Technology Transfer EPA 625/8-79-002

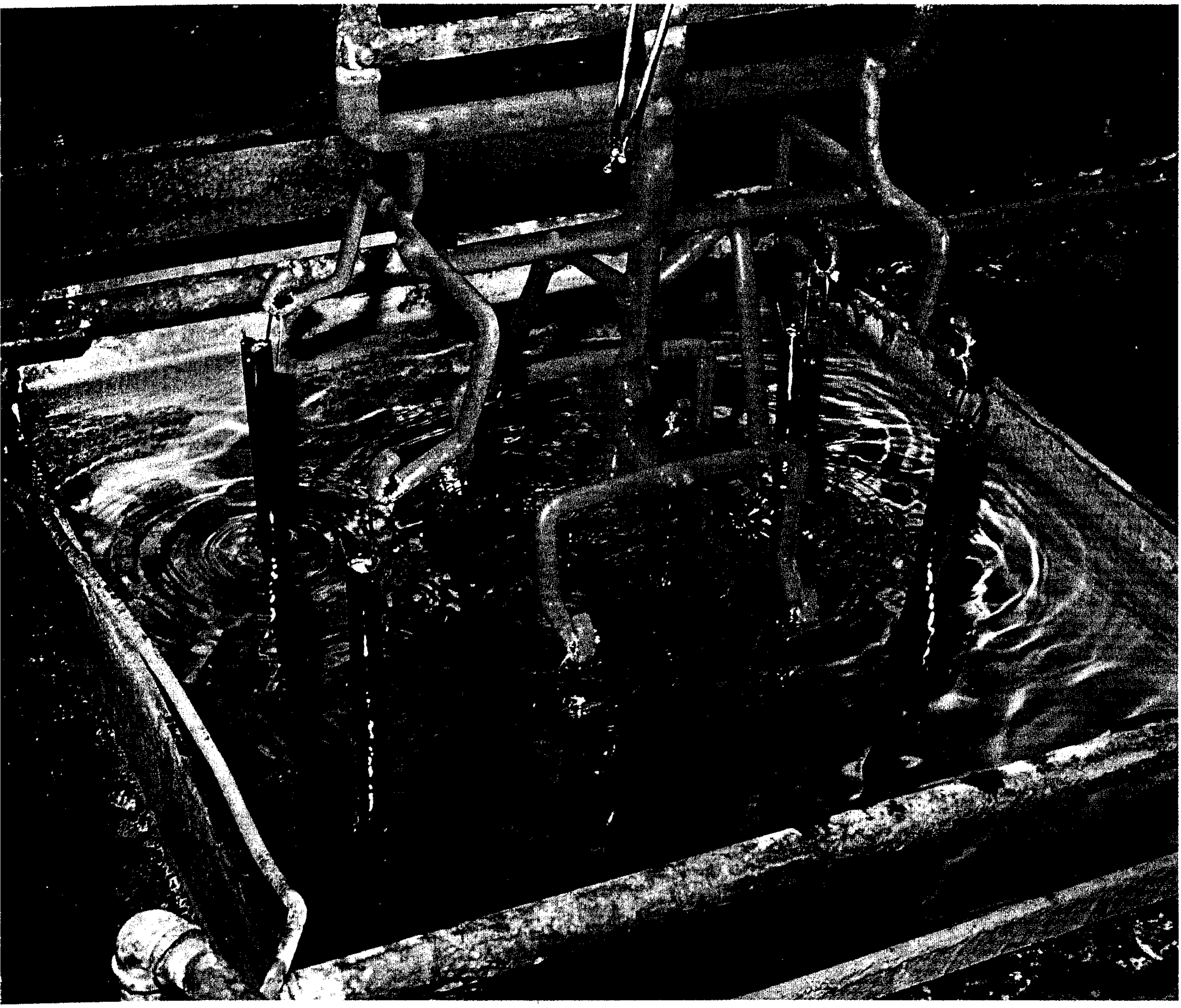
Summary Report

Control Technology for the Metal Finishing Industry

Evaporators

June 1979

This report was developed by the
Industrial Environmental Research Laboratory
Cincinnati OH 45268



