Technology Transfer EPA 625/8-82-008

Summary Report

Control and Treatment Technology for the Metal Finishing Industry

In-Plant Changes

January 1982

Overview

The metal finishing industry in the United States is subject to a variety of changing business conditions. Two of the most significant factors are the increasing costs of materials, such as plating chemicals and process water, and the environmental considerations, which include the need to control the discharge of effluent waste streams and the disposal of hazardous wastes. The survival of many metal finishing companies will depend on how effectively they deal with the impact of these changes and requirements.

The basic plating operation involves immersing parts in a process solution and then rinsing off the clinging film of plating chemicals, which is known as drag-out. If performed inefficiently, this operation wastes several pounds (kilograms) per day of expensive plating chemicals and creates thousands of gallons (liters) per day of contaminated rinse water. Inefficient operation, therefore, significantly affects the interrelated factors of material costs and pollution control.

By January 28, 1984, electroplating job shops that discharge to publicly owned treatment works must reduce contamination in the rinse water and other process wastewaters to federally regulated levels. The disposal of treatment residuals is governed by the hazardous waste regulations promulgated in the Resource Conservation and Recovery Act (RCRA). Details of the wastewater and solid waste regulations for the electroplating industry are provided in an earlier U.S. Environmental Protection Agency (EPA) report.[1]

Because of rising prices and changing regulations, it is necessary to reevaluate water pollution control techniques and costs and to examine methods for improving raw material yields. In many cases, changing the manufacturing process can significantly alter chemical losses and water flow rates. These in-plant changes usually involve techniques for reducing both the drag-out removed from process solutions and the amount of water used in the rinsing process. The overall effect is a reduction of:

- **Chemical purchases**
- **Water use (resulting in lower water and sewer costs)**
- **Wastewater treatment needs and disposal costs**

Although Federal law does not require compliance with electroplating pretreatment standards until January 28, 1984, in-plant changes should be instituted immediately. in addition to providing chemical savings and reducing water use costs, in-plant changes provide a basis for a pollution control system design. Waste treatment equipment needs—whether wastewater concentrating techniques, such as ion exchange, or conventional end-of-pipe treatment systems—often will be reduced significantly by in-plant changes. In some cases, electroplates will be able to reduce flows to less than 10,000 gal/d (38,000 l/d), thereby reducing their pollution control requirements as prescribed in the EPA pretreatment standards.[2] This report describes the first steps a plater should take to comply with either wastewater or RCRA regulations.

The EPA publication, *Economics of Wastewater Treatment Alternatives for the Electroplating Industry,*[3] addresses the costs of meeting water pollution control requirements. That report provides information on reducing the costs of waste water treatment through in-plant modifications to the plating baths and rinse systems. This summary report expands that information through additional discussion of waste generation phenomena and abatement measures involving in-plant changes.

Pollution Sources and Characteristics

Contaminants in the effluent from electroplating shops originate in several ways. The most obvious source of pollution is the drag-out of various processing baths into subsequent rinses. 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, and several interrelated parameters of the process solution, including concentration of toxic chemicals, temperature, viscosity, and surface tension.

With conventional rinsing techniques, drag-out losses from process solutions result in large volumes of rinse water contaminated with relatively dilute concentrations of cyanide and metals. Rinse waters that follow plating solutions typically contain 15 mg/L to 100 mg/L of the metal being plated.

Most job shops operate several plating lines that contain different types of cleaning and electroplating baths, such as zinc, copper, nickel, cadmium, and chromium. The combined rinse waters dilute the concentrations of individual metals, usually to less than 50 mg/L. The results of a recent survey of effluent from 22 electroplates in the Cleveland area are presented in Table 1.

Another source of effluent contamination is discarded process solutions. These solutions are primarily spent alkaline and acid cleaners used for surface preparation of parts before electroplating. The solutions are not usually made up of metals; however, there are a few cleaners that contain cyanide. Plating baths and other process solutions containing high metal concentrations, such as chromate solutions, are rarely discarded.

The amount of pollutants contributed to the total pollution load by discarded process solutions varies considerably among plating shops. It is not uncommon to find cyanide and heavy metals in concentrations of several thousand milligrams per liter in spent solutions. This contamination is caused by drag-in from previous process cycles and attack of the basic metals by the chemicals in the cleaning solutions. Table 2 presents an analysis of some typical process solutions.

Accidental spills, leaks, and drips of process solutions also can contribute significantly to effluent contamination. The plating room usually is laid out so that the entire area drains on the floor, which is only an extension of the sewer system leaving the facility. Although it is not common for a tank to spring a leak that would allow the entire solution to leak away undetected, a slow leak amounting to a solution loss of 10 to 20 gal/d (38 to 76 L/d) could go undetected for months in many shops. Also, it is not unusual to compensate for evaporation losses in a process tank by adding water to a process solution with an unattended hose that causes overflow of the solution to the floor drains.

In some shops, the dripping of plated parts is a significant source of pollution. Process solution tanks and rinse tanks often are separated by a distance of several feet (meters) or more. Carrying the racks of parts between tanks will cause plating solution or drag-out to drip on the floor and enter the drain system.

Other sources of contaminants from electroplating shops exist; however, they are not as universally present as the preceding waste sources. Additional pollution sources include sludges from the bottoms of plating baths generated during chemical purification, backwash from plating tank filter systems, and stripping solutions.

Table 1.

Effluent Characteristics of 22 Cleveland Electroplating Shops

Pollutant	Effluent concentration (mg/L)		
	Minimum	Maximum	Average
Cyanide, total	<0.1	95.9	14,4
Copper	0.1	47.2	4.7
Nickel	<0.1	52.2	5.7
Chromium, total	0.1	178.0	20.2
Zinc	0.4	101.4	19.3
Lead	<0.1	3.0	0.4
Cadmium	<0.1	24.3	4.3

The percentage contributed by each pollution source to the pollutant concentration of the final effluent can vary substantially among electroplating shops. For shops whose primary process is the chrome plate (copper-nickel-chromium), drag-out usually will be the major cause of metal loss. At facilities that engage in large nickel plating operations, more nickel is lost from the operation of the chemical purification filters and through the sludge bottom dumps after purification than through normal drag-out. The main contribution to effluent metal concentration in zinc or cadmium plating is often the zinc or cadmium that is either stripped off the danglers or rack tips in the acid dip step of the cleaning cycle or removed from the work in dichromating.[4]

Although some shops may have a higher contribution of pollutants from other sources, in almost every case, the most significant pollution problem is drag-out and the resultant contaminated rinse water. The size and cost of pollution control equipment depend primarily on wastewater volumetric flow rate. Because the volumes of rinse water are overwhelmingly larger than the volumes of all other waste sources, it follows that contaminated rinse water is the major source of pollution. A recent survey in Cleveland showed that the average rate of rinse water discharged from 22 electroplating shops was 18,500 gal/d (70,000 L/d), whereas spent process solution accounted for only 60 gal/d (230 L/d).

Electroplating shops should concentrate on drag-out and rinse waters during the planning stages of pollution control. The emphasis of this report, therefore, is on the reduction of drag-out and rinse water use. To provide a comprehensive approach to in-plant control, however, other sources of contamination, such as accidents and discarding of process solutions, will be addressed.

Table 2.

Analysis of Typical Spent Process Solutions That Are Dumped Periodically

Pollutant or parameter	Sample solution						
	Alkaline cleaner			Electrocleaner	Acid dip		
	1	2	3		1	2	3
Volume (gal)	325.0	340.0	338,0	390.0	65.0	50.0	165.0
Cyanide, total (mg/L)	2.5	85.5	2.8	1.3	(a)	(a)	(a)
Cadmium(mg/L)	0.2	2.6	0.4	0.8	6.4	0.1	1,990.0
Chromium, total (mg/L)	40.0	(a)	0.1	36.5	39.2	10.8	(a)
Copper (mg/L)	58.1	19.4	10.9	1.9	12.1	0.1	(a)
Nickel(mg/L)	6.9	0.9	0.3	5.2	128.0	0.6	(a)
Lead (mg/L)	4.4	(a)	0.7	1,9	11.6	0.1	(a)
Zinc (mg/L)	1,2	74.0	162.0	10.5	365.0	5,240.0	(a)

[a] Solution was not analyzed for particular pollutant.

Drag-Out Minimization

For the typical electroplating job shop, the drag-out of process solutions and the subsequent contamination of rinse waters are the major pollution control problems. This section explains the basic principles of drag-out theory and explores the function and applicability of the various drag-out minimization techniques in use today.

Principles

Electroplates are well aware that drag-out varies considerably among the various parts plated at their shops. For example, the volume of drag-out in rack plating differs visibly from that in barrel plating. When a barrel emerges from a process tank, it usually carries with it over 10 times more solution than does a typical rack. In addition to the obvious effects of rack and barrel design and shape of parts, there are more subtle factors that affect the volume of drag-out. These parameters include viscosity and chemical concentration, surface tension, and temperature.

The viscosity of a plating process solution can be described as its resistance to motion or removal by another liquid (in this case, rinse water) because of the attractive forces of the molecules of the solution. The difference between high and low viscosity can be demonstrated with honey and water. A much thicker film will form on a knife dipped in honey than on one dipped in water. Honey, therefore, has the higher viscosity because of its adhesive quality. The same effect can be observed with plating solutions. If two identical surfaces are immersed in separate chromium baths with concentrations of 53 oz/gal (397 g/L) and 33 oz/gal (247 g/L), respectively, the lower concentration bath will produce 73 percent less volume of drag-out.[5]

Surface tension is another physical phenomenon that has a significant effect in the plating shop. According to kinetic theory, molecules of a liquid attract each other. At the surface of a solution, such as a plating bath, the molecules are subjected to an unbalanced force because the molecules in the gaseous phase are so widely dispersed. As a result, the molecules at the surface are under tension and form a thin, skinlike layer that adjusts to create a minimum, surface area. The property of surface tension causes liquid droplets to assume a spherical shape, water to rise in a capillary tube, and liquids, such as water, to move through porous materials that they are capable of wetting.[6]

In the plating process, the volume of solution that clings to a workpiece surface depends largely on the surface tension. The force of surface tension appears to be most effective at the bottom edge of the part as it passes through and leaves the process solution. This force and the resultant volume of drag-out appear to be greatly affected by the orientation of the part relative to the surface of the liquid. Positioning parts so that only a small surface area makes contact with the liquid surface at parting results in less volume of drag-out.[7]

The third major factor that influences drag-out volume is the temperature of the process solution. Temperature is interrelated with viscosity and surface tension. As the temperature of a plating solution is increased, its viscosity, surface tension, and, therefore, drag-out volume are reduced. As a possible exception, when a part is withdrawn too rapidly from a hot process solution, evaporation may concentrate the film and impede drainage.[8] This problem, however, can be overcome by reducing withdrawal time and using a fog spray rinse on the parts as they emerge from the plating solution.

Techniques

Many devices and procedures can be used successfully to reduce drag-out. These techniques usually are employed to alter viscosity, chemical concentration, surface tension, velocity of withdrawal, and temperature. Also used are drag-out tanks for capturing lost plating solution and returning it to the bath.

Most drag-out reduction methods are inexpensive to implement and are repaid promptly through savings in plating chemicals. An additional savings many times the cost of the changes will be realized once a pollution control system is installed. The reduced drag-out will decrease the need for treatment chemicals and, subsequently, the volume of sludge produced. By reducing sludge volume, many platers may be able to meet the RCRA definition of a small generator and thereby take advantage of reduced regulatory requirements.

For some process solutions, return of drag-out may be impractical. For example, in the case of processing baths that become steadily depleted in use, the return of drag-out would simply increase the frequency of dumping.

Controlling Plating Solutions. As a rule, as the chemical content of a solution is increased, its viscosity increases. The result is a thickening of the film that clings to the work withdrawn from the process solution. Increased viscosity contributes not only to a larger volume of drag-out but also to a higher chemical concentration of drag-out. The consequent need for more rinse water creates additional pollution control problems.

Often plating baths can be operated at significantly lower concentrations than those recommended by chemical manufacturers, Research on chromium plating[9] indicates that chromium deposits from solutions containing chromic acid (CrO_3) at only 3.3 to 6.6 oz/gal (25 to 50 g/L) are acceptable. In the experiments conducted, the operating conditions were almost the same as those for the standard 33.4-oz/gal (250-g/L) bath. The bright range was narrower, however, with lower $Cr0_3$ concentrations. Chromate films, which appeared on the surface of deposits from the dilute baths, could be removed by dipping for a short period in the plating solution.

Chemical manufacturers and suppliers have become concerned with the pollution control problems of their clients—the platers. As a result, research and development efforts by the chemical manufacturers have produced more environmentally sound plating solutions.

Cyanide plating baths have been a major target of the chemical manufacturers. The conventional cyanide bath has been preferred for many plating applications, such as zinc and cadmium. Because of stricter effluent limitations on cyanide, however, an alternative to high-concentration cyanide baths is being sought. The chemical manufacturers have experimented and, in some cases, have developed alkaline noncyanide or low-cyanide baths and acid baths including neutral chlorine solutions.[10]

Platers should investigate and evaluate the various advantages and disadvantages of the new chemical solutions. As a rule, the acid bath substitutes do not offer the ease of control or the overall satisfactory operating conditions and deposit quality that are available from the cyanide bath. For zinc, cadmium, brass, and precious metals, the cyanide plating bath continues to be the most commonly used solution.

Most of the substitute solutions also are limited in application. For instance, the acid copper bath, which is not only widely accepted but sometimes preferred over the cyanide copper bath, cannot be used for direct application to steel and zinc die castings. A cyanide copper strike is essential on zinc die castings, and either a cyanide copper or a nickel strike is necessary on steel before it enters the acid copper bath. If these substitute baths are applicable to a plater's manufacturing conditions, however, they may be a major factor in the pollution control strategy.

