the drag-out, the concentration of plating chemicals that can be tolerated in the final rinse tank before poor plating results, and the number of counter-current rinse tanks. The mathematical rinsing models are based on complete rinsing (i.e., removal of all drag-out from the part/fixture) and complete mixing (i.e., homogeneous rinsewater). These conditions cannot be achieved without sufficient residence time and agitation in the rinse tank.

Spray Rinsing. The common form of spray rinsing involves the use of a dedicated spray rinse tank in which two to four rows of high velocity spray jet nozzles are mounted. Spray nozzles are available in a wide range of flow rates and spray patterns. Generally, the sprays are operated at the water pressure in the municipal service line. Spray rinses can be very efficient in terms of water usage when compared to a single-stage overflow rinse. However, the water use savings depend heavily on the part configuration, as discussed below. Other factors greatly influence the efficiency of spray rinsing, including the arrangement of nozzles to work pieces, water pressure, specific flow rate, spray time, and the mechanical design of the delivery system. Spray rinsing is basically a point-of-sight technique.

Spray rinsing is most effective for flat-surfaced parts because the spray can directly strike the entire surface of the part. Spray rinsing is ineffective for rinsing parts with recessed and hidden surfaces. Also, it cannot be used for small racked parts that could be displaced from the rack by the force of the spray or with plating barrels that prevent the spray from adequately reaching the parts.

Spray rinsing can be most effectively utilized with single or multi-station immersion rinse tanks to simulate additional counter-current rinse stations. Water makeup to a heated process tank is provided by means of a spray rinse fed by immersion rinse one, which is fed by a spray rinse, and so on. In this scenario the spray volume must be equal to the evaporative volume.

Recovery Rinsing

Recovery rinsing takes advantage of the metal finishing process tendency to require addition of water. Atmospheric evaporation must occur from the plating process tank for recovery rinsing to be used. Forms of recovery rinsing include use of drag-out tanks and fog rinsing.

Atmospheric Evaporation. Atmospheric evaporation includes both inherent, or natural, evaporation and enhanced evaporation. Inherent atmospheric evaporation refers to surface evaporation from metal finishing tanks. For process and rinse tanks operated at ambient temperatures, inherent evaporation is approximately zero. The higher the operating temperature of a given solution, the greater the inherent evaporation. Enhanced atmospheric evaporation refers to the use of an evaporation unit that operates under atmospheric pressure (i.e., as opposed to the more sophisticated vacuum and vapor recompression types) and increases the evaporation rate provided by inherent evaporation. These techniques, used separately or combined, are important waste minimization/recovery tools in the metal finishing shop.

The key factors affecting the rate of inherent atmospheric evaporation are the solution temperature and the surface area of the tank. Other factors include the relative humidity of the shop, the ventilation exhaust rate or the flow of air across the surface of the tank, and the solution agitation method/rate. These other factors are negligible at high solution temperatures (>140°F), but are significant at lower solution temperatures (<110°F). Most process baths have an operable temperature range, rather than a precise temperature requirement. When operated at the higher end of this range, the inherent atmospheric evaporation rate is maximized. Generally, the increased energy cost for operating at a higher temperature is small in comparison to the savings in plating chemicals and waste treatment costs.

Drag-out Tank. The drag-out tank is a rinse tank or tanks used to make up evaporative losses from the process and recover a portion of drag-out chemicals for return to the process. The use of a single drag-out tank will generally reduce chemical losses as much as 50 percent. The recovery rate is derived from the evaporation to drag-out ratio. The rate of recovery can be increased by either increasing evaporation or reducing drag-out.

The efficiency of the drag-out tank arrangement can be increased significantly by adding a second drag-out tank. Use of a two-stage drag-out system usually reduces drag-out losses by 70 percent or more. Multiple drag-out tanks can be used to return almost 100 percent of the material that would otherwise be lost to drag-out.