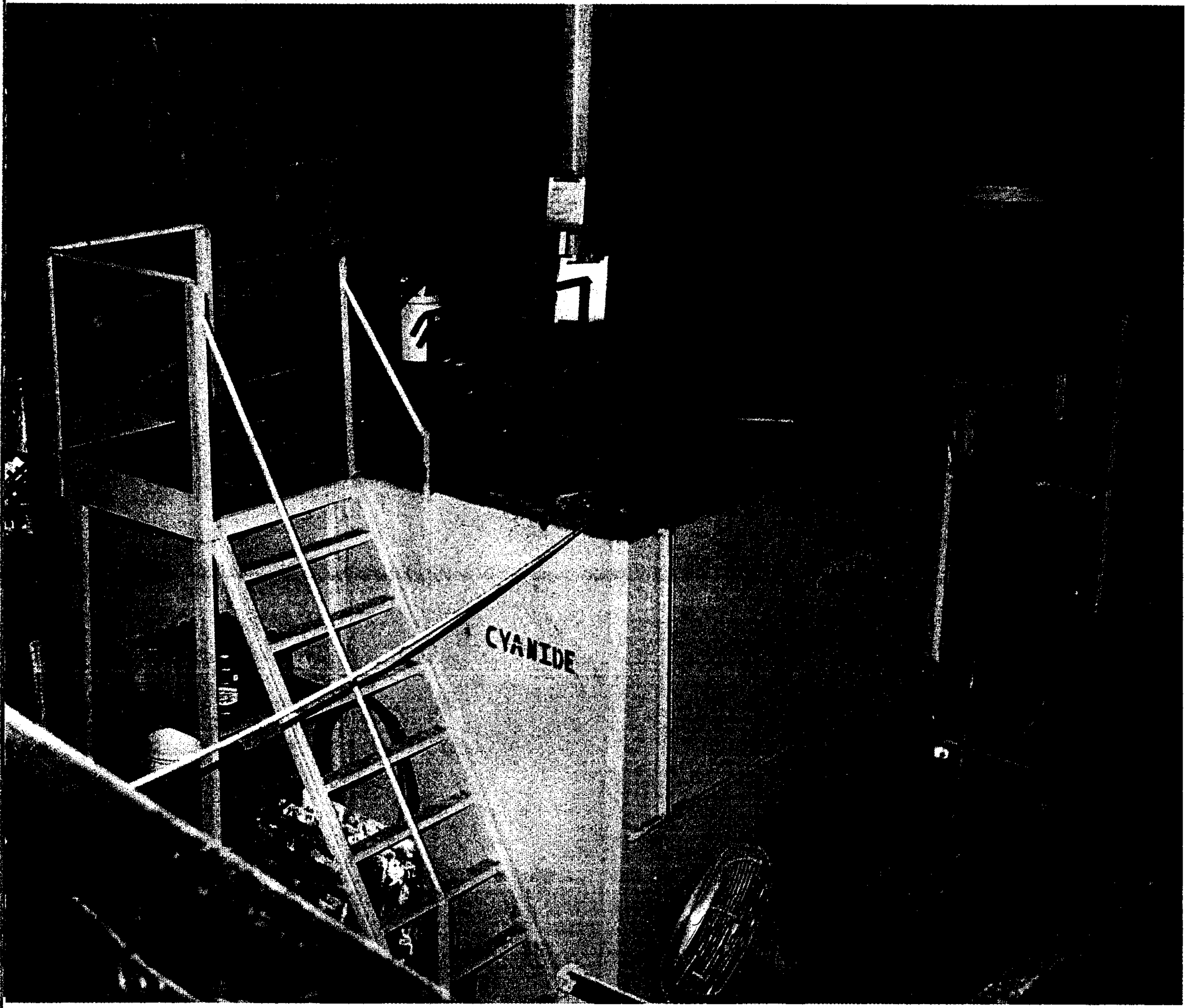
Final rinse station

Overview

Plating chemicals, such as chromic acid, nickel sulfate, and zinc cyanide, are among many solutions used throughout the electroplating industry to produce decorative or protective finishes on metal and plastic products. Cleaning steps, plating baths, and rinsing are similar in most plating processes; however, proprietary variations occur in formulations and process control parameters. All platers must provide adequate rinsing after the plating bath to remove excess plating chemicals and contaminants that could cause spotting or staining on the product. The water from this rinse is the major pollution control problem. Actually the problem is twofold: wastewater pollution control and loss of valuable plating chemicals.

Pollution control is achieved by chemical treatment or the elimination of pollutants from the effluent. To recover plating chemicals many platers use evaporators, which not only concentrate plating chemicals in the rinse water for reuse in the bath, but also reduce the amount of pollutants to be chemically treated. The evaporator method also can decrease the cost of plating operations.

The technical and economic advantages, including order-of-magnitude investment costs, operating costs, and cost saving benefits, are illustrated in this report for evaporators used in electroplating processes.



Cyanide oxidation wastewater treatment module

Conventional Wastewater Treatment

Introduction

Four major factors contribute to costs and selection of conventional wastewater treatment systems (shown in Figure 1), including:

- Volumetric flow rates: The major contributor to the volume of process water containing pollutants is the rinse water that comes in direct contact with the workpiece. The size and investment cost of systems to treat this water are in direct proportion to the wastewater flow rate.
- Pollutant type: The treatment steps needed to remove the pollutants from the wastewater are determined by the type of pollutants encountered. Neutralization and clarification are common to the treatment systems of most platers, while separate systems for chromium reduction and cyanide oxidation are required only if the plating operations use these materials.
- Pollutant loading: The costs for treatment chemicals and the quantity of solid waste (sludge) increase in direct proportion to the mass flow of pollutants in the wastewater. Reduction of water flow rate and pollutant loading will decrease the use of treatment chemicals, and pollutant loading and choice of treatment chemicals will determine the quantity of solid waste for disposal.
- Environmental regulations: Regulations also affect the selection of wastewater treatment systems as well as the selection of treatment chemicals.

Recovery systems, such as evaporators, can reduce the operating and investment costs for conventional wastewater treatment processes by substantially reducing the mass flow rates of pollutants entering the wastewater or by eliminating pollutants that are difficult to treat. Installing a recovery system often can ease the burden of meeting environmental regulations.

Operating costs for evaporators depend to a great extent on the flow rate of wastewater (feed to evaporator); the savings depend on the value and quantity of the plating chemicals reclaimed from the wastewater. For these reasons, this section briefly describes the methods for reducing rinse water rates. Also, the techniques and chemical treatment costs for conventional wastewater treatment are presented to define the savings attributable to recovery systems.