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. Their use has also found recent popularity 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. Atypical plating bath solution has a surface tension close to that of pure water at room temperature, about 0.0050 lbf/ft (73 dyn/cm). The addition of very small amounts of surfactants can reduce surface tension considerably—to as little as 0.0017 to 0.0024 lbf/ft (25 to 35 dyn/cm).[10]

Kushner[5] estimates that the use of wetting agents will reduce drag-out loss by as much as 50 percent. He recommends the use of nonionic wetting agents that are not harmed by electrolysis in the plating bath. The safest maximum amount of wetting agent should be used in the bath. A check of the surface tension of the solution will determine whether sufficient wetting agent has been added. A stalagmometer or a DeNuoy Tensimeter can be used for this purpose.

Kushner further suggests keeping the concentration of all dissolved salts at the minimum needed for proper operation. To follow this recommendation, the plater should not permit substances to build up in the plating bath, if it is possible to control and maintain them at the proper level, For example, cyanide baths are permitted to build up very high carbonate concentrations even though the concentration level could be controlled by treatment. Such a buildup could increase drag-out by as much as 50 percent.[5]

Positioning on Rack. The metal finisher's primary consideration in the positioning of workplaces on a rack is proper exposure of the parts to the anodes for optimal coverage and uniform thickness of the electrodeposit. Drainage and rinsability are important considerations in racking. Damage to the workpiece 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 of drag-out. This position could be determined by experiment, but unless a , significant number of similar items are to be plated, it may be advisable to follow the suggestions of Kushner[5] and Wallace:[7]

- Tilt all solid objects with plane or single-curved surfaces so that drainage is consolidated, that is, twist or turn the part so that the clinging fluid will flow together and off the part by the quickest route.
- Rack all parts so that they are extended more in area than in depth; this will decrease the average depth to which the parts are lowered into a solution and, as proven mathematically, will decrease the film thickness of the drag-out.
- If possible, avoid racking parts directly over one another to prevent lengthening the drainage path of the plating solution.
- Avoid tablelike surfaces by tipping the part, but not at the expense of forming solution "pock ets."
- Orient parts so that only a small surface area comes in contact with the liquid surface as it leaves the plating solution.

Workpiece 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[5] 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 automated equipment. If the metal finishing cycle is operated by hand, however, the withdrawal velocity is less controllable. The best control method is to place a bar or rail above the process tank where the rack may be suspended for drainage while its predecessor is removed from the rail and transported to the next phase of the finishing cycle,

The withdrawal motion also affects drag-out volume. When a rack is jerked from a process solution, surface tension forces do not have a chance to operate and a much larger volume of liquid will cling to the surface. An automatic machine that performs smooth, gradual withdrawal usually will drag out less solution per item racked than will manually operated equipment.

Accurate predictions of the drag-out volume to be saved by a given reduction in withdrawal speed or by a smooth withdrawal motion are not possible. A savings maybe expected, but the degree will be determined by the specific application.

Draining time over the tank may be limited by the tendency of the plated object to spot when the plating solution dries on the surface. A fog spray that uses water from the first rinse is very effective in keeping the surface from drying, accelerating the drainage process, and maximizing the time available for draining.

When considering the purchase of new equipment, close attention should be given to withdrawal and drainage times. These factors are especially important when purchasing barrel plating equipment. Slow barrel rotation during withdrawal has reduced drag-out volumes by as much as 50 percent. Machines may be automated readily to accommodate this type of rotation at the time of design.[8]

Maintenance and Design of Racks and Barrels. As an industry average, maintenance of racks, fixtures, and rack coatings has been poor. Transport of chemicals inside loose-rack coatings from one process to another is not uncommon. Chromium-bearing solutions, for example, appear in plant effluent in spite of treatment systems designed to handle the normal chromium discharge sources. These solutions have been traced to rinse tanks and process solutions that are located some distance from the chromium discharge points. The chromium-bearing solutions reach these remote areas by way of loose rack coatings. Increased attention to rack maintenance not only will eliminate this potential hazard but also will contribute to a welcome reduction in the number of workplaces rejected because of poor contact.

Rack stripping plays an important role in rack maintenance. The plater, therefore, should organize rack stripping as a separate operating line. A separate rack strip line has a number of practical advantages.

It prevents the introduction of possible contaminants to the plating line (for example, chrome stripping in the soak cleaners and electrocleaners). A separate rack strip line also eliminates uncontrolled spreading of solutions over the plant floor and allows for more regular, frequent, and efficient stripping.

This separate rack strip line should be incorporated into the racking operation. A racking workflow for all plating should be organized in the following cycle:

- Rack off machine
- Rack unloading
- Rack stripping
- Rack loading
- Rack onto machine

The rack strip line should employ multiple counterflow rinses and drip tanks for maximum discharge control.

When new racks and barrels are purchased, the shape of the rack and the coating material should be examined closely. The shape should not hamper the drainage of plating solution, and the rack coating must be a nonwetting material. The size and shape of the holes on the barrels also need to be considered because they affect the rate of drainage. Increasing the drainage area with larger holes, when feasible, can speed drainage and reduce drag-out.

Simple Drag-Out Recovery

Commercially available equipment for the recovery of plating bath chemicals includes types that apply such principles as ion exchange, reverse osmosis, electrodialysis, and evaporation. These devices usually are applied to a single plating bath where they concentrate the salts in the rinse water, return them to the plating bath, and recycle the purified water to rinse tanks.

Before determining the costs and benefits of recovery equipment, the plater should consider several simple methods of drag-out recovery that require much less capital to implement. After using these methods and establishing new drag-out conditions, the plater should consider the applicability of additional recovery through commercially available units. A discussion of four simple drag-out recovery methods follows.

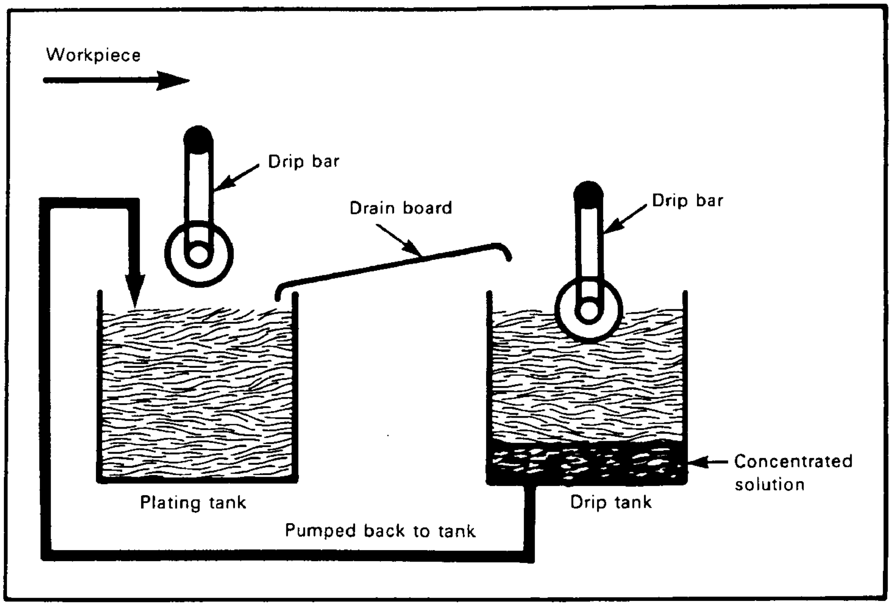


Figure 1.

Simple Drag-Out Recovery Devices

Drain Board. A drain board is the simplest method of drag-out recovery. It can capture drips of plating solution as racks and barrels are transferred between tanks (Figure 1). Not only do drain boards save chemicals and reduce rinse water requirements, they also prevent unnecessary floor wetting.

The drain surface can be plastic or metal. For acid solutions, the best materials are vinyl chloride, polypropylene, polyethylene, and Teflon®-lined steel. Stainless steel should be used for hot alkaline solutions.[5] The drain surface should be positioned at an angle that allows the plating solution to return to the bath.

Drip Tank. A drip tank is an ordinary rinse tank that, instead of being filled with water, simply collects the drips from racked parts and barrels after plating and before rinsing. The drip tank is useful with work that involves continuous dripping over a period of time. Barrel plating, therefore, is a better candidate than rack plating for drip tanks. With barrel plating, the barrel should be rotated while it is suspended over the drip tank to ensure maximum drainage. When a sizable volume of solution has been collected in the drip tank, it can be returned to the plating bath.

Using a drip tank tends to restrict the potential use of a rinse tank. As will be discussed, an additional rinse tank used as a drag-out tank or in a series arrangement may be more beneficial. The determining factors are the volume of drag-out and the evaporation in the plating bath.

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 workpieces, but it may preclude the use of a drag-out tank as a recovery option. For fog rinsing to be effective, work must be withdrawn from the process tank at a slow rate.

Drag-Out Tank. The drag-out tank (Figure 2) is a rinse tank that initially is filled with pure water. As the plating line is operated, the drag-out rinse tank remains stagnant; the salt concentration increases as more work passes through the rinse tank. Air agitation must be used to aid the rinsing process because there is no water flow within the tank to cause turbulence. The presence of a wetting agent is helpful.[5]

After a period of operation, the diluted plating salts in the drag-out tank can be used to replenish the losses to the plating bath. If sufficient evaporation has taken place, a portion of the drag-out tank solution can be added directly to the plating bath. Evaporation usually will be sufficient with baths, such as nickel, that are operated at elevated temperatures. Low-temperature baths have minimum surface evaporation and their temperature cannot be increased without degrading heat-sensitive additives. Recently, new additives, which are not as readily degraded by heat, have been developed for many of these plating baths. These additives might make operation of the plating bath possible at higher temperatures, facilitating drag-out recovery by recycle techniques. Usually the value of the recovered chemicals is much greater than the increased energy cost associated with operating the bath at a higher temperature.

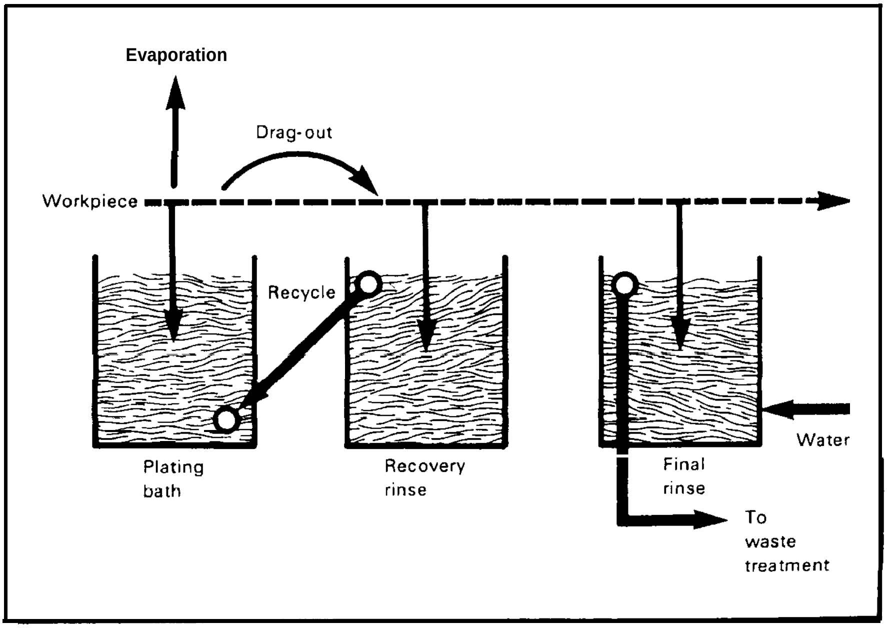


Figure 2.

Recovery With a Drag-Out Tank

As a rule, the use of a drag-out tank will reduce chemical losses by 50 percent or more. 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.

The applicability and benefits of drag-out tanks are discussed in more detail in the next section.

Rinsing

The major pollution control problem for electroplates is process solution on workplaces being dragged out and subsequently rinsed with water. Many electroplating shops still employ single, flow-through rinse tanks to remove the clinging dissolved salts and solids from workplaces. This method of rinsing is extremely inefficient and, for a typical plating shop, results in the generation of thousands of gallons (liters) per day of rinse water contaminated with dilute concentrations of cyanide and metals.

The enforcement of pollution control standards and the rising costs of water and sewer use are disrupting the conventional rinsing practices of the plating industry. Traditional rinsing techniques are being replaced by more efficient methods, such as parallel and series rinse tank arrangements and drag-out rinses, that reduce water use and the amount of pollutants to be treated or discharged.

Principles

The purpose of rinsing is to prepare the surface of the workpiece for the next step in the plating process. A film of process solution that is picked up in the previous plating step clings to the workpiece. Rinsing must remove enough of this film to ensure that the solution in the next process tank will be effective and remain uncontaminated.

To meet this objective, the plater must use a rinsing strategy that includes:[5]

- Turbulent motion between workpiece and water
- Adequate period of contact between workpiece and water
- Presence of sufficient water during contact to reduce the concentration of the salts that are washed off the surface

These three principles apply to all rinsing operations, including those using flow-through or still rinse tanks.

Turbulence. Agitation is needed to implement the first principle. Agitation can be in the form of flowing water, such as in conventional, single, flow-through rinse tanks. This form is inefficient, however, because a very high flow velocity is necessary to achieve the required turbulence when water flows into a rectangular tank.

Direct water flow can be used efficiently with spray, fog, and flood rinsing. With spray rinsing, the workpiece is exposed to high-velocity water jets. Spray rinsing uses from one-eighth to one-fourth the amount of water that would be used for equivalent dip rinsing,[5] but this method has limited application because it is not effective with recessed and hidden surfaces.

In both spray rinsing and fog rinsing, water is applied to the workpiece from nozzles. With fog rinsing, however, the water is so highly atomized that it approaches the consistency of vapor. The fog rinsing method uses less water than the regular spray and is used most often directly over the plating bath to remove a major portion of the drag-out before the workpiece goes to the rinse tank.

With flood rinsing, the workpiece is rinsed under a faucet that is connected to an air entrainer or aspirator. The air bubbles improve the effectiveness of the water movement by increasing the agitation and displacing some of the plating solution from the workpiece surface. The flood rinse usually is operated by pressure on a foot treadle.

Agitation also can be achieved by moving the workpiece in the water, This method is used on manually operated hand rack lines, and its effectiveness depends on the conscientiousness of the operator. It is possible to move the workpiece mechanically, but, in most instances, the bar would have to be moved so rapidly that the pieces would tend to fall off the racks.