Fog Rinsing. Fog rinsing is used at exit stations of process tanks. A fine fog is sprayed on the work, diluting the drag-out film and causing a run back into the process solution. Fog rinsing is applied when process operating temperatures, high enough to produce a high evaporation rate, allow replacement water to be added to the process in this manner. Fog rinsing prevents dry-on patterns by cooling the work pieces, but it may preclude the use of a drag-out tank as a recovery option through reduced evaporation makeup potential. This limitation can be overcome by using rinsewater as the feed; however, this can introduce ventilation problems that must be closely evaluated. For fog rinsing to be effective, work must be withdrawn from the process tank at a slow rate.

Rinsewater Control

The design configuration of the rinse system has a major impact on water use. Equally as important is the method of rinsewater control. Multiple stage counter-current rinses are extremely efficient in terms of water use; however, even these systems can waste water if water flow is continuous and the work flow is intermittent. To maximize the savings from rinsing systems, the water use should be matched to work flow.

When the work flow is steady, the rinsewater rate can be set by installing flow restrictors in the incoming water line. The restrictors can be purchased at flow rates from 0.1 gpm up to the maximum carrying capacity of the pipe.

With intermittent work flow, there are four basic techniques used to control water flow: (1) use continuous small water flow, (2) rely on operators to open and close the water valves when necessary, (3) install conductivity controls, or (4) install timer rinse controls.

Using a small continuous water flow results in wasted water during low production periods and poor rinsing during high production periods. Relying on operators to control water flow results in occasional overloading of recovery and treatment facilities. Conductivity controls are devices that detect the level of dissolved salts in the rinse tank and automatically open and close a solenoid valve on the water line to maintain a preset conductivity. Timer rinse controls are simple devices where the plater pushes a switch at a rinse tank and the switch activates a timer and opens a solenoid valve for a preset time period (operator adjustable). After the time period has expired, the valve automatically closes. It is best to select a time period that provides consistently clean water without excessive waste.

Tank-side Process Management

Tank-side process management refers to technologies for maintaining process bath contaminant concentrations. Tank-side technologies include atmospheric evaporation (mentioned previously) and technologies for recovery of drag-out and rinsewater such as electrowinning, ion exchange, diffusion dialysis, membrane electrolysis, and microfiltration/ultrafiltration. New technologies and applications of old technologies continue to evolve, and metal finishers must be receptive to these evolving technologies.

Electrowinning. Electrowinning is widely used in the metal finishing industry for metal recovery from waste and wastewater. Since most electrolytic units work best in concentrated solutions, it is common practice to concentrate metal bearing solutions prior to using this process. In the electroplating industry, concentration is typically achieved by using drag-out tanks or by combining electrowinning with ion exchange. Spent ion exchange regenerant usually contains a sufficient ion concentration for the efficient application of electrolytic recovery.

Ion Exchange. Ion exchange is used for a variety of purposes in the metal finishing shop, including recovery of plating chemicals from rinsewater, purification of plating solutions, wastewater treatment, and wastewater polishing.

Ion exchange is an excellent technology for recovering plating chemicals and/or pure water from dilute rinsewaters. In the typical configuration, rinsewater containing a dilute concentration of plating chemicals is passed through an ion exchange column and the metals are removed from the rinsewater and held by the ion exchange resin. When the capacity of the unit is reached, the resin is regenerated and the metals are concentrated into a manageable volume of solution. Depending on the chemical nature of the process, the regenerant solution can be returned directly to the plating tank for reuse, further processed and returned, or the metals can be recovered by another technology such as electrowinning. The most common applications of this technology are with the recovery of copper, nickel, and precious metals.

Drag-out recovery tanks can be combined with ion exchange to reduce the needed capacity of the ion exchange columns. With this concept, the common configuration includes a drag-out tank followed by a recirculating overflow rinse that feeds an ion exchange column. In operation, the drag-out tanks return the bulk of the plating chemicals to the plating bath and an ion exchange column captures only the residual quantities of chemicals. The needed size of the ion exchange unit is therefore reduced.

Diffusion Dialysis. Diffusion dialysis is a nonelectrolytic membrane separation technology that can be used to maintain and reclaim spent or contaminated acids by removing metallic compounds from the acids. The application of this technology is evolving and is expected to gain wider acceptance.

Membrane Electrolysis. Membrane electrolysis is a specialized electrodialysis technology that uses a cation-specific membrane and a simple two-cell arrangement. This technology has been commonly used with chromic acid solutions. Multi-cell systems have been utilized with highly corrosive acids such as nitric acid and hydrofluoric acid in order to isolate the electrodes.