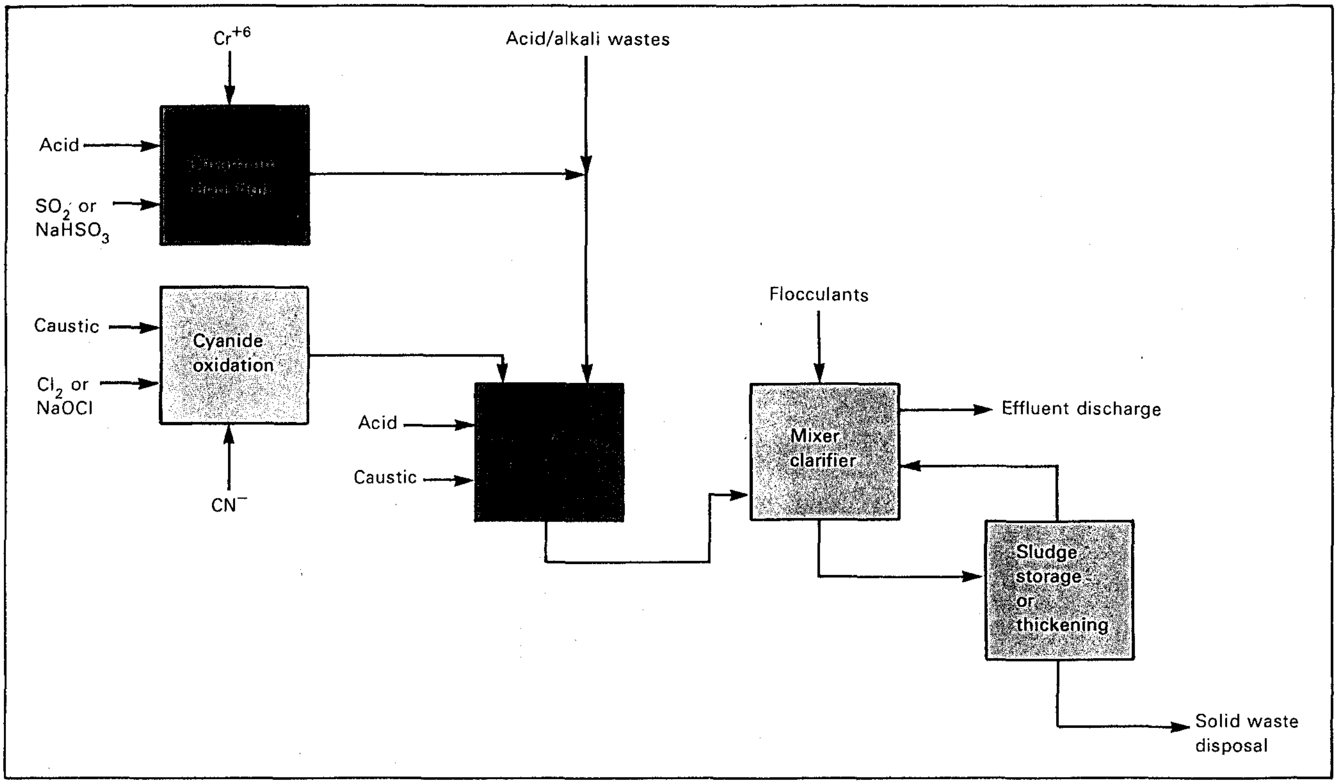


Figure 1.

Simplified Conventional Wastewater Treatment

Pollution Control: Conventional Method of Wastewater Treatment

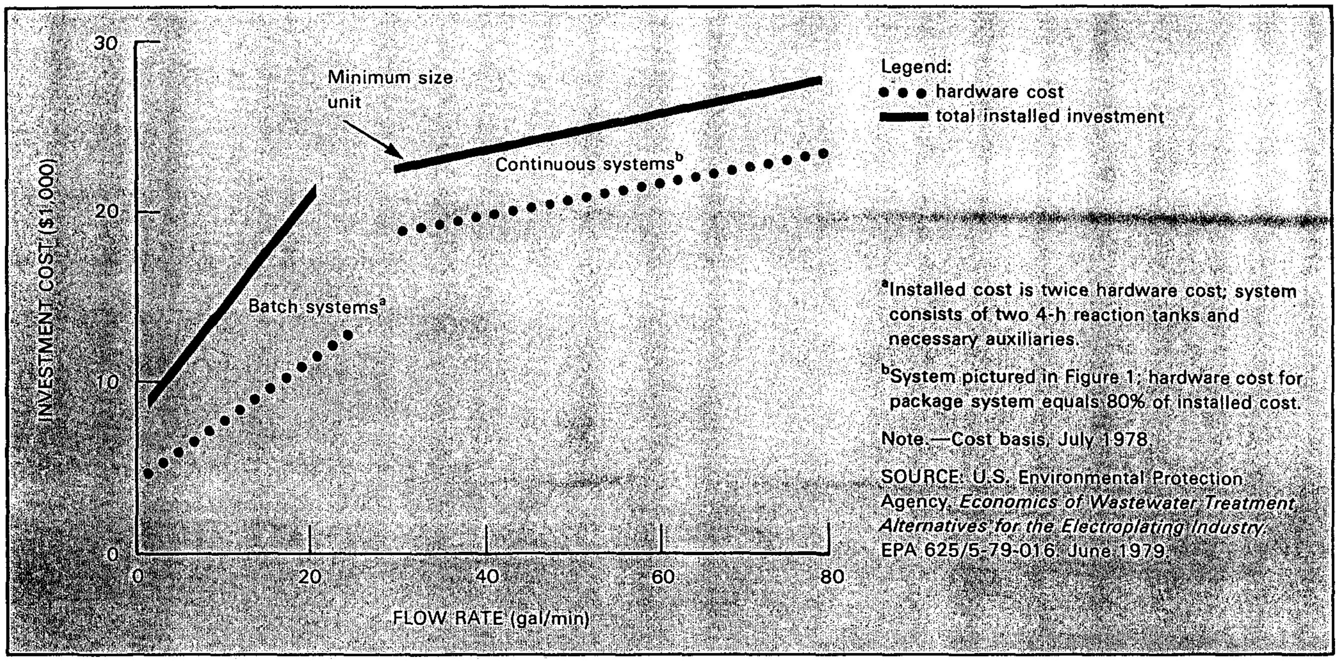
System Description. Currently many electroplaters are meeting effluent regulations by treating the wastewater by means of chemicals that react with the soluble pollutants to produce insoluble byproducts. As shown in Figure 1, the conventional wastewater treatment systems can include chromium reduction, cyanide oxidation, and neutralization; these steps are followed by clarification of the wastewater to remove the precipitates. The dilute sludge is usually thickened before disposal.

Chromium in wastewater is found either as hexavalent chromium (Cr^{+6}) or as trivalent chromium (Cr^{+3}). For chromium to precipitate out as a hydroxide, the hexavalent chromium must be reduced to the trivalent state. The reduction is achieved by reaction of either SO_2 gas or sodium metabisulfite with hexavalent chromium. Acid also is added to control the pH between 2 and 3, because the reaction proceeds rapidly under this condition.

Cyanide in wastewater is oxidized to bicarbonates and nitrogen by the introduction of chlorine gas or sodium hypochlorite. This procedure is carried out in a split-tank configuration where caustic or lime is added to control the pH between 9 and 11 in the first stage and at approximately 8.5 in the second stage.