The most common and efficient means of creating adequate turbulence is to apply forced convection within the rinse tank by pumping water, by propeller action, or by blowing air through the water. The first two methods are used only for special purposes and usually are not as efficient as the air blower for agitating a rinse tank. Pump rinsing, for example, has been satisfactorily applied in wire plating,

Of the forced-convection methods, air bubbles usually produce the best rinsing. Air bubbles create sufficient agitation within the rinse tank to dislodge the plating solution from the workpiece. Air usually is filtered and then blown at the bottom of the tank through a pipe distributor. Air also can be forced into the water by means of an air entrainer on the water feed line.

Contact Time. The second principle of a good rinsing strategy is to allow an adequate period of contact between the workpiece and the water. For any particular instance, this time will depend on the effectiveness of the turbulence in the rinse tanks. With good agitation and a wetting agent, 5 s may be long enough in the rinse water, if there is little agitation and the geometry of the work hinders forced convection, even 10 min may not be enough. Usually, however, when good agitation is present, a contact period of 10-15 s will be sufficient. If the agitation is only fair, 30-60 s usually is sufficient.[5]

Rinse Water Volume. The final principle of good rinsing is the presence of sufficient water during the contact period for proper reduction of the concentration of salts that are washed off the surface. Because water volume is the main contributor to waste treatment costs, this principle must be studied closely.

As discussed, the conventional method of rinsing uses the single, flow-through rinse tank. A workpiece covered with a thin film of process solution enters the rinse tank and the solution is removed to an allowable limit before proceeding to the next process tank. The volume of rinse water necessary to complete this process depends mainly on the agitation within the tank, the period of contact, and the maximum allowable concentration of process solution on the workpiece.

The maximum allowable concentration becomes a very important parameter when the other two parameters are satisfied, In fact, maximum allowable concentration is the governing factor with respect to water use. To understand the importance of this parameter, it will be helpful to begin the discussion of rinsing equations.

Equations

To determine the proper water flow and to evaluate the advantages of rinsing techniques (such as parallel, series, and still tanks), plating managers can use two equations or their equivalent nomographs.[5] The relationship between the concentration of salts in the plating bath and the allowable concentration within the rinse is referred to as the rinsing criterion, R. Under conditions of complete mixing, which are closely approached when turbulence is achieved, R can be determined by:

$$R = C_p / C_n \qquad (1)$$

where

C_p = concentration of salts in process solution
C“ = allowable concentration in rinse

When the volume of drag-out entering the rinse is considered, Equation 1 can be expanded to calculate the required rinse rate:

$$Q = \theta(C_p/C_n) \qquad (2)$$

where

Q = rinse tank flow rate
θ = drag-out rate

The following simple example illustrates the use of Equation 2.

Sample Problem. A Watts nickel plating solution contains a nickel concentration of 11.3 oz/gal (84.6 g/L). The drag-out rate is 0.05 gal (0.19 L) per rack, and the production rate is 15 racks per hour. What flow is necessary to maintain rinse tank nickel concentrations of 50 mg/L and 25 mg/L?

Solution. First convert 11.3 oz/gal to milligrams per liter using the multiplication factor of 7,489:

11.3 oz/gal X 7,489 = 84,626 mg/L

Calculate the drag-out rate in gallons per minute:

θ= 0.05(15/60)
=0.013 gal/rein

Then, apply Equation 2 using an allowable rinse tank concentration of 50 mg/L:

Q = 0.013(84,626/50)
= 22.0 gal/min

Using an allowable limit of 25 mg/L, the required flow would be exactly twice as much as for a 50-mg/L concentration:

Q = 0.013(84,626/25)
= 44.0 gal/rein

Techniques

The most effective means of reducing water use and waste treatment costs is to alter rinsing techniques. Changes can range from simple piping alterations for recycling rinse water to more complex changes, such as installation of two or three additional rinse tanks that are arranged to combine the advantages of series and recovery rinsing. A discussion of current rinsing methods follows. The discussion is accompanied by examples of using the rinsing equations to evaluate the various rinsing techniques.

Drip guards tailored from inexpensive plastic pipe and installed over space between countercurrent rinse tanks

Rinse Water Recycling. Use of a simple method of water conservation is becoming more widespread. It involves the reuse of rinse water at two or more rinse tanks where the contaminants in the rinse water after a processing step do not detract from the rinse water quality at another station. This method is applied most often to the rinses following acid dips and alkaline cleaners. For example, instead of using 5 gal/rein (1 9 L/rein) of rinse water in each rinse tank [total of 10 gal/rein (38 L/rein)], the rinse water used following the acid dip can be reused as rinse water directly after the alkaline cleaner. This practice will reduce the water use for these two tanks by 50 percent. In most cases, contamination does not appear to be a problem. In fact, the rinsing following the alkaline cleaner appears to improve. The diffusion part of the mass transfer process is accelerated as the concentration of alkaline material at the interface between the alkaline drag-out film and the surrounding water is reduced by the chemical reaction there. Also, alkaline solutions usually are more difficult to rinse off than acid solutions because of the higher viscosities, so neutralization aids in this respect.[5]

Other recycling arrangements can be employed where the less contaminated overflow from critical or final rinsing operations is reused for intermediate rinse steps, such as acid dips and alkaline cleaning steps. The rinse water following a nickel plating bath can be routed to the rinse tank following the acid dip. This rinse water, in turn, could be routed to the alkaline cleaner.

Choosing the optimal configuration requires analysis of the particular rinse water needs. Interconnecting rinsing systems might make operations more complicated, but the cost advantage justifies the extra attention required.

Multiple Rinse Tanks. The benefits from recycling rinse water are limited because that method of conservation cannot be applied to all rinse tanks. Methods exist, however, that can be applied more widely and that result in more dramatic water savings. The three most common methods are parallel and series rinsing and the use of still rinse tanks.

A parallel rinse tank arrangement using three rinse tanks is illustrated in Figure 3a. With the parallel feed system, each tank is individually fed with fresh water. The rate of water flow to each tank should be the same to obtain the optimal water savings.

The flow rate is controlled most easily by installing flow regulators on the fresh water lines feeding each tank. These devices, which are available in a wide range of flow settings, control the flow rate within a narrow limit despite variations in line pressure. Flow regulators also eliminate the need to reset the flow each time the valve is closed. Some are designed to act as siphon breakers and aerators (by the venturi effect).

The effect of parallel rinsing on water use can be evaluated using the following equation:

Q = (cp@/en)"'/" (3)

where

n = number of parallel rinse tanks

Equation 3 is used in the following example. Using the operating parameters from the sample problem illustrating Equation 2, determine the water flow necessary to obtain a rinsing concentration of 50 mg/L with two parallel tanks and with three parallel tanks.

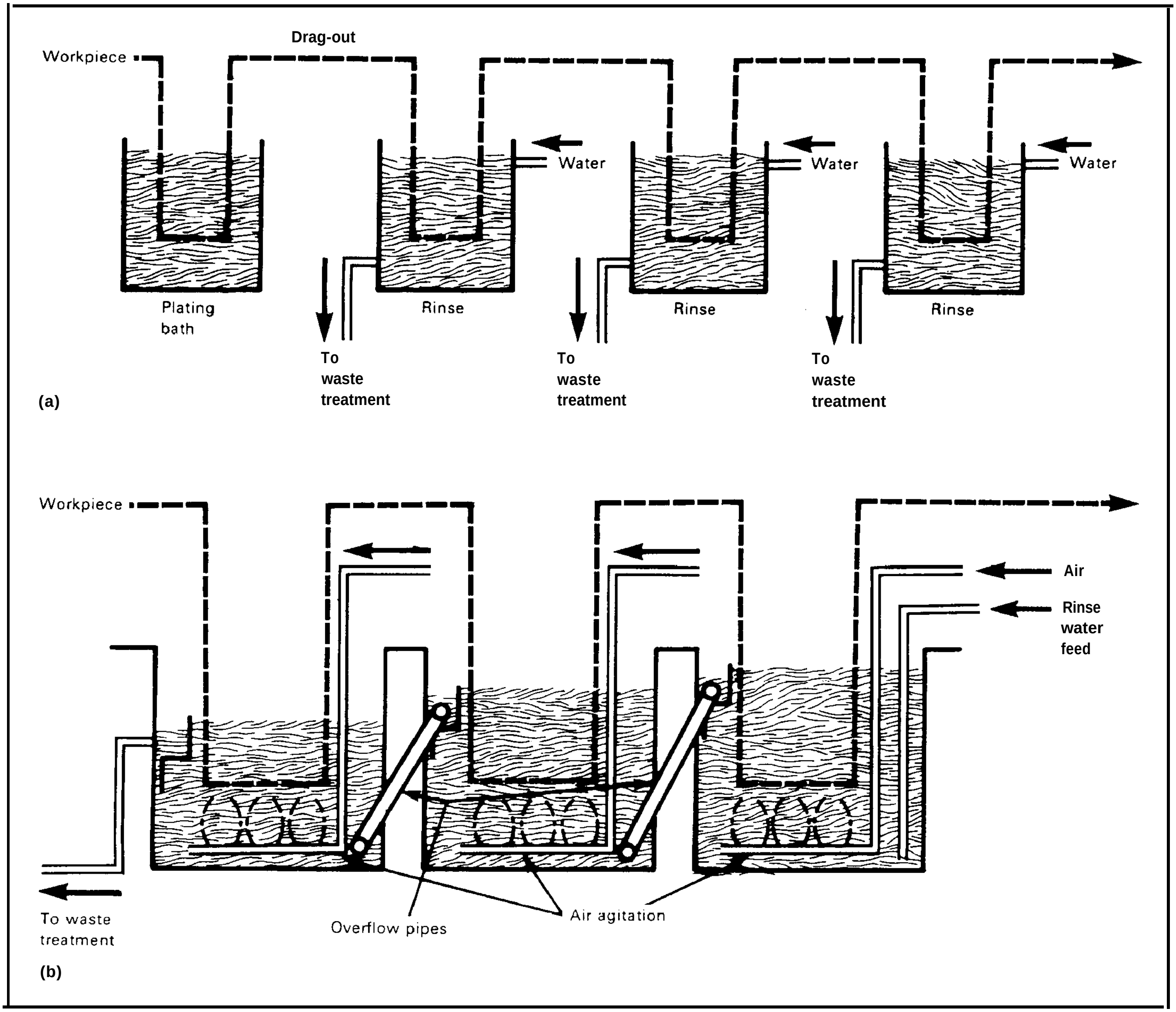


Figure 3.

Three-Stage Rinse Systems: (a) Parallel and (b) Series With Outboard Arrangement

For two parallel rinse tanks:

$$Q = \left[\frac{(84{,}626)(0.013)^2}{50}\right]^{1/2}$$

0.54 gal/min per rinse tank, or 1.08 gal/rein total flow

For three parallel rinse tanks:

$$Q = \left[\frac{(84{,}626)(0.013)^3}{50}\right]^{1/3}$$

=0.16 gal/min per rinse tank, or 0.48 gal/min total flow

Using a series, or countercurrent, rinse tank arrangement, the plater can achieve even greater water savings than with the parallel system.
With the series feed (Figure 3b), water flows into the rinse tank farthest away from the plating tank and moves toward the rinse tank closest to the plating tank either by gravity or by pumping. The workpiece is dipped in the least pure water first and in the cleanest water last.

A conductivity probe can be used with a series rinse system to ensure efficient operation. This water-saving device controls a conductivity cell, which measures the level of dissolved solids in the rinse water and, when the level reaches a preset minimum, shuts a valve interrupting the fresh water feed.

When the concentration of dissolved solids builds up to the maximum allowable level, the conductivity probe opens the valve. The probe is especially valuable with an irregular or varied work sequence and probable fluctuations in the level of dissolved salts in the rinse system.

The quantity of chemicals entering the final rinse will be significantly smaller than that entering a single-tank rinse system. The amount of rinse water required for dilution will be reduced the same degree.

Another equation can be applied to solve for the required flow with series rinsing.

$$Q = [(C_p/C_n)^{1/n} + 1/n]\theta \qquad (4)$$

The use of Equation 4 is illustrated in the following example. Using the operating parameters from the sample problem following Equation 2, determine the water flow rate necessary to obtain a rinsing concentration of 50 mg/L with two series tanks and with three series tanks.

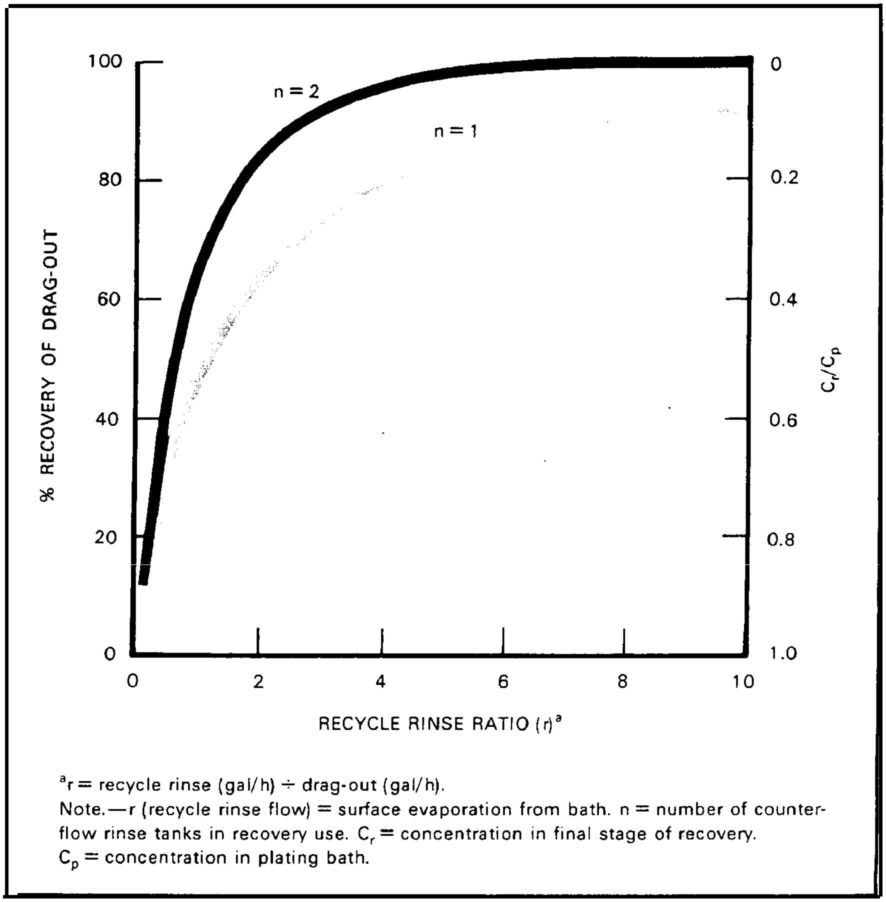
For two series rinse tanks

$$Q = [(84{,}626/50)^{1/2} + 1/2]0.013$$
$$= 0.54 \text{ gal/min}$$

For three series rinse tanks:

$$Q = [(84{,}626/50)^{1/3} + 1/3]0.013$$
$$= 0.16 \text{ gal/min}$$

A rinse tank arrangement employing a drag-out tank (Figure 2) is another application of multiple rinse tanks. This arrangement is almost always associated with the recovery of drag-out solution; therefore, it is only applicable to rinsing following plating baths where the bath is of significant value.