Microfiltration/Ultrafiltration. Microfiltration/ultrafiltration is a technology that uses membrane-based separation to remove process impurities such as suspended solids and high molecular weight molecules. It is evolving as a viable means to maintain and reclaim spent or contaminated alkaline cleaners.

Wastewater Treatment

Wastewater treatment cannot be completely avoided in the operation of a metal finishing process facility. Contaminants that would otherwise accumulate to unacceptable concentrations in the process and rinse baths must be purged from the system.

Two alternative process wastewater treatment scenarios were compared:

- No effort made to optimize process facility operations in order to minimize wastewater treatment requirements
- Every cost-effective measure used to optimize process facility operations in order to minimize wastewater flow and contaminant loads

Two types of wastewater treatment systems were compared under each scenario:

- Conventional treatment system such as many metal finishing process facilities have, with precipitation and settling processes that require disposal of sludge and discharge of treated wastewater
- Zero discharge wastewater treatment systems with ion separation, evaporation, and drying that require disposal of brine solids and recycle of wastewater (although discharge of high quality treated water may be required if the metal finishing process system goes out of water balance due to an upset condition)

Treatment Without Optimized Requirements

The wastewater treatment requirements for the metal finishing shop that has not optimized treatment requirements are characterized by high contaminant load, high wastewater flow rate, and relatively low concentrations due to dilution from the high water flow rate. The high wastewater flow rate is from inadequate process bath and rinsewater flow rate management. The high contaminant load is from poor process bath management.

Conventional Treatment

The conventional treatment system includes cyanide oxidation and chromium reduction as pretreatment processes, with all wastewater treated through an iron coprecipitation process followed by clarification and filtration. Treated wastewater is discharged to either a receiving stream or local sanitary sewer system. Sludge from the iron coprecipitation process is settled, separated, thickened, and dewatered in a filter press for disposal.

Iron coprecipitation is required instead of lime precipitation to achieve low concentration limits in the discharge while treating high flow at low concentration resulting from the dilution effect of the high rinsewater flow. A filter is required following the precipitation clarifier to capture the smaller suspended solids precipitate material that does not settle well.

This system produces a high quantity of sludge for disposal. The wastewater cannot be recycled because the iron coprecipitation process does not remove ions such as sodium, calcium, chloride, and sulfate that must be purged from the metal finishing process facility.

The challenge for most facilities will be converting existing lime precipitation processes without optimizing wastewater treatment flow rate requirements. Most existing lime precipitation facilities were designed with a hydraulic capability to treat only process wastewater. They cannot readily accommodate treating waste rinsewater that may represent a ten-fold increase in hydraulic throughput. A conventional treatment system consisting of iron coprecipitation may require investment in a complete overhaul of the existing wastewater treatment system.

Zero Discharge

The zero discharge system consists of reverse osmosis followed by a mixed bed ion exchange system. The reverse osmosis reject and the spent ion exchange regenerant must be evaporated and dried for disposal.

The reverse osmosis system removes a majority (95 percent) of the inorganic contaminants in the wastewater. The mixed bed ion exchanger removes the inorganic material that passes through the reverse osmosis membrane. The reverse osmosis unit is useful upstream of the mixed bed ion exchanger to minimize the quantity of secondary waste for treatment and disposal. A system composed entirely of ion exchangers requires the addition of regenerant chemicals that add to the secondary waste burden and require special handling due to contamination with metal finishing waste materials.

The dried brine solids from the zero discharge system are similar in mass to the sludge from the iron coprecipitation system. The treated water is high purity water suitable for use in the metal finishing shop for process bath makeup or rinsewater.

The zero discharge system is typically two to five times more expensive to build and operate compared to the conventional wastewater treatment system. The secondary wastes from the two systems are approximately equal and are expected to have equal costs for disposal. The main reasons for selecting the zero discharge system would be that management has selected zero discharge as a goal or external requirements make discharge unacceptable.