Effluents from chromium reduction, cyanide oxidation, and acid/alkali waste streams are mixed together in a neutralizer. The pH is controlled carefully at the point of minimum solubility for that mix of metals, that is, in the range of 8.0 to 9.5. The retention time needed for effective precipitation is usually 10 to 20 minutes.

The neutralizer can be either single stage or multistage, depending on whether there are rapid changes in flow rates or pH. The pH is controlled by adding caustic soda or sulfuric acid as required.



[a] Installed cost is twice hardware cost; system consists of two 4-h reaction tanks and necessary auxiliaries.

[b] System pictured in Figure 1; hardware cost for package system equals 80% of installed cost.

Note.—Cost basis, July 1978.

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

Figure 2.

Investment Cost for Chromium Reduction Units

Following the neutralizer, the metal hydroxides and other insoluble pollutants are transferred to a clarifier and separated from the water by gravity settling. The rate of settling may be increased by adding coagulating agents, such as polymers, alum, or ferrous sulfate. When the settling characteristics of the suspended solids are improved, the overflow from the clarifier will contain lower levels of pollutants.

The underflow from the clarifier is transferred to sludge storage. Here, thickening of the clarifier underflow will reduce the volume of solids required for hauling to disposal sites.

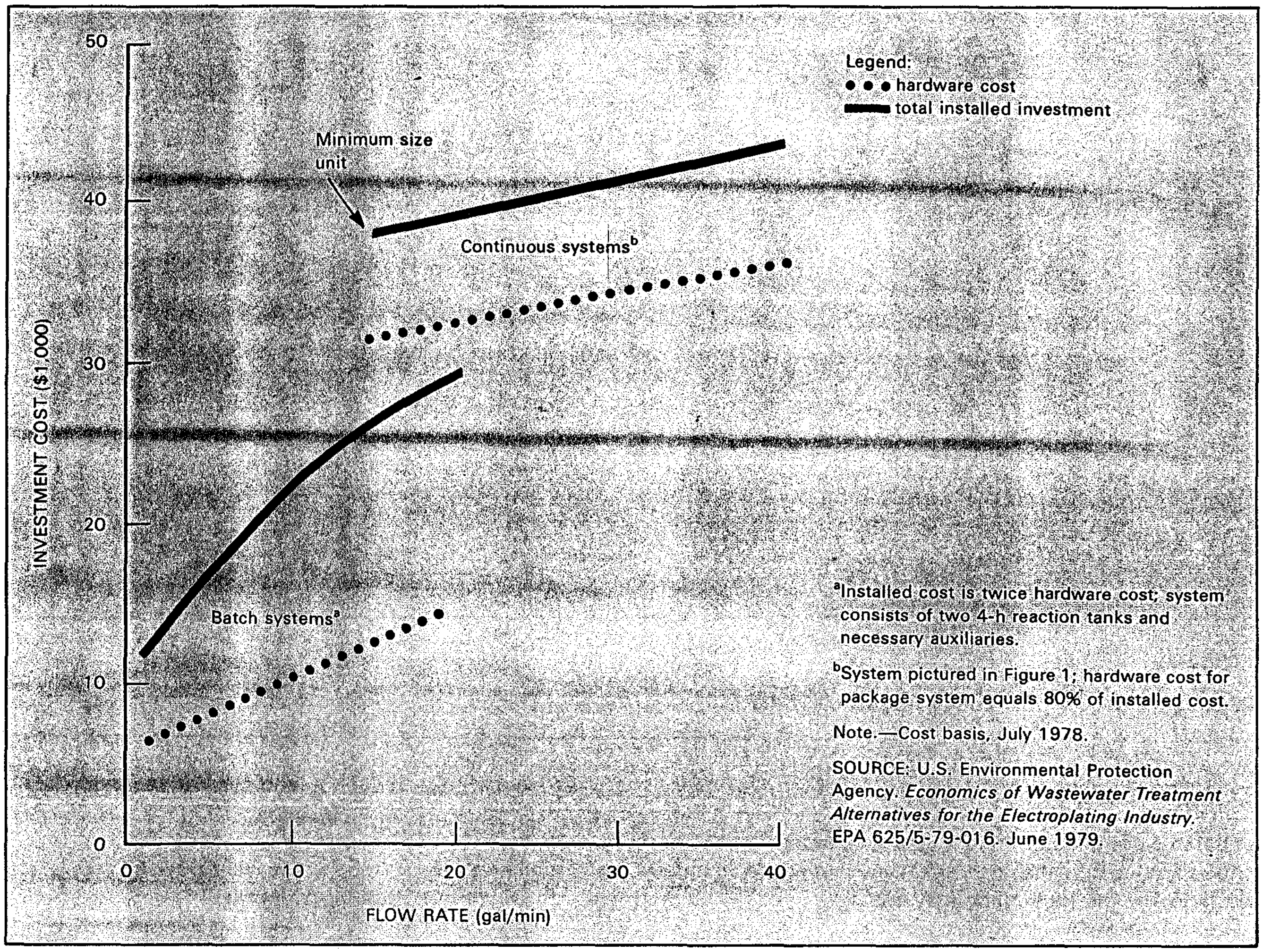
Cost of Conventional Wastewater Treatment. Three major costs are associated with wastewater treatment techniques for pollution control:

- Fixed costs associated with capital investment
- Chemical costs associated with treatment of pollutants, varying according to the types and mass flow rates of the pollutants
- Disposal costs associated with the volume and chemical composition of the sludge generated

Because recovery systems reduce wastewater treatment costs, in many cases these systems are economically attractive. For instance, a plant may be faced with choosing between a wastewater treatment system needed to handle the segregated rinse water from a plating operation or a recovery system that may eliminate the need for that treatment system, as is often the case with cyanide and chromium plating rinse waters. The avoidance of capital and operating costs for these treatment systems may be offset by the capital and operating costs of an evaporative recovery system. Typical investment costs for chromium reduction and cyanide oxidation systems are shown in Figures 2 and 3.

Although recovery systems can reduce the size and investment costs of neutralization and clarification systems, the benefit is minimal and usually is better achieved by reducing the volumetric flowrate of wastewater by in-plant modifications, such as multistage rinse tanks. Improved rinsing systems benefit both chemical treatment and recovery systems.