[a] r = recycle rinse (gal/h) ÷ drag-out (gal/h).

Note.—r (recycle rinse flow) = surface evaporation from bath. n = number of counterflow rinse tanks in recovery use. C_r = concentration in final stage of recovery. C_p = concentration in plating bath.

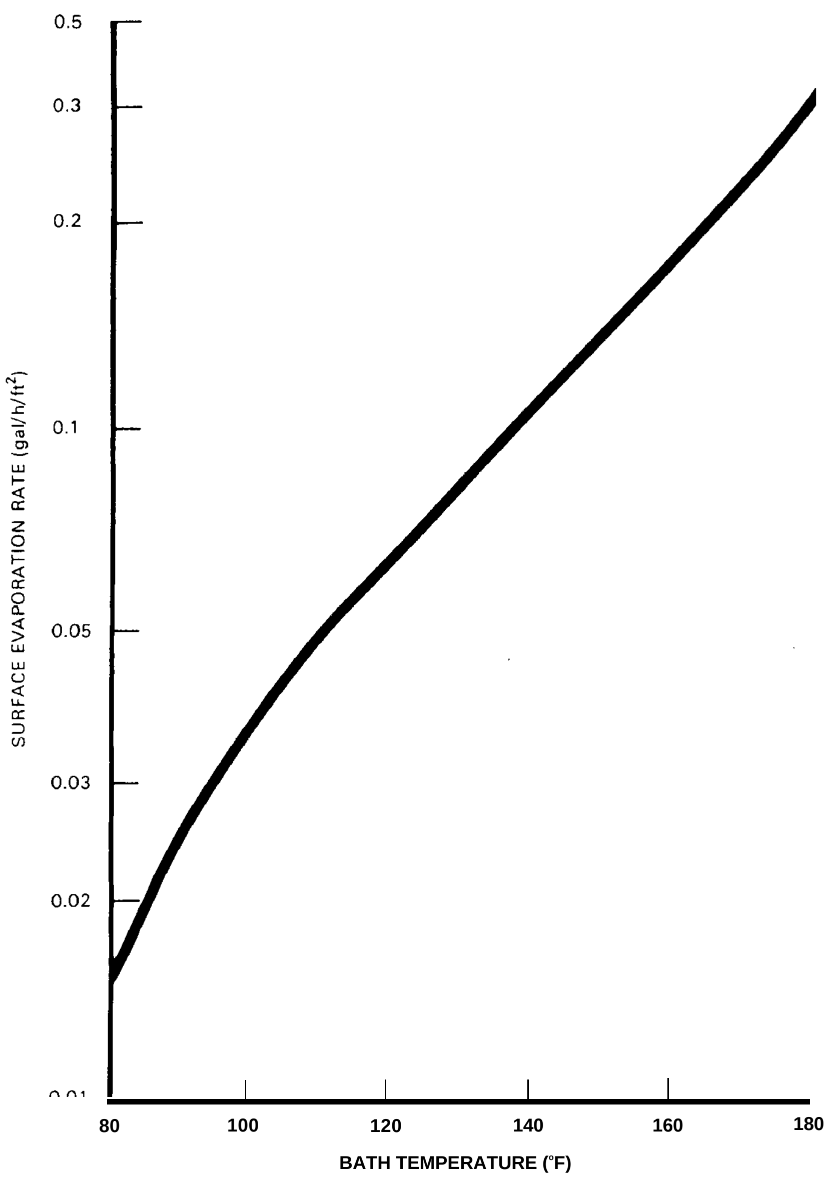
Figure 4.

Percentage of Drag-Out Recovery With Rinse-and-Recovery System

The use of drag-out tanks usually results in less water savings than does parallel or series rinsing. The operational procedure used with drag-out tanks is responsible for this effect. The rinse water in the drag-out tank increases in plating salts concentration until a portion is returned to the plating bath to compensate for evaporative losses. The concentration of salts in the drag-out tank can reach as high as 75 percent of the plating bath concentration. Consequently, a significant water flow in the rinse following the drag-out tank would be necessary to meet the maximum allowable concentration.

Figure 4 can be used to determine flow rates with drag-out recovery. The percentage recovery of drag-out is first defined as a function of the recycle ratio, r, which is the volume of recycled rinse divided by the volume of drag-out. The recycle rinse rate in the recovery rinse tanks is equal to the evaporation rate. Evaporation rates can be figured using Figure 5. Equation 2 can be used to determine the required water rates for the final rinse once the concentration in the final rinse is known.

Figure 4 is used in the following example. Using the operating parameters from the sample problem following Equation 2 and a surface evaporation rate of 3 gal/h (1 1 L/h), determine the water flow necessary in the free-flowing rinse to obtain a rinsing concentration of 50 mg/L using a single drag-out tank (as in Figure 2) and with a two-stage drag-out tank.



Note. —Ambient conditions are 75°F, 75% relative humidity. Plating solution is 95% mole fraction H_2O.

Figure 5.

Surface Evaporation Rate From Plating Baths With No Aeration

The recycle ratio would be:

$$\frac{3\ \text{gal/h}}{0.013\ \text{gal/min} \times 60\ \text{min}} = 3.8$$

From Figure 4, a one-stage recovery rinse and recycle system would reclaim 78 percent; a two-stage system would reclaim 97 percent. At these recovery rates, the concentration ratios are 0.21 and 0.05, respectively. Because the plating bath concentration is 84,626 mg/L, the concentration entering the final rinse is 0.21 X 84,626 = 17,772 mg/L for a single drag-out tank and 0.05 X 84,626 = 4,231 mg/L for a two-stage system.

Applying Equation 2, using the concentration of the last drag-out tank as C_P, the required rinse rates would be:

$$Q_1 = 0.013(17{,}772/50)$$
$$= 4.6\ \text{gal/min}$$
$$Q_2 = 0.013(4{,}231/50)$$
$$= 1.1\ \text{gal/min}$$

A relatively new. application of multiple rinse tanks is the drag-in/drag-out configuration (Figure 6). With the drag-in/drag-out system, the rinse tank preceding the plating bath (drag-in tank) is connected to the recovery rinse (drag-out tank) following the bath; the recovered drag-out solution is circulated by a pump. The concentrations of salts in the drag-in and drag-out tanks remain about equal. When a rack or barrel is processed, it drags in plating solution to the plating tank, thereby increasing recovery.

The drag-in/drag-out system finds application with plating baths that have a low evaporation rate. The recycle ratio, which determines recovery efficiency, is calculated as the volume of recycled rinse plus the volume of drag-out divided by the volume of drag-out. The recycle ratio, therefore, is greater with a drag-in/drag-out system than a common recovery tank. If the evaporation rate is low, the difference between the recycle ratios for common recovery and drag-in/drag-out systems is significant. When evaporation ratios are high, the difference is less.

To illustrate the benefits of a drag-in/drag-out system, consider adding a drag-in tank to the recovery system just discussed. The recycle ratio would become:

$$r = \frac{3\ \text{gal/h} + 0.78\ \text{gal/h}}{0.78\ \text{gal/h}} = 4.8$$

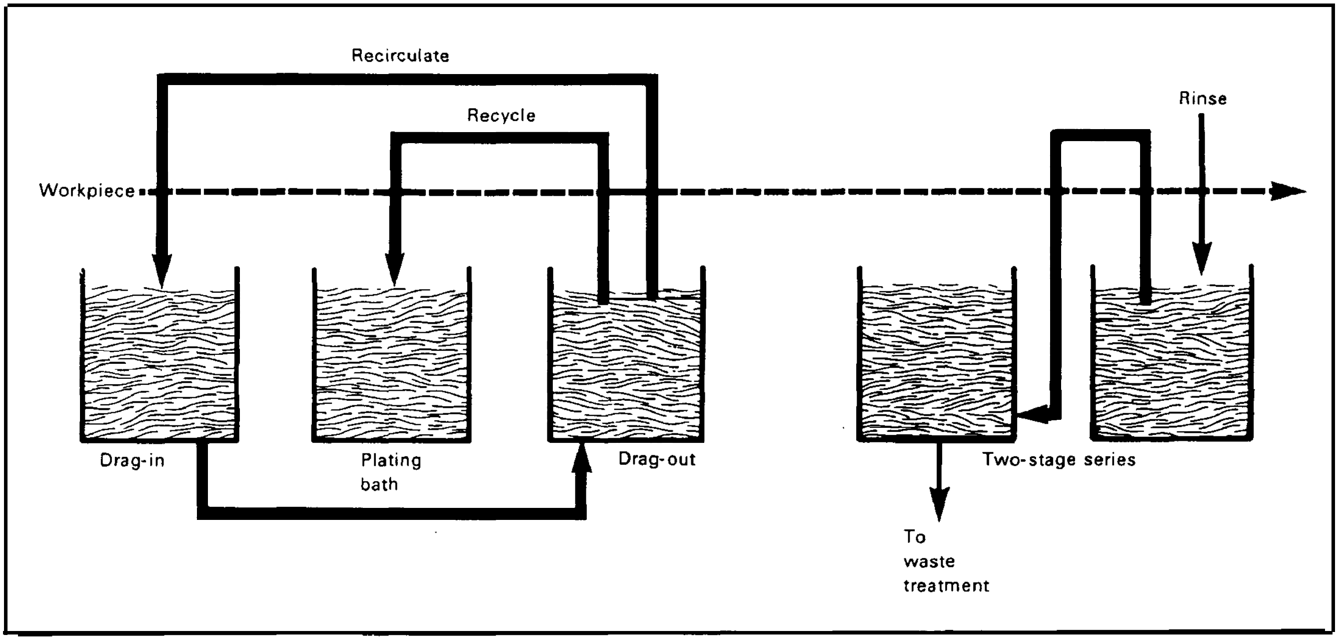


Figure 6.

Drag-In/Drag-Out Recovery Arrangement

From Figure 4, a one-stage recovery rinse and recycle system would reclaim 83 percent. The increase in percentage recovery is only 5 percentage points. Considering the cost of an additional tank and pump, this change is not likely to be cost effective,

If the evaporation rate were only 1 gal/h (4 L/h), the recycle ratio for a recovery rinse system would be:

$$r = \frac{1 \text{ gal/h}}{0.78 \text{ gal/h}} = 1.28$$

For a drag-in/drag-out system, the recycle ratio would be:

$$r = \frac{1 \text{ gal/h} + 0.78 \text{ gal/h}}{0.78 \text{ gal/h}} = 2.28$$

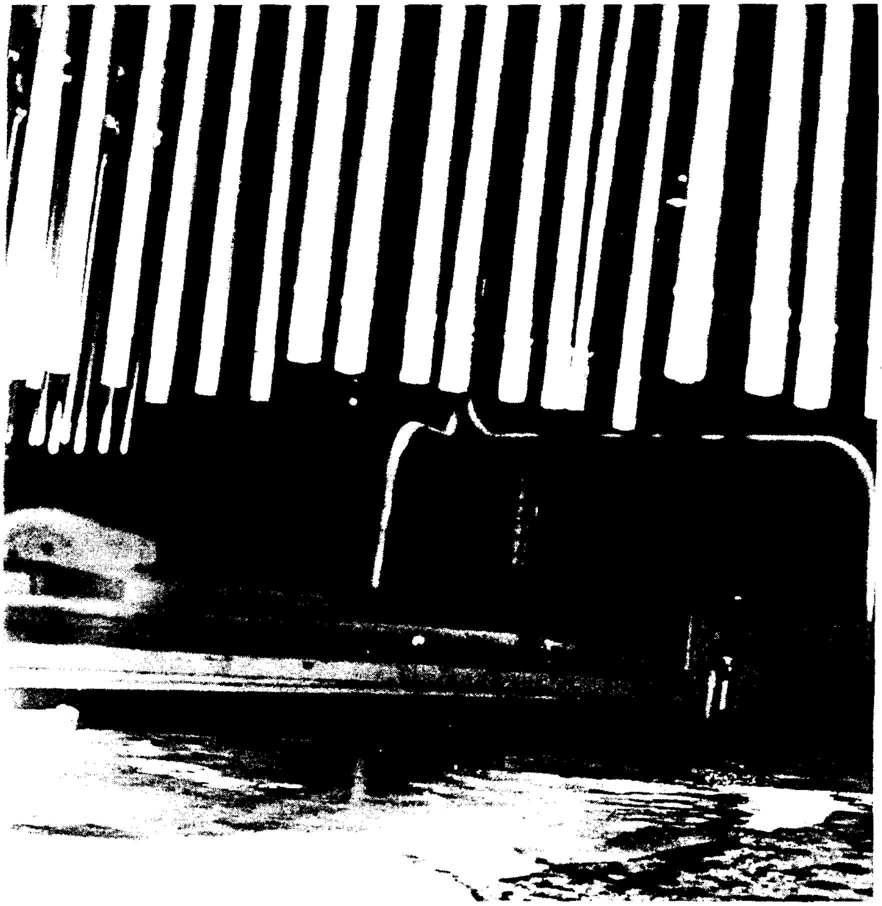
The percentage recovery, in this case, would increase from 51 percent to 68 percent by adding a drag-in tank.