Treatment With Optimized Requirements

The wastewater treatment requirements for the metal finishing shop that has been optimized for wastewater flow rate and contaminant load are characterized by lower flow and a lower contaminant load compared to a similar process facility without process and rinsewater optimization. The wastewater flow can be as low as 10 percent of the flow rate from a similar facility without flow optimization. The contaminant load can be as low as 20 percent of the contaminant load from a similar facility that has not been optimized.

Conventional Treatment

The conventional treatment system used for the optimized process facility can be the same as the one used for the facility that has not been optimized for wastewater flow rate and contaminant load. Iron coprecipitation can be flexible to wastewater influent flow rate turndown and lower influent contaminant concentrations by maintaining a high sludge recycle flow. The recycle sludge provides the surface onto which wastewater contaminants precipitate, and the net response to turndown in throughput and load is a proportional reduction in sludge purge and disposal requirements.

With the reduction in flow rate associated with optimization, it is feasible that a conventional lime precipitation process as exists in most metal finishing facilities can be upgraded to an iron coprecipitation process without major capital investment, making this the most cost-effective capital investment in wastewater treatment.

The wastewater from the conventional treatment system is not suitable for recycle because of the system's inability to remove typical metal finishing total dissolved solids contaminants. The sludge disposal rate for the conventional wastewater treatment system with optimization can be as low as 20 percent of the sludge disposal rate from a similar wastewater treatment system without optimization.

Zero Discharge

The zero discharge treatment processes used for the optimized process facility can be the same as the one used for the facility that has not been optimized for wastewater flow rate and contaminant load. The equipment should be smaller in proportion to the reduced wastewater throughput rate to take advantage of investment in optimization.

The system will produce effluent suitable for recycle to the metal finishing processes. The brine disposal rate is expected to be equivalent to the sludge disposal rate from a conventional wastewater treatment system in a similar metal finishing process facility.

Zero discharge implementation and operation costs can be much lower with optimized wastewater treatment requirements compared with either wastewater treatment system alternative without optimization. Considering the high cost of implementing a zero discharge system to treat metal finishing process wastewaters, it must be recommended to include metal finishing wastewater load reduction in any zero discharge project.

Comparison and Recommendation

A general comparison among the treatment alternatives must be made for each metal finishing process facility on a case-specific basis. Facility-specific conditions lead to widely different requirements; a top requirement for one facility decision process may be an incidental requirement for another facility.

Conventional treatment with optimized treatment requirements can be the most cost-effective wastewater management alternative. Many metal finishing process facilities already have such treatment systems, and the sludge disposal requirement can be greatly decreased by reducing the wastewater load.

Zero discharge implementation and operation costs are higher than for similar capacity conventional treatment and discharge systems, but can be much lower with optimized wastewater treatment requirements.

The continuous improvement approach to achieve zero discharge if it is selected as a long-term goal would be to:

- Reduce the wastewater treatment requirements over time by implementing successfully proven wastewater minimization projects

- Upgrade the existing wastewater treatment and discharge systems to accommodate changes in the metal finishing processes

- Define the zero discharge wastewater management system requirements only after all the wastewater flow and load optimization projects have been implemented

- Design the zero discharge system only after the requirements can be defined in specific, measurable, achievable, and compatible terms

Vision of the Future

Zero discharge may or may not be the wastewater management philosophy for the metal finishing industry in the 21st century. Whatever the 21st century requires for the metal finishing industry, requirements for reducing waste are confronting us today. Whether or not zero discharge becomes required in the long-term depends to some extent on how we conform to the requirements confronting us in the short-term. Zero discharge may be avoided entirely if we take advantage of all opportunities and show reasonable progress toward achieving waste reduction today.

We can use our time effectively to gradually reduce the production of waste in a cost-effective manner by improving our existing processes now.

We can improve the quality of our metal finishing and wastewater management processes by starting with an increased process understanding, pilot testing process improvements, and institutionalizing pilot modifications that are proven effective for meeting our requirements.

We can improve the effectiveness of our end-of-pipe treatment processes by gradually reducing the loads placed on the system through continuous improvement of our metal finishing processes.

Our overall investment will be optimized if we take advantage of metal finishing process improvements before replacing the end-of-pipe wastewater management system with a zero discharge system.