In most plants, a wastewater treatment system consisting of a neutralizer and clarifier will be required whether or not recovery systems are installed. Treatment systems for handling spills, or at least holding tanks necessary to collect plating bath discharges, may be required for backup to the recovery systems. For these reasons, the cost benefits for recovery will be based primarily on savings in treatment costs associated with chemical use and sludge disposal as well as on savings in raw materials (plating chemicals).



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[b]System pictured in Figure 1; hardware cost for package system equals 80% of installed cost.

Note.—Cost basis, July 1978.

SOURCE: U.S. Environmental Protection Agency. *Economics of Wastewater Treatment Alternatives for the Electroplating Industry.* EPA 625/5-79-016. June 1979.

Figure 3.

Investment Cost for Cyanide Oxidation Units

Chemical costs for wastewater treatment can be approximated based on pollutant composition and mass flowrates. A detailed discussion of costs for conventional wastewater treatment is presented in the EPA publication, *Economics of Wastewater Treatment Alternatives for the Electroplating Industry.*[a]

The costs of wastewater treatment for plating plants vary, depending on site-specific conditions and types of chemicals used for treatment. Table 1 lists the costs that will be used in this report for plating chemicals, treatment chemicals, and utilities. As a rule, the chemical additives used by platers will increase the bulk costs listed for pure chemicals. To correct for site-specific changes and for the changes in recovery and treatment costs for different raw material prices, approximate costs may be obtained by multiplying the values given in this report by the ratio of actual plant costs divided by costs shown in the table. Because the costs of the chemicals listed are for bulk quantities, the savings attributable to recovery techniques and the costs for conventional wastewater treatment may be higher.

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[a]EPA 625/5-79-016, June 1979.

Table 1.

Raw Materials, Pollution Control Chemicals, and Utilities Used by the Electroplating Industry

Item	1978 cost
Plating chemicals ($/lb):	
Boric acid, H_3BO_3	0.176
Cadmium chloride, $CdCl_2$	2.60
Chromic acid, H_2CrO_4	0.78
Copper cyanide, $Cu(CN)_2$	1.95
Copper sulfate, $CuSO_4$	0.88
Nickel chloride, $NiCl_2$	1.04
Nickel sulfate, $NiSO_4$	0.76
Sodium cyanide, NaCN	0.40
Zinc, as Zn metal	0.31
Zinc cyanide, $Zn(CN)_2$	1.41
Water pollution control chemicals ($/lb):	
Calcium hydroxide, $Ca(OH)_2$	0.017
Calcium oxide, CaO, quicklime	0.016
Chlorine, Cl_2	0.075
Ferrous sulfide, FeS	0.40
Hydrochloric acid, 28% HCl	0.023
Sodium bisulfite, $NaHSO_3$	0.13
Sodium carbonate, 58% Na_2CO_3	0.03
Sodium hydroxide, 98% NaOH equivalent	0.08
Sodium hypochlorite, NaOCl	0.40
Sodium sulfide, Na_2S	0.12
Sulfur dioxide, SO_2	0.085
Sulfuric acid, H_2SO_4	0.023
Utilities ($):	
Electricity (per kWh)	0.045
Steam (per 1,000 lb), *energy source*	
Natural gas	2.10
No. 2 fuel oil	3.50
Water (per 1,000 gal):	
Use fee	0.50
Sewer fee	0.60

Note.—Plating chemical costs are for bulk chemicals and do not include additive chemicals for proprietary formulations.

SOURCE: "Current Prices of Chemicals and Related Materials," *Chemical Marketing Reporter*, Feb. 20, 1978.

Table 2 shows typical operating costs experienced in treating wastewater, based on the mass flow of pollutants and an average concentration of 100 mg/l. The total cost consists of three key factors:

- Replacement cost of plating chemicals lost
- Treatment cost for destruction chemicals and polymers
- Disposal costs for sewerage and sludge handling

A plant either can calculate its own actual treatment costs or can estimate them using Table 2.

For example, if a rinse stream contains the equivalent of 2 lb/h (0.9 kg/h) of chromic acid, then the hourly costs for wastewater treatment will include:

- Replacement cost, 2 lb/h (0.9 kg/h) × $0.78/lb = $1.56
- Treatment cost using sodium bisulfite, 2 lb/h (0.9 kg/h) × $0.69/lb = $1.38
- Disposal costs at 4 percent solids and $0.10/gal, 2 lb/h (0.9 kg/h) × $0.32/lb = $0.64

Total costs per hour would come to $3.58.

If the cost for chromic acid plating solutions is $1.00/lb and sludge disposal costs are $0.25/gal, then the cost will be as follows:

- Replacement costs, 2 lb/h (0.9 kg/h) × $1.00/lb = $2.00
- Treatment cost using sodium bisulfite, unchanged = $1.38
- Disposal costs at 4 percent solids and $0.25 gal,[b] ($0.64 at $0.10/gal) × (25/10) = $1.60

Total costs per hour will then be $4.98.

Rinse Water. The major source of contaminated wastewater is from the rinse tanks, although further contamination can come from leakage and spills. Following the plating bath, the chemicals adhering to the workpiece (drag-out) must be removed by rinsing. The spent rinse water containing the plating chemicals must be treated by conventional wastewater treatment processes or must be concentrated using recovery techniques for recycle to the plating tanks.

[b] *For disposal of solid waste at different solids concentrations, the costs in Table 2 can be adjusted by: disposal cost per lb at X% of solids = (disposal cost per lb at 4% solids)* × (4%/X%). This adjustment does not account for sludge density changes.

Table 2.