Chemical Rinsing. The technique of chemical rinsing has been used by the metal finishing industry for many years. One of its earliest applications was to eliminate staining from chromium solution, which is notoriously difficult to rinse. By simply making the first rinse after chromium plate a stagnant rinse containing sodium bisulfite, the drag-in of hexavalent chromium was converted to trivalent chromium. The rinsability of the workpiece in the second rinse was improved considerably by changing the chemical nature of the film on the workpiece in the stagnant rinse and by reducing film concentrations before attempting to rinse by diffusion. The same principles are frequently employed in “neutralizing” dips.

The application of chemical rinsing to plant effluent treatment, known in the industry as integrated waste treatment, has been described by Lancy[11] and Pinner.[12] Aside from the environmental benefits, this type of chemical rinsing also prevents the majority of heavy metal solids formed in the chemical rinse from reaching the succeeding water rinses by removing these materials in an external settling vessel. Removal of these solids is accomplished by flowing the chemical rinse solution to a treatment reservoir. The overflow from the reservoir is pumped back to the rinse tanks, forming a complete closed-loop system.

Chemicals are added to the reservoir to provide a controlled excess of reagent in the solution. The reservoir acts as a combined reaction and settling tank. Because of the presence of a controlled excess of reagents in the chemical rinse tank, toxic materials and heavy metals are removed from the metal finishing sequence and are prevented from entering the subsequent water rinse. At the same time, rinsing is improved because the diffusion layer, which is present during conventional water rinsing, is broken down by the chemical reaction.

Rinsing Recovery Systems. The information provided on drag-out and rinsing principles can be formulated into a strategy for simple recovery systems using multiple rinse tanks and a minimum of additional equipment. Examples will be presented for various plating applications and considerations, such



Stationary drain board under rack passing between tanks

as space Imitations. Before waste treatment equipment is installed, the implementation of these systems will generate substantial savings in plating chemicals and water. After waste treatment equipment is Installed, the system can continue to operate and will provide further benefits by reducing waste treatment costs.

The tank arrangement in Figure 2, which consists of a drag-out tank followed by a flow-through rinse tank, is the simplest recovery system. The drag-out rinse collects a significant portion of the process solution carried on the parts, rack, or barrel. Periodically, the strong solution in the drag-out tank is returned to the plating tank. The volume returned is limited to the volume made available in the process tank by evaporation,

The efficiency of a drag-out tank recovery system can be improved significantly by the addition of a rinse tank. The additional tank could be used as a second recovery tank to decrease chemical losses further, or it could be used in a series arrangement by connecting it with the overflow rinse (Figure 3b). The latter change would provide a water savings but would not reduce chemical losses.

Various other rinsing configurations could be developed by adding tanks. The choice of a best arrangement is difficult because of the tradeoffs involved between further reducing chemical losses and further reducing the rinse flow rate. Obviously, the value of the lost chemicals is a significant cost. Chemical losses also result in additional rinse water and waste treatment chemical requirements and more sludge.[13]

Although complex, the evaluation and selection of a multiple rinse tank system can be accomplished by analyzing each rinsing configuration. Such an evaluation involves using the equations and graphs presented in this section and comparing cost factors, such as water, sewer, and waste treatment. The results of the evaluation will enable the plater to determine whether a multiple rinse tank arrangement is beneficial and to identify the most appropriate configuration. It is important to find this optimal point because the space needed for additional rinse tanks is limited.

The application of the complex rinsing evaluation will be presented through the use of examples, Two widely used electroplating baths—a concentrated chromium and a Watts nickel bath—will be considered. These baths were selected because they differ with respect to two important factors affecting the selection of an optimal rinsing configuration: operating temperature and bath concentration. The concentrated chromium bath normally is operated at 110° F (43” C) with a chromium concentration of 200,000 mg/L. The Watts nickel bath normally is operated at a temperature of 140° F (60° C) with a nickel concentration of 85,000 mg/L. The higher evaporation rate and lower plating bath metal concentration make nickel a better candidate for recovery. A summary of the operating conditions for the two baths is presented in Table 3.

The cost evaluation of complex rinsing systems must include all significant operating and investment costs that are affected by the inclusion of additional rinse tanks and either flow or chemical loss reduction. Some site-specific costs, such as plating room rearrange-

Table 3.

Operating Parameters for Watts Nickel and Concentrated Chromium Baths

Parameter	Bath	
	Watts nickel	Concentrated chromium
Concentration (mg/L)	85,000	200,000
Operating temperature (IF)	140	110
Surface area of plating tank (ft^2)	25	25
Maximum allowable concentration in final rinse (mg/L)	50	35

Table 4.

Cost Variables for Evaluating Rinsing Options

Parameter	cost
Water and sewer ($/1,000 gal wastewater)	2.00
Additional rinse tanks, 10 yr depreciation ($/yr/tank)[a]	240
Treatment chemicals	
Chromium (Cr):[b]	
$/lb Cr.	0.41
$/1,000 gal wastewater.	0.28
Nickel (Ni):[c]	
$/lb NI.	0.18
$/1,000 gal wastewater	0.21
Sludge disposal:[d]	
$/lb Cr.	1.48
$/lb Ni.	1.15
Plating chemicals:	
$/lb Cr.	4.20
$/lb Ni.	6.35
De-ionized water, 5-yr depreciation ($/yr)	1.080

[a] Cost is for flanged, open-top, mild steel tank lined with polyvinyl chloride; cost does not include installation, which is highly site specific.

[b] Treatment chemicals for chromium: sulfur dioxide, 2 lb/lb Cr: sulfuric acid. 0.2 lb/1000 gal wastewater; sodium hydroxide (NaOH), 1.5 lb/1,000 gal wastewater; NaOH, 2.3 lb/lb Cr flocculent, 0.1 lb/1,000 gal wastewater,

[c] Treatment chemicals for nickel: NaOH, 1.0 lb/1,000 gal wastewater; NaOH, 2.0 lb/lb Ni: flocculent, 0.1 lb/1,000 gal wastewater.

[d] $0.25/gal at 4% solids by weight,

Note. —All costs, except those for treatment chemicals, are in 1981 dollars. Costs for treatment chemicals, originally in 1979 dollars, were updated to reflect average 1980 prices using the Monthly Labor Review Producer Price Index for industrial commodities,

SOURCE: U.S. Environmental Protection Agency, *Environmental Regulations and Technology: The Electroplating Industry,* EPA 625/10-80-001, Aug. 1980.

ment, must be considered in the analysis. Because these costs will vary from shop to shop, however, they will not be included in this analysis. Instead, only those costs that are common to all shops will be considered (Table 4).

The actual cost for individual plants will differ from those used in the analysis. For instance, the water and sewer cost ($2/1 ,000 gal, in 1981 dollars) varies considerably among municipalities. Platers are urged to insert the costs that best reflect their situations, including any additional costs, before proceeding with their analyses.

For the two examples, 15 different rinsing configurations were considered (Figure 7). Configuration 1 is the basic single overflow rinse. Configurations 2 through 4 are the three possible options using two rinse tanks. Configurations 5 through 9 use three rinse tanks, and Configurations 10 through 15 employ four rinse tanks.

Each of the 15 configurations can be analyzed using the methods presented earlier in this report. Examples already have been presented for Configurations 1 through 7. Such arrangements as Configuration 8 are more complex, but they can be divided into simpler problems and analyzed using Equations 2 and 4 and Figure 4. The following example will illustrate this method.

A Watts nickel plating solution contains a nickel concentration of 85,000 mg/L The drag-out rate is 1 gal/h (4 L/h), or 0.017 gal/min (0.063 L/min), and the evaporation rate (Figure 5) is 2.75 gal/h (1 0.41 L/h). Determine the percentage of nickel solution that is saved and the flow required to meet a maximum allowable nickel concentration criterion of 50 mg/L in the final rinse using Configuration 8.

First, calculate the recycle ratio:

$$r = \frac{\text{recycle rinse}}{\text{drag-out}} = \frac{2.75}{1} = 2.75$$

Then, using Figure 4, find the percentage recovery for a single-stage drag-out tank, which is 77 percent. At this recovery rate, the concentration ratio is 0.23. Now calculate the concentration entering the final rinse:

0.23 X 85,000 mg/L = 19,550 mg/L

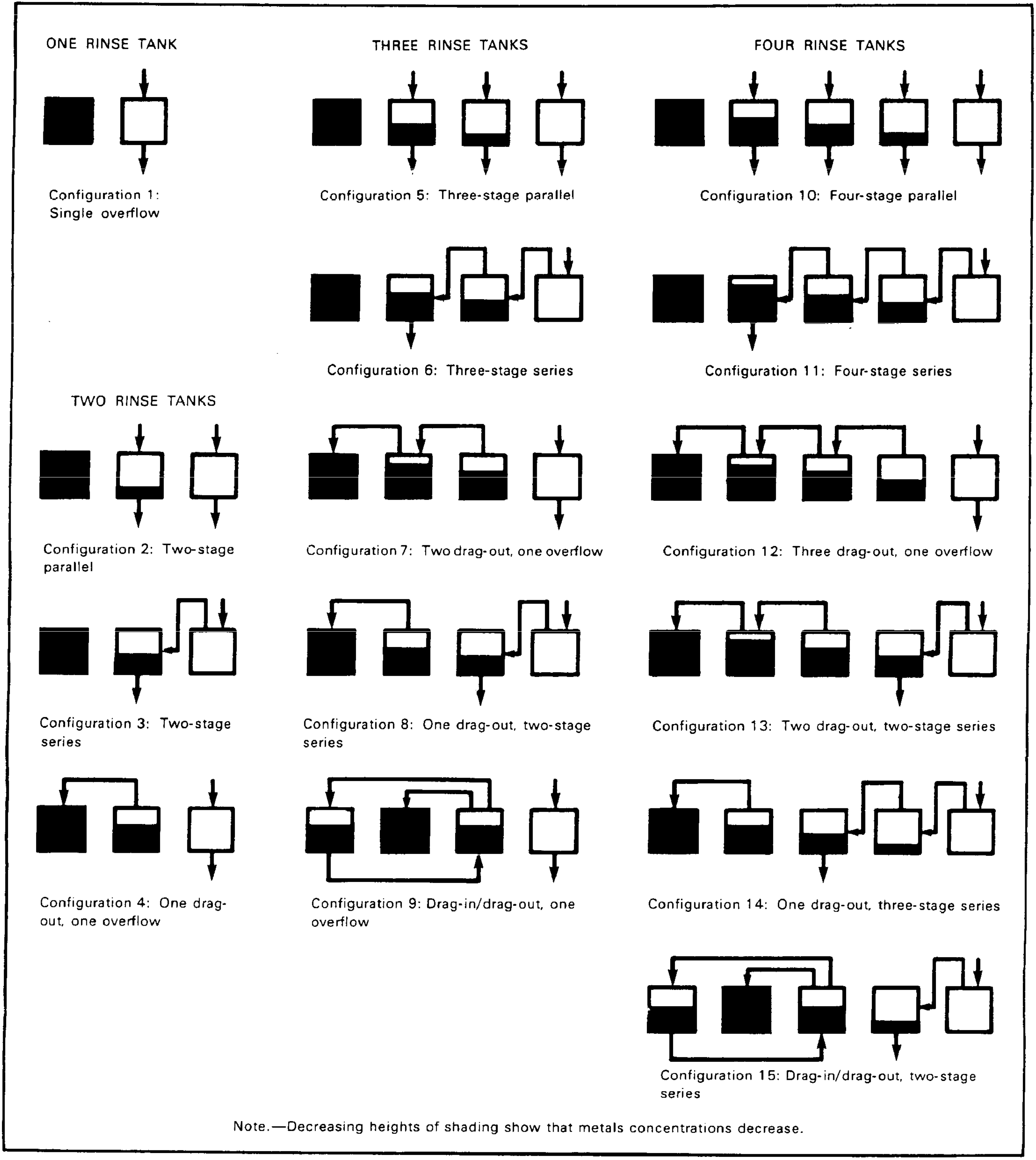


Figure 7.

Rinsing Configurations

Table 5.

Evaluation of Chromium and Nickel Rinsing Systems

Configuration	I-gal/h drag-out			Z-gal/h drag-out		
	Water use		Plating chemicals lost (lb/yr)[a]	Water use		Plating chemicals lost (lb/yr)[a]
	gal/rein	1,000 gal/yr		gal/rein	1,000 gal/yr	
Chromium plating						
1	97.1	24,236	6,950	188.6	47,074	13,900
2	2.6	649	6,950	5.0	1,248	13,900
3	1.3	324	6,950	2.5	624	13,900
4.	46.6	11,638	3,336	127.0	31,699	9,313
5	0.9	225	6,950	1.5	374	13,900
6.	0.2	50	6,950	0.3	75	13,900
7	27.2	6,789	1,946	102.0	25,459	7,500
8	0.9	225	3,336	2.1	524	9,313
9	28.6	7,131	2,065	80.0	19,968	5,838
10.	0.5	125	6,950	1.0	250	3,900
11.	0.1	25	6,950	0.1	256	13,900
12	16.5	4,133	1,204	84.0	21,080	6,151
13.	0.7	175	1,946	1.9	474	7,500
14.	0.3	75	3,336	0.6	150	9,313
15.	0.7	175	2,085	1.6	412	5,838
Nickel plating						
1.	28.9	7,213	2,950	56.6	14,127	5,900
2.	1.4	349	2,950	2.7	674	5,900
3.	0.7	175	2,950	1.4	349	5,900
4,	6.4	1,587	650	26.9	6.714	2,484
5	0.6	150	2,950	1.6	400	.5.900
6	0.2	50	2,950	0.2	50	5,900
7	2.0	500	177	15.7	3,918	1,383
8	0.4	100	650	1,0	250	2,484
9	6.2	1,555	649	17,6	4,383	1,829
10.	0.4	100	2,950	0.7	176	5,900
11.	0.1	25	2,950	0.1	25	5,900
12	0.9	225	91	8.2	2.071	859
13.	0.3	75	177	0.7	174	1,383
14.	0.2	50	650	0.3	75	2,484
15.	0.3	75	649	0.8	195	1,829

[a] Pounds of metal (chromium or nickel) per *year.*

Next, apply Equation 4, using 19,550 as C_P:

$$Q = [(19{,}550/50)^{1/2} + 1/2](1/60)$$
$$= (19.8 + 0.5)(0.017)$$
$$= (20.3)(0.017)$$
$$= 0.35 \text{ gal/min}$$

Using a similar approach *of* breaking down the complex problem into two lesser problems, the flow and percentage recovery of most rinsing systems can be determined. After finding these parameters, a cost analysis can be performed using the data in Table 4, and the optimal configuration can be identified.

To illustrate the use of the cost analysis, the 15 configurations have been analyzed for a concentrated chromium bath and a Watts nickel bath. The operating parameters for the baths were shown in Table 3. Two analyses are performed for each bath. The first assumes a drag-out rate of 1 gal/h (4 L/h) and the second assumes a drag-out rate of 2 gal/h (8 L/h). The results are presented in Tables 5 through 7.

The following conclusions can be drawn from the cost analysis of the chromium and nickel rinsing systems:

- Single overflow rinses require extremely high flow rates to meet good rinsing criteria, even at low drag-out rates.

Table 6.

Chromium Rinsing System Costs

Configuration	Flow rate (gal/min)	cost($)							
		Water and sewer at $2/1,000 gal	Additional rinse tanks at $240/tank	Treatment chemicals at		Sludge at $1.48 /lb Cr	Plating chemicals lost at $4.20/lb Cr	De-ionized water	Total
				$0.41/lb Cr	$0.28/1,000 gal wastewater				
1-gal/h drag-out									
la.	97.1	48,472	0	2,850	6,786	10,286	29,190	0	97,584
2	2.6	1,298	240	2,850	182	10,286	29,190	0	44,046
3	1.3	648	240	2,850	91	10,286	29,190	0	43,305
4[a].	46.6	23,276	240	1,368	3,259	4,937	14,011	1,080	48,171
5	0.9	448	480	2,850	63	10,286	29,190	0	43,317
6	0.2	100	480	2,850	14	10,286	29,190	0	42,920
7[a].	27.2	13,578	480	798	1,901	2,880	8,173	1,080	28,890
8	0.9	450	480	1,368	63	4,937	14,011	1,080	22,389
9[a].	28.6	14,262	480	855	1,997	3,086	8,757	1,080	30,517
10	0.5	250	720	2,850	35	10,286	29,190	0	43,331
11	0.1	50	720	2,850	7	10,286	29,190	0	43,103
12	16.5	8,250	720	494	1,155	1,782	5,057	1,080	18,538
13.	0.7	350	720	798	49	2,880	8,173	1,080	14,050
14	0.3	150	720	1,368	21	4,937	14,011	1,080	22,287
15	0.7	350	720	855	49	3,086	8,757	1,080	14,897
2-gal/h drag-out									
1	188.6	94,148	0	5,699	13,181	20,572	58,380	0	191,980
2	5.0	2,496	240	5,699	349	20,572	58,380	0	87,736
3	2.5	1,248	240	5,699	175	20,572	58,380	0	86,314
4.	127.0	63,398	240	3,818	8,876	13,783	39,115	1,080	130,310
5	1.5	748	480	5,699	105	20,572	58,380	0	85,984
6	0.3	150	480	5,699	21	20,572	58,380	0	85,302
7.	102.0	50,918	480	3,075	7,129	11,100	31,500	1,080	105,282
8	2.1	1,048	480	3,818	147	13,783	39,115	1,080	59,471
9’	80.0	39,937	480	2,393	5,591	8,640	24,520	1,080	82,641
1 o.	1.0	500	720	5,699	70	20,572	58,380	0	85,941
11	0.1	50	720	5,699	7	20,572	58,380	0	85,428
12	84.0	42,160	720	2,522	5,902	9,103	25,834	1,080	87,321
13	1.9	948	720	3,075	133	11,100	31,500	1,080	48,556
14.	0.6	300	720	3,818	42	13,783	39,115	1,080	58,858
15	1.6	842	720	2,393	115	8,640	24,520	1,080	38,310

[a] High rinse rate required with this configuration to meet maximum allowable concentration in the final rinse (35 mg/L Cr) may preclude its use.

Note. —All costs, except those for treatment chemicals, are in 1981 dollars. Costs for treatment chemicals, originally in 1979 dollars, were updated to reflect average 1980 prices using the Monthly Labor Review Producer Price Index for industrial commodities.

- Multiple rinse tank arrangements can provide significant cost savings.
- With low recycle ratios (1.37 or less), drag-out recovery is impractical because of high water requirements, unless three or more drag-out tanks are used (see upper half of Table 6, Configuration 11) or series rinsing follows drag-out (see upper half of Table 6, Configurations 12 and 13).
- With recycle ratios of 2.75 or greater, all additional tanks should be used as drag-out tanks rather than in parallel or series arrangements.
- Drag-in/drag-out systems usually must include series rinsing. These systems become cost effective with recycle ratios at or below 1.25 (see lower half of Table 6, Configuration 15).

Plating baths that operate at lower temperatures than those described in the foregoing examples have lower evaporation rates and offer fewer opportunities for rinse recovery. If the bath can be operated at an elevated temperature, even though it is not required, the cost of added energy usually will be more

Table 7.

Nickel Rinsing System Costs

Con fig-uration	Flow rate (gal/rein)	cost ($)							
		Water and sewer at $2/1,000 gal	Additional *rinse* tanks at $240/tank	Treatment chemicals at		Sludge at $1.15 /lb Ni	Plating chemicals lost at $6.35/lb Ni	De-ionized water	Total
				$0.18/lb Ni	$0.21/1,000 gal wastewater				
I-gal/h drag-out									
1’	28.9	14,426	0	531	1,515	3,393	18,733	0	38,598
2	1.4	698	240	531	73	3,393	18,733	0	23,668
3	0.7	350	240	531	37	3,393	18,733	0	23,284
4	6.4	3,174	240	117	333	748	4,127	1,080	9,819
5	0.6	300	480	531	3	2 3,393	18,733	0	23,469
6	0.2	100	480	531	11	3,393	18,733	0	23,248
7	2.0	1,000	480	32	105	204	1,123	1,080	4,024
8	0.4	200	480	117	21	748	4,127	1,080	6,773
9	6.2	3,110	480	117	327	748	4,127	1,080	9,989
10	0.4	200	720	531	21	3,393	18,733	0	23,598
11	0.1	50	720	531	5	3,393	18,733	0	23,432
12	0.9	450	720	16	47	104	578	1,080	2,995
13	0.3	150	720	32	16	204	1,123	1,080	3,325
14	0.2	100	720	117	11	748	4,127	1,080	6,903
15	0.3	150	720	117	16	748	4,127	1,080	6,958
Z-gal/h drag-out									
1[a]	56.6	28,254	0	1,060	2,967	6,785	37,465	0	76,531
2	2.7	1,294	240	1,060	142	6,785	37,465	0	46,986
3	1,4	698	240	1,060	73	6,785	37,465	0	46,321
4[a]	26.9	13,428	240	447	1,410	2,856	15,773	1,080	35,234
5	1.6	800	480	1,060	84	6,785	37,465	0	46,674
6	0.2	100	480	1,060	11	6,785	37,465	0	45,901
7[a]	15,7	7,836	480	249	823	1,590	8,782	1,080	20,840
8	1.0	500	480	447	53	2,856	15,773	1,080	21,189
9.	17.6	8,766	480	329	920	2,104	11,614	1,080	25,293
10, ...,	0.7	348	720	1,060	37	6,785	37,465	0	46,415
11, ...	0.1	50	720	1,060	5	6,785	37,465	0	46,085
12	8.2	4,142	720	155	435	987	5,455	1,080	12,974
13 . . .	0.7	348	720	249	37	1,590	8,782	1,080	12,806
14	0.3	150	720	447	16	2,856	15,773	1,080	21,042
15.	0.8	390	720	329	41	2,104	11,614	1,080	16.278

[a] High rinse rate required with this configuration to meet maximum allowable concentration in the final rinse (5O mg/L Ni) may preclude its use.

Note, —All costs, except those for treatment chemicals. are in 1981 dollars, Costs for treatment chemicals, originally in 1979 dollars, were updated to reflect average 1980 prices using the Monthly Labor Review Producer Price Index for industrial commodities,

than offset by the benefits of recovery. Drag-in/drag-out systems offer perhaps the best situation for implementing the techniques presented here when the recycle ratio is low. Nevertheless, when the evaporation rate is very low, the most cost-effective solution may be concentration of the drag-out rinse itself, such as by an evaporator or by ion exchange, before replacement in the plating tank.[14]

Plant Assessment

Procedures

A plant assessment is the initial step in a pollution control program, It involves a thorough analysis of the operations of a metal finishing plant that relate to pollutant sources and water use. The information generated during a plant assessment is used in evaluating the applicability of in-plant changes for reducing chemical loss and water use.

A plant assessment includes the following steps:

- Inspect the plating room layout.
- Review plant operating practices.
- Examine process water use.
- Conduct sampling and laboratory analysis to characterize waste streams and to determine drag-out rates.
- Identify the frequency, volume, and characteristics of batch dumps.

A plant assessment can be performed by the plater or by a qualified engineering consultant. Although the plater has the advantage of thoroughly knowing the manufacturing process, the consultant can frequently provide a fresh and impartial view of the plant and often can identify overlooked possibilities. If the plater performs the assessment, a laboratory can be hired to analyze the samples. Most laboratories qualified to perform the analyses charge between $12 and $20 for each heavy metal parameter that is analyzed and from $20 to $40 for cyanide analysis.' When the plant assessment is performed by a consultant, the complete service ranges from $4,000 to $10,000, depending on the size and complexity of the shop and the extent of the survey and subsequent evaluation.

In nearly every case, the benefits of a plant assessment will far outweigh the amount of time and money expended. Usually the assessment will be repaid in less than 1 year through savings in chemicals and water.

Inspect Plating Room Layout. The first step in a plant assessment is relatively simple; it involves the preparation of drawings showing the layout of the plating room(s). For many platers, this task will have been performed already.

The drawings should be made to scale showing the location of all relevant equipment and tanks. Each tank should be numbered and labeled with its contents (for example, Tank 1, soak cleaner; Tank 2, rinse). Individual plating lines should be identified, such as zinc barrel and chrome plate rack. Also, water feed lines, gutters, sumps, and sewer lines should be indicated. On the water lines, all control valves and flow regulators should be identified.

Review Plant Operations. Al I operations of the plating room that relate to chemical or water use—including the plating sequences for each plating line—should be reviewed and documented. Often sequences will vary on a particular line because of differences in plating requirements and specifications. Each major variation should be listed.

Estimates of production for each line should be developed. Production can be measured either by hours of operation or by production units, such as number of square feet (square meters) plated or number of parts, racks, or barrels to pass through a particular plating line or sequence.

Other, more specific information that is needed on the plating operation can be gathered through observation during manufacture. If automatic lines are used in plating, rinsing and draining times should be measured. If manual hoist or hand

---

'Costs in this section are given in 1981 dollars, except for treatment costs, which are in 1980 dollars.

lines are used, the efficiency of the operators in rinsing and draining should be noted. Also, if the tank arrangement requires that racks or barrels be transported between tanks that are not located next to one another, the relative amount of dripping onto the floor should be recorded.

Table 8.

Process Water Survey Sample

Water use	Plating line				
	Barrel	Anodizing	Zinc rack automatic	Hoist	Still
Gallons per minute:					
Metered	21.5	10.0	24.0	23.6	9.5
Measured	20.0	9.5	22.5	22.0	8.9
Difference:					
Number	1.5	0.5	1.5	1.6	0.6
Percent	7	5	6.25	6.8	6.3
Gallons per 8-h shift:					
Metered	10,320	4,800	11,520	11,328	4,560
Measured	9.600	4,560	10,800	10,560	4.272
Difference:					
Number	720	240	720	768	288
Percent	7	5	6.25	6.8	6.3

Examine Process Water Use. A survey of water use is a basic step in the plant assessment because the capital costs of water pollution abatement equipment depend primarily on the volume of water used. Wherever water is used, therefore, accurate measurements must be taken. To increase the accuracy of these data, the plater should start by reviewing past water bills to determine an expected water use rate in gallons (liters) per day and per minute. The plater should then measure and record the actual water use at each process step. Because most of the water at a plating shop is used in rinsing, rinse flow rates must be measured. Then, a comparison of actual flow versus metered flow (that is, water bills) can be made. This comparison is referred to as a water balance.

Table 8 shows an example of a water balance in which the plant had individual water meters installed on each line, (Whereas many plants have meters only at the water source, individual meters should be considered for their value in monitoring and controlling water use.) The actual, or measured, flow rates are within an acceptable limit (15 percent or less), indicating that there are no unforeseen water losses,

Often, however, measured water use differs considerably from water bills. One potential source of variance is faulty water meters. This problem can be resolved by requesting the local water authority to certify the water meter. A discrepancy is more likely to result from periodic water use for washing down floors or simply from hoses being allowed to run without regard to waste.

Water uses other than rinsing also may contribute to a difference in measured versus metered flow. For many plating shops, these non-rinsing uses of water include fume scrubbers, water-cooled rectifiers, heat exchangers, boilers, heating and cooling coils, air conditioners, and welders.

Water flow rate measurement at rinse tanks can be performed simply using one of several methods. First, a bucket with a predetermined volume can be set under the overflow from a rinse tank, provided rinse water is discharged through an accessible vertical pipe. The time it takes to fill the bucket is measured and the flow rate calculated. Often this method cannot be used because of the location or construction of the discharge pipe.