Economic Penalty for Losses of Plating Chemicals

Chemical	Cost of chemical treated ($/lb)			
	Replacement	Treatment[a]	Disposal[b]	Total
Nickel:				
As $NiSO_4$	0.76	0.28	0.17	1.21
As $NiCl_2$	1.04	0.29	0.24	1.57
Zinc cyanide as $Zn(CN)_2$				
Using Cl_2 for cyanide oxidation	1.41	0.72	0.25	2.38
Using NaOCl for cyanide oxidation	1.41	1.53	0.25	3.19
Chromic acid as H_2CrO_4				
Using SO_2 for chromium reduction	0.78	0.48	0.32	1.58
Using $NaHSO_3$ for chromium reduction	0.78	0.69	0.32	1.79
Copper cyanide as $Cu(CN)_2$				
Using Cl_2 for cyanide oxidation	1.95	0.72	0.25	2.92
Using NaOCl for cyanide oxidation	1.95	1.53	0.25	3.73
Copper sulfate as $CuSO_4$	0.56	0.28	0.17	1.01

[a] Based on cost of conventional treatment at a concentration of 100 mg/l in wastewater.

[b] *Based on 4% solids and disposal cost of $0.10/gal.*

Plating solution entering the rinse tanks in many cases can represent as much as 50 to 90 percent of the plating solution consumed in the plating process. The concentration of the drag-out entering the first rinse tank is identical to the plating bath solution. Assuming good rinsing efficiency, the concentration of the drag-out from a rinse tank is the same as the rinse water in that tank. The concentration of the drag-out can be decreased satisfactorily using one rinse tank and a high rinse water flowrate; however, additional rinse tanks usually are included to reduce the quantity of rinse water used.

The volume of water required for rinsing will depend on many factors, such as the volume and concentration of drag-out, number of countercurrent rinse tanks, rinsing efficiency, and final concentration of plating chemicals permissible on the product after rinsing. Usually, the concentration of the plating chemicals adhering to the workpiece after the final rinse will be in the range of 5 to 50 ppm, although some plating operations require final concentrations of dissolved solids as low as 1 ppm. Typical concentrations of total dissolved solids in final rinses are 16 ppm for chromium plating, 45 ppm for nickel plating and 50 ppm for cyanide plating.

The arrangement and number of rinse tanks usually depend on economics and space limitations. Typically, one to five rinse tanks are used. With a given number of rinse tanks, a countercurrent rinse system (in which the rinse water flows in the opposite direction to the product, as shown in Figure 4) will minimize the consumption of rinse water. In this arrangement, the first rinse tank has the highest concentration of plating chemicals.

The ratio of the rinse water volumetric flowrate to the drag-out volumetric flowrate is defined as the *rinse ratio* (r). A theoretical relationship between the rinse ratio, the number of rinse tanks and the resulting dilution in the rinse tanks has been developed to predict countercurrent rinse water requirements, as shown in Figure 5. The values shown in Figure 5 are based on:

$$\frac{C_p}{C_n} = r^n \qquad (1)$$

where

n = number of rinse tanks
C_p = plating bath concentration
C_n = concentration in n^{th} rinse tank ($n = 1, 2, 3, \ldots$)
r = rinse ratio

Figure 5 also compares the percent recovery of the plating solution contained in the rinse water with that entering the rinse as drag-out on the workpiece. This percentage is potentially available for recovery and is defined by:

$$\text{Percent recovery} = \left(1 - \frac{C_n}{C_p}\right) \times 100\% \qquad (2)$$

Usually it is assumed that the concentration of the drag-out from the final rinse tank is equal to the concentration of the chemicals in the final rinse tank.

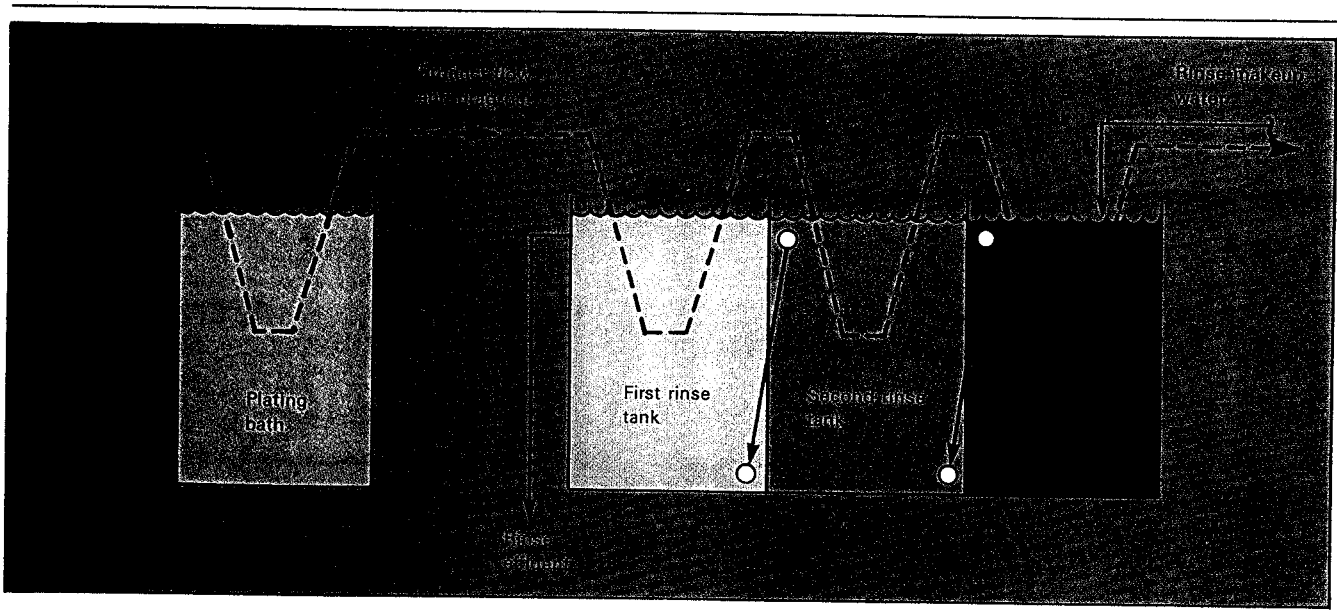
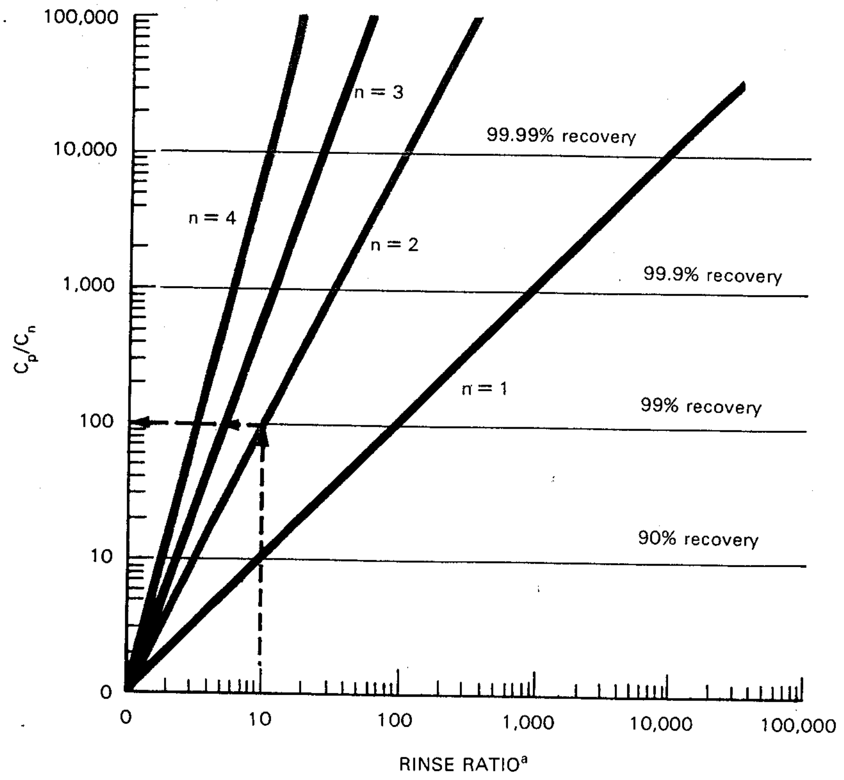