An alternative for measuring water flow rate is to shut off the incoming water and remove a specific amount of water from the rinse tank [5 to 10 gal (19 to 38 L)]. The water is then turned back on, and the time it takes the water level in the tank to return to its overflow height is measured,

A third method of measurement involves depressing a 5-gal (19-L) bucket into the flowing rinse so that the water reaches the top of the bucket but does not enter it. This will cause 5 gal (19 L) of water to be depleted from the rinse tank immediately. Once the overflow from the rinse tank appears normal, the empty bucket should be removed and the time it takes the water to resume an overflow should be measured.

If the second or third method is employed, the test should be repeated several times and the results averaged. Averaging is recommended because it is difficult to ascertain visually the exact time at which the flow over the overflow dam or weir reaches a stabilized flow condition. It is especially important to repeat the test if the rinse tank has a high flow rate or if air spargers are used to create turbulence.

Conduct Sampling and Analysis. The usual procedure for sampling at a plating shop is to sample the final effluent, as local pollution control authorities often do. During the plant assessment, the final effluent is sampled for the same reason, that is, to determine which pollutants are not in compliance with the regulations. The effluent, however, is only one of several points for sampling and analysis during the plant assessment. Samples also should be taken of all individual rinse tanks, overflows, batch dumps, and, to some extent, plating solutions. Plating solutions are sampled when calculations of drag-out are needed. These additional samples will be used to isolate sources of pollution, to calculate chemical losses, and to evaluate the potential benefits of drag-out reduction and flow minimization techniques.

Sampling can be performed by taking a single, or grab, sample of the effluent or rinse water. A grab sample gives an instantaneous reading of the conditions of the water. If conditions are variable (for instance, if plating is intermittent, causing fluctuations in pollutant concentrations), the sample is not likely to be representative. When variability is significant, it is necessary to composite samples over a period of time (usually one sample every 15 to 30 min over a single shift or a single day) and to analyze the composite to determine the average conditions.

Compositing is recommended for samples taken of final effluent and individual rinse tanks. Grab samples will suffice for batch dumps and plating solutions.

Electroplates conducting their own plant assessments will need sampling containers. Often the *containers* can be secured through the laboratory performing the analysis. If they are not available from that source, appropriate containers can be purchased from an analytical supply house. Because the analysis will be limited to pH, metal lies, and cyanide, either plastic or glass containers can be used. The plastic containers cannot be used if trace organics are to be measured. The appropriate plastic containers are made of polypropylene or polyethylene and should have a volume of approximately 0.26 gal (1 L).

If metals are to be analyzed, it will be necessary to collect at least 0.13 gal (0.5 L). Usually this sample will be enough to analyze for the six federally regulated metallic pollutants in the common metals electroplating subcategory.[1] If cyanide is to be analyzed, an additional 0.13 gal (0.5 L) of sample must be taken and placed in a separate container. Cyanide is relatively unstable and must be “fixed” once it reaches the laboratory.

Samples should be delivered to a laboratory as quickly as possible to retain the accuracy of the analysis. Speed is especially critical with cyanide samples, which should reach the Laboratory within 24 hours.

The sample of the final effluent should be taken at a point where all rinse waters and other plating wastes are combined but before the introduction of domestic and other process wastes. Often this point is not accessible to manual sampling, so it may be necessary to rent a compositing device.

The final effluent analysis includes pH, all metals being plated, base metals, regulated metals, and cyanide. For shops plating over 10,000 gal/d (38,000 L/d), the analysis usually includes pH, chromium, copper, lead, cadmium, zinc, nickel, iron (a base metal), and cyanide; the cost of this effluent analysis usually ranges from $115 to $180.

Rinse tanks are sampled to determine whether a smaller overflow rate is possible and to isolate the sources of pollution. Also, sampling of rinses following soak cleaners and acid dips may provide data showing concentration levels of pollutants below the standards; such rinses would not need further treatment.

Because pollutant concentrations in the rinses fluctuate, a composite sample is advisable. A composite sample can be taken by running plastic tubing from a rinse tank to a collection container and placing a clamp on the tubing. By creating a siphon with the tube and controlling the flow with the clamp, a sample can be taken over the time period of a shift without constant attention. Care must be taken, however, to avoid positioning the end of the tube in a “dead” zone of the rinse tank, such as a corner. If the tank is not aerated and fully turbulent, the end of the tube should be placed in or near the overflow.

A complete analysis usually is not necessary for rinse samples because it can be assumed, based on knowledge of the manufacturing process, that some metals or cyanide are not present. By reviewing the plating operation, a significant savings in analytical work can be achieved. The analysis, however, should include any metals and cyanide if they are present anywhere on the plating line where the rinse is located, even when the rinse precedes the plating of a specific metal. Plating solution often remains on racks, especially if they are worn, resulting in contamination of process solutions, such as soak cleaners. The concentration of chromium, for instance, can build up to such a level in a soak cleaner that the rinse following the soak cleaner has a chromium concentration above 5 mg/L.

Drag-out measurements are performed at plating tanks to determine the amount of metal or cyanide contributed by these sources. This information is used to evaluate the applicability and potential benefits of drag-out minimization techniques and innovative rinsing systems.

Because drag-out volume is affected by the size and shape of the parts and racks or barrels, measurement of drag-out on a particular line with significant variability of these factors will have little meaning. Where variability is extreme, the plater should refer to typical drag-out rates found in the literature instead of producing meaningless data.

The method of drag-out measurement described in this report differs slightly from those presented by Kushner.[5] The first step in the drag-out measurement is to stop the flow in the rinse tank following the plating tank and empty its contents, If the rinse tank is a still rinse or drag-out tank, it should be considered as a plating bath and the rinse following it should be used.

After filling the rinse tank with clean water, the water should be shut off and a sample should be taken and marked'' Time O.'' A sample should also be taken from the plating tank (or drag-out rinse, if applicable). The plating line should then be operated. After three to five racks have gone through, a second sample of the rinse should be taken and the number or racks and elapsed time recorded. The line is again operated and several more racks are plated and rinsed. A third sample is taken and the number of racks and elapsed time are recorded.

The plating solution sample and the three rinse tank samples should be analyzed for the plated metal. The drag-out is then calculated based on unit production [gallons (liters) per part or rack] or time [gallons (liters) per hour] for the two increments and is averaged.

Identify Batch Dump Parameters. Process solutions, such as alkali cleaners and acid dips, become exhausted after a period of use. These solutions are routinely dumped to the sewer, usually on a weekly or monthly schedule. They often contain significant concentrations of heavy metals and, therefore, will require treatment by January 28, 1984. Also, these solutions are by nature either very basic or acidic and can cause a significant pH fluctuation in the total effluent when discharged directly to the sewer. Such changes in pH often result in noncompliance with local pH standards.

Attention should be given to batch dumps concerning their future impact on waste treatment chemical requirements and their current impact on compliance with local pH standards. In terms of analytical parameters, batch dumps should be analyzed for cyanide and all metals that have a potential for accumulating in the solution. A separate sample should be taken to determine pH adjustment requirements.

The adjustment of pH on batch dumps is performed by adding either an acidic (usually sulfuric acid) or basic (usually caustic soda) solution until an acceptable pH is reached. Local regulations often require that the pH of discharges be in the range of 6.0 to 9.0. The Federal general pretreatment regulations[15] require that the pH be above 5.0.

By determining the relative strengths of the alkaline cleaners and acid dips, the plater often can develop a batch dump schedule that uses these solutions to neutralize each other. This practice will provide a significant savings in pH adjustment chemicals.

Application. The information gathered during a plant assessment provides the plating shop with the input needed to evaluate the opportunities for rinse recovery. These data are useful in assessing other in-plant changes as well, such as those designed to reduce total wastewater flow to less than 10,000 gal/d (38,000 L/d).

Case Study

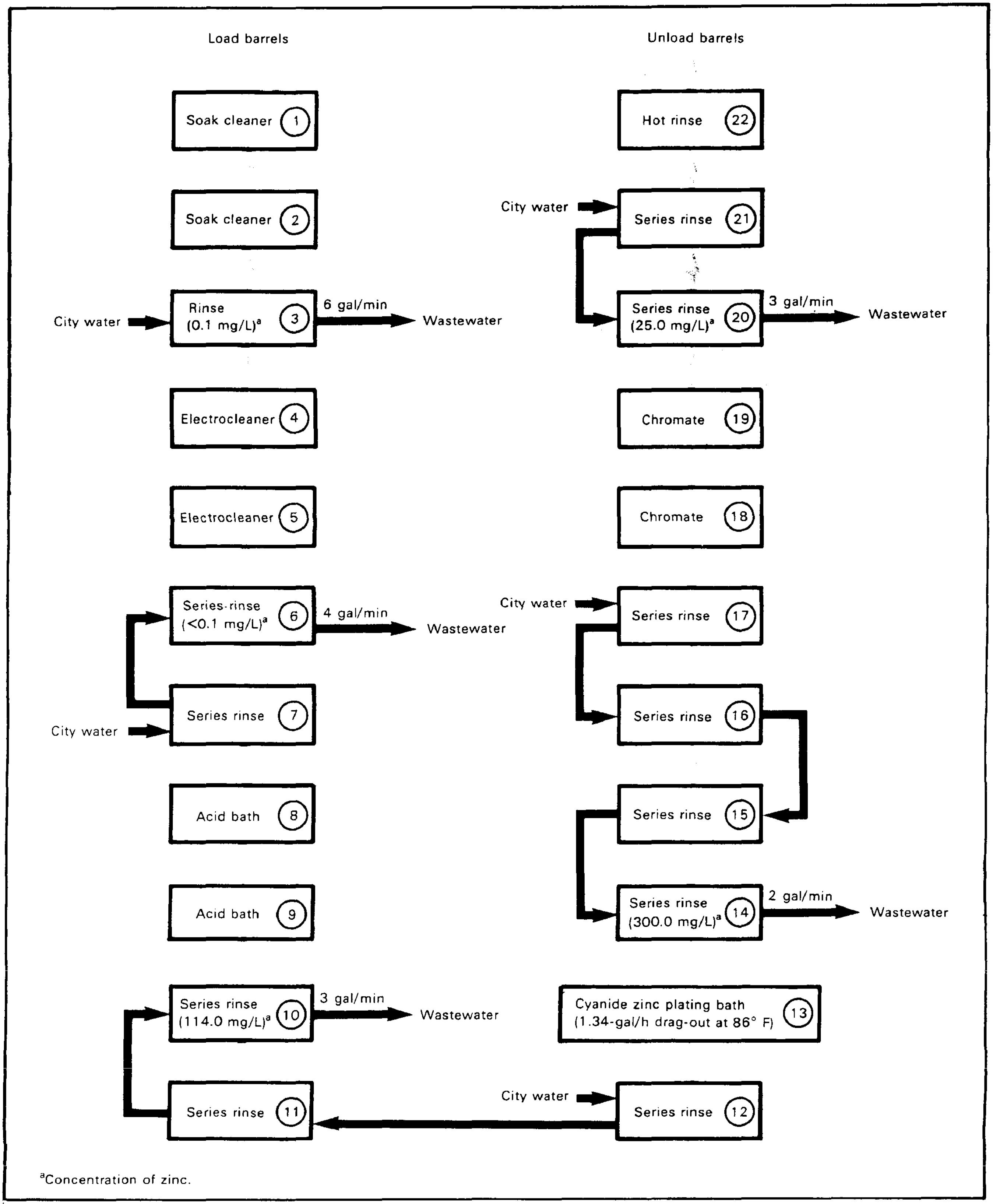
The following case study is an example of the procedures for performing a plant assessment and evaluating optional in-plant changes. The data are based on an actual plant's operation; however, an incomplete data base necessitated the assumption of certain parameters. The plating shop in the example performs mostly zinc, cadmium, and tin plating as well as chromate conversion coatings. The analysis focuses on the shop's automatic cyanide zinc barrel line.

Data Gathering. The initial step in the plant assessment or data gathering phase is to inspect the plating room and develop drawings showing the location of all relevant equipment and tanks. A drawing of the cyanide zinc line is presented in Figure 8.

After sufficient information is gathered to prepare drawings, the operating practices of the plant should be observed. In this example, only one work sequence is used. It involves the following steps

- Barrels are filled with parts at the loading area.
- The barrels proceed through each process and rinse tank (Tanks 1 through 22) in a straight-line order. The observed time at each station was 2 rein; the draining time was 15 s.
- Finished parts are unloaded at the end of the line. The observed production rate was 12 barrels per hour.
- The empty barrels are transported back to the loading area.

It was observed that once the barrels were removed from one tank, they were not allowed to drain fully before immersion in the subsequent tank. Another potential problem noted was the lack of air agitation in the rinse tanks following acid dip and zinc plating.



[a] Concentration of zinc.

Figure 8.