Figure 4.

Preferred Countercurrent Rinse Arrangement for Plating Process



[a] Rinse rate (gal/h) ÷ drag-out rate (gal/h).

Notes.—For countercurrent rinsing, C_n = concentration in n^{th} rinse tank; C_p = concentration in process bath; n = number of rinse tanks, n = 1, 2, 3, . . . Example: If the rinse ratio were 10 in a two-tank rinse system, C_p/C_n would be 100. A closed loop recovery system would recover 99% of the drag-out plating chemicals.

Figure 5.

Rinse Water Dilution vs. Rinse Ratio for Multitank Countercurrent Rinsing

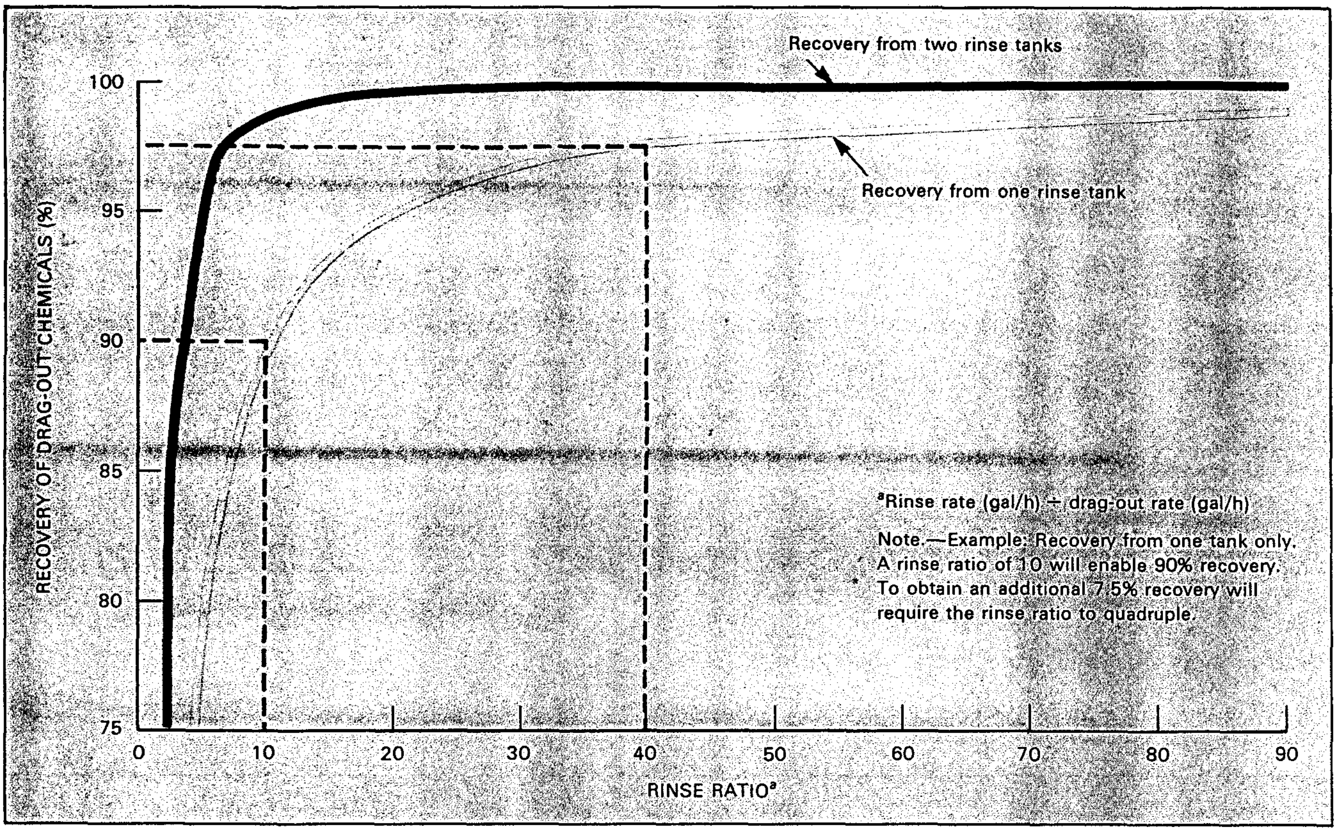


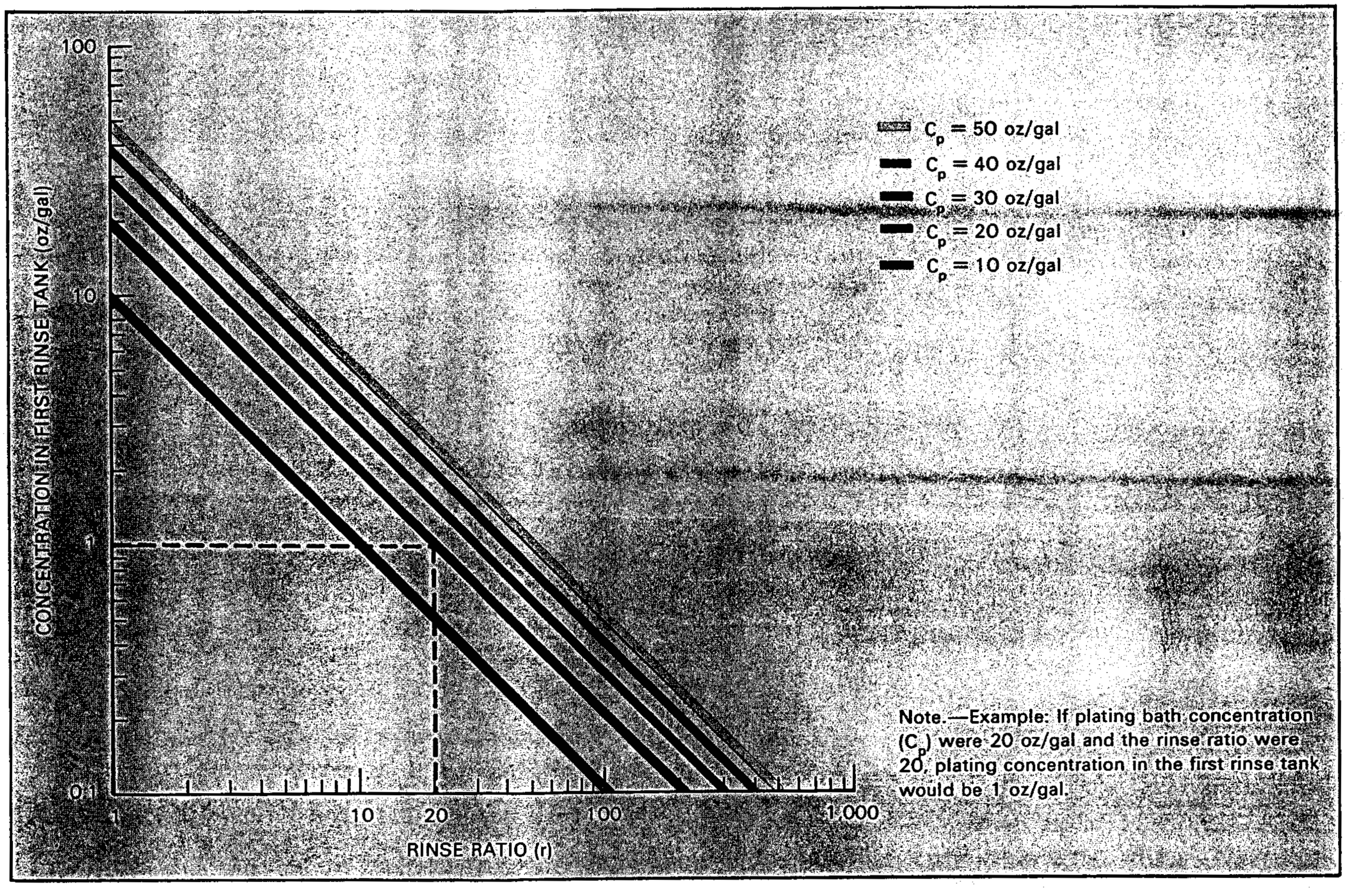
Figure 6.

Rinse Ratio Effect on Percent Recovery of Drag-Out Chemicals from Rinse Systems

Figure 6 shows different levels of chemical recovery over a range of rinse ratios for recovery from one or two rinse tanks. For example, if chemical recovery were from one rinse tank only, and the rinse ratio were 10, then it would be possible to recover 90 percent of the drag-out chemicals from the rinse tank. If the rinse ratio were increased to 40, only an additional 7.5 percent recovery would be possible. If recovery were from two rinse tanks and the rinse ratio were 10, then 99 percent recovery would be possible. If the rinse ratio were increased to 40 in the two-tank rinse system, then 99.9 percent recovery would be possible.