Cyanide Zinc Line Before Plant Assessment

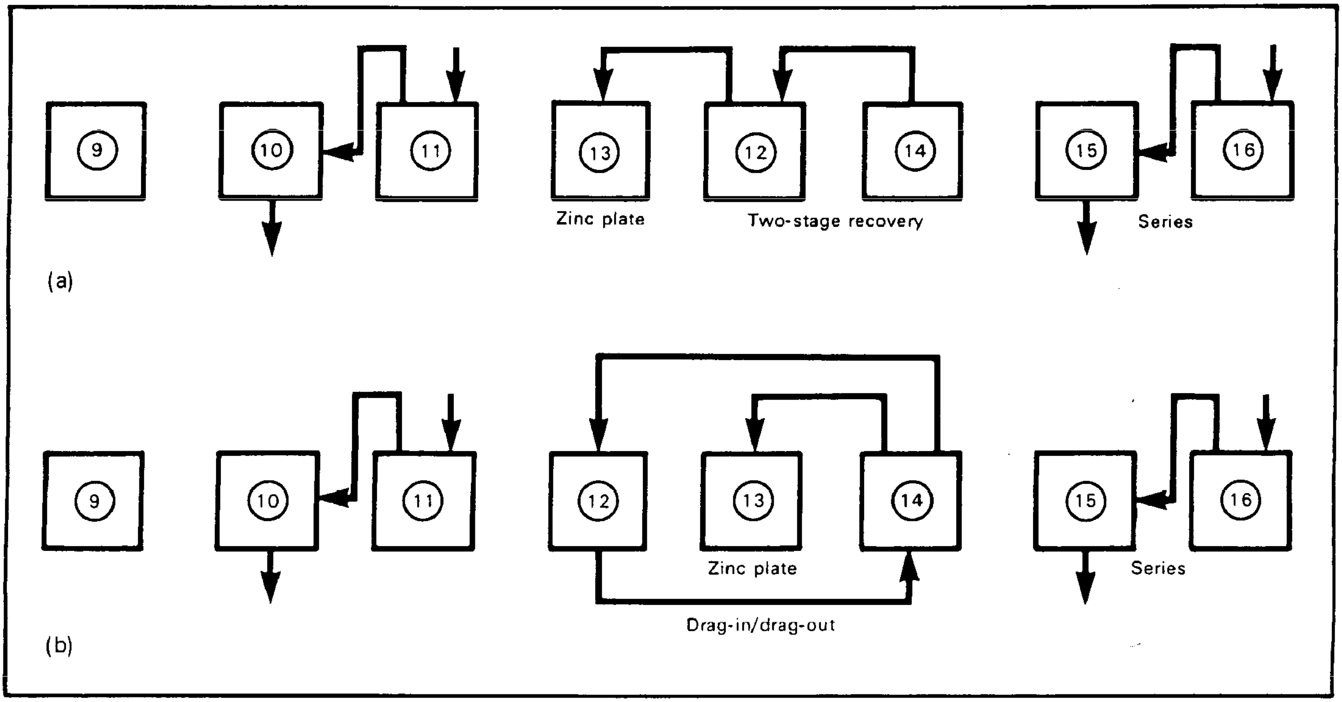


Figure 9.

Rinsing Alternatives Considered: (a) Alternative 1 and (b) Alternative 2

A water use survey was conducted by measuring tank flow rates. Samples were taken from the rinse tanks and the plating bath and were analyzed for zinc. A drag-out measurement was taken at the plating bath. The results from this work are shown on Figure 8.

Evaluation. The rinse water flow rates in Tanks 3 and 6 appear to be excessive, especially in Tank 6, which is part of a two-stage series rinse. The flows to these tanks were regulated by hand valves, which were nearly wide open. Flow control devices should be installed on the water feed lines to these tanks. Tank 3 probably could operate effectively at 3 gal/rein (1 1 L/rein) and Tanks 6 and 7 at 1 gal/rein (4 L/rein). Control devices are readily available in these sizes. Two flow regulators would cost approximately $40 and could save about $1,500/yr in water and sewer costs.

At lower flow rates, the concentration of zinc in the rinse waters would be expected to increase to 0.2 mg/L and approximately 0.4 mg/L, respectively, for Tanks 3 and 6. At these concentrations, the rinse waters are still below Federal pretreatment standards and will not require metal removal. (Cyanide is not introduced until Tank 13.) Depending on local regulations, however, pH adjustment still may be necessary.

The major portion of zinc pollution from the sample plating line is found in the rinse waters discharged from Tanks 10 and 14. Tank 10 follows an acid dip solution, which is dumped periodically. Because recovery would only shorten the life of this solution, it will not be a candidate for drag-out recovery. Tank 14 follows the zinc plating operation and, therefore, can be considered for recovery. The chemical losses from drag-out at Tank 13 are 1.34 gal/h (5.07 L/h) of plating solution. The replacement cost of this solution is approximately $2,425/yr.[b]

With the current rinsing arrangement, the water use is 5 gal/rein for the rinses following the acid bath and zinc plating. This water use rate is high considering the use of a series rinse. It is apparent that the efficiency of the rinsing systems is reduced because of poor mixing in the rinse tanks. Chemical losses from the zinc plating operation are 1,280 lb/yr (581 kg/yr) of zinc and 1,477 lb/yr (670 kg/yr) of cyanide, assuming one shift per day and 260 days of operation per year.

Two alternatives were considered for improving the rinsing system (Figure 9). Alternative 1 involves

---

[b] Based on a value of $0.87/gal and operating 2,080 h/yr.

moving the final rinse tank following the acid bath and converting this rinse and the three-stage series rinse arrangement following plating to a two-stage recovery rinse and two-stage series rinse. Using Alternative 1, approximately 34 percent of the drag-out could be recovered. Air spargers also would be added to the rinse tanks to increase the mixing and improve the efficiency of rinsing. The addition of air spargers would lower the water use rate after zinc plating to 0.3 gal/rein (1 .1 L/rein). The rinse system following the acid dip is unchanged in Alternative 1.

Alternative 2 employs the drag-in/drag-out rinsing configuration. The drag-in tank (Tank 12) was originally the final rinse following the acid dip. To eliminate the need for additional water in the acid dip rinsing system, air spargers are added to Tanks 10 and 11. Similarly, air spargers are added to the rinses in the new zinc plate rinsing system.

The drag-in/drag-out rinsing configuration provides 77 percent recovery of plating chemicals. This relatively high rate is primarily a result of increasing the recycle ratio from 0.35 in Alternative 1 to 1.35 in Alternative 2.

Tables 9 and 10 summarize the water use and cost analysis of the rinsing options. For this plating line, the best choice is the drag-in/drag-out rinsing system. The major benefits include a savings in plating chemicals and waste treatment and sludge disposal costs.

Table 9.

Evaluation of Case Study Rinsing Systems

Rinse system	Water use		Plating chemicals lost (lb/yr)	
	gal/min	1,000 gal/yr	Zinc	Cyanide
Current	5	1,248	1,280	1,477
Alternative	3.3	824	845	975
Alternative	3.3	824	294	340

Table 10.

Evaluation and Cost Comparison of Case Study Rinsing Alternatives

Parameter	Rinse system		
	Current	Alternative 1	Alternative 2
Flow rate (gal/min)	5	3.3	3.3
cost ($):			
Water and sewer at $2/1,000 gal wastewater	2,496	1,648	1,648
Additional rinse tanks at $240/tank	0	0	0
Treatment chemicals at			
$1.33/lb cyanide	1,964	1,296	452
$0.18/lb zinc	230	152	53
$0.21/1,000 gal wastewater	262	173	173
Sludge at $1.15/lb zinc	1,472	972	338
Plating chemicals lost at $1.89/lb zinc	2,419	1,597	556
De-ionized water	0	1,080	1,080
Others	0	160	280
Total cost	8,843	7,078	4,580

---

[a] Cost of retrofitting tanks with air and repiping spargers ($200 per tank depreciated over 5 yr).

Note.—All costs, except those for treatment chemicals, are in 1981 dollars. Costs for treatment chemicals, originally in 1979 dollars, were updated to reflect average 1980 prices using the Monthly Labor Review Producer Price Index for industrial commodities,

Recommended changes to the zinc barrel line are presented in Figure 10. The investment cost of the charges will be approximately $6,840, which includes installation of a de-ionized water unit ($5,400), retrofitting of tanks with air spargers and repiping ($1,400), and flow control devices ($80). Considering the reduced water and sewer costs, reduced treatment and disposal costs, and the savings in plating chemicals, the benefits of in-plant changes total $7,123/yr.

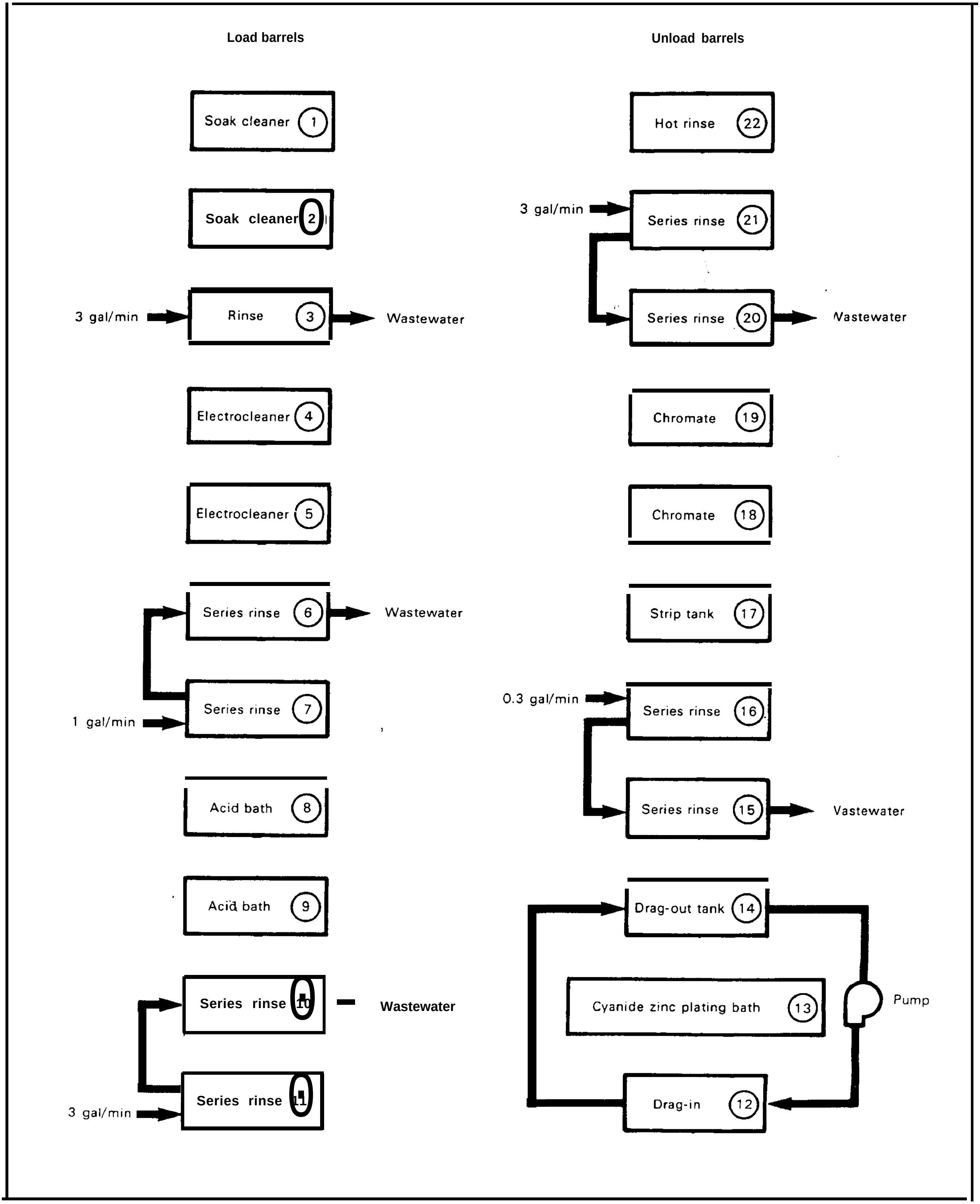


Figure 10.

Recommended Rinsing Arrangement for Cyanide Zinc Line

References

[1] U.S. Environmental Protection Agency. *Environmental Regulations and Technology: The Electroplating Industry.* EPA 625/1 0-80-001. Aug. 1980.

[2] U.S. Environmental Protection Agency. “Effluent Guidelines and Standards; Electroplating Point Source Category Pretreatment Standards for Existing Sources.” *Federal Register 46(18): 9462-9473,* Jan. 28, 1981.

[3] U.S. Environmental Protection Agency. *Environmental Pollution Control Alternatives: Economics of Wastewater Treatment Alternatives for the Electroplating Industry,* EPA 625/5-79-016. June 1979.

[4] Steward, F. A., and Leslie E. Lancy. “Minimizing the Generation of Metal-Containing Waste Sludges. ” In U.S. Environmental Protection Agency and American Electroplates’ Society, Inc. (cosponsors), *First Annual Conference on Advanced Pollution Control for the Metal Finishing Industry,* NTIS No. PB 282-443. Jan. 1978.

[5] Kushner, Joseph B. *Water and Waste Control for the Plating Shop.* Cincinnati OH, Gardner publications, 1976.

[6] Sawyer, Clair N., and Perry L. McCarty. *Chemistry for Sanitary Engineers.* (2nd ed.) New York NY, McGraw-Hill, 1967.

[7] Wallace, A. J., Jr. “Solution Dragout and Rinsing After Chromium Plating .“ *Plating and Surface Finishing, 66(1 1):47-51, Nov. 1979.*

[8] *U.S.* Environmental Protection Agency. *In-Process Pollution Abatement: Upgrading Metal-Finishing Facilities to Reduce Pollution.* EPA 625/3-73-002. NTIS No. PB 260-546. JUlY 1973.

[9] Konishi, Saburo, and Mitsuaki Tadagoshi. “Chromium Plating From Low Concentration Baths. Part 1. Effect of Bath Composition and Plating Conditions on Appearance.” *Metal Finishing. 71(11):* 49-52, Nov. 1973.

[10] Lowenheim, Frederick A. *Electroplating —Fundamentals of Surface Finishing. New* York NY. McGraw-Hill, 1978.

[11] Lancy, L. E. *Metal Finishing, 49(2):56, 1951.*

[12] *Pinner, R. Electroplating and Metal Finishing,* July -Aug. -Sept. 1967. (3-pt. article)

[13] Roy, Clarence. “Methods and Technologies for Reducing the Generation of Electroplating Sludges.” In U.S. Environmental Protection Agency and American Electroplates’ Society, Inc. (cosponsors), *Second Conference on Advanced Pollution Control for the Metal Finishing Industry.* EPA 600/8-79-014. NTIS No. PB 297-453. Feb. 1979.

[14] Crampton, Peter. “The Application of Separation Processes in the Metal Finishing Industry. ” In U.S. Environmental Protection Agency and American Electroplates’ Society, Inc. (cosponsors), *Third Conference on Advanced Pollution Control for the Metal Finishing Industry.* EPA 60012-81-028. Feb. 1981.

[15] U.S. Environmental Protection Agency. “General Pretreatment Regulations for Existing and New Sources.” *Federal Register 46(18):9439-9460,* Jan. 28, 1981.

* U S GOVERNMENT PRINTING OFFICE. 560565 (R)