To illustrate the application of the rinse ratio and the drastic changes in wastewater flowrates, assume that a chromium plating bath concentration (C_p) is 40 oz/gal (300 g/l) and the product specifications require a final rinse concentration of 0.002 oz/gal (15 mg/l). The drag-out rate is 1.5 gal/h (5.71 l/h) and a single-stage rinse tank is installed. The ratio of C_p/C_n (40/0.002) is 20,000 and, from Figure 5, the rinse ratio becomes 20,000. Therefore, 30,000 gal/h (113,550 l/h) of rinse water are required. If the plant installs two additional rinse tanks to have a three-tank countercurrent rinse system, the rinse ratio, according to Figure 5, is 27. The final rinse concentration is maintained at 0.002 oz/gal (15 mg/l) using a rinse water flowrate of 40 gal/h (151 l/h) (27 × 1.5 gal/h).

The concentration in the first rinse tank that would discharge to the wastewater treatment process is 1.5 oz/gal (11.2 g/l), as determined from Figure 7. The total mass flow of pollutants requiring treatment remains unchanged, although the volume of wastewater is reduced by a factor of 750. The investment cost for a wastewater treatment system would then decrease and the chemical requirement for pH adjustment would be less.



Note.—Example: If plating bath concentration (C_p) were 20 oz/gal and the rinse ratio were 20, plating concentration in the first rinse tank would be 1 oz/gal.

Figure 7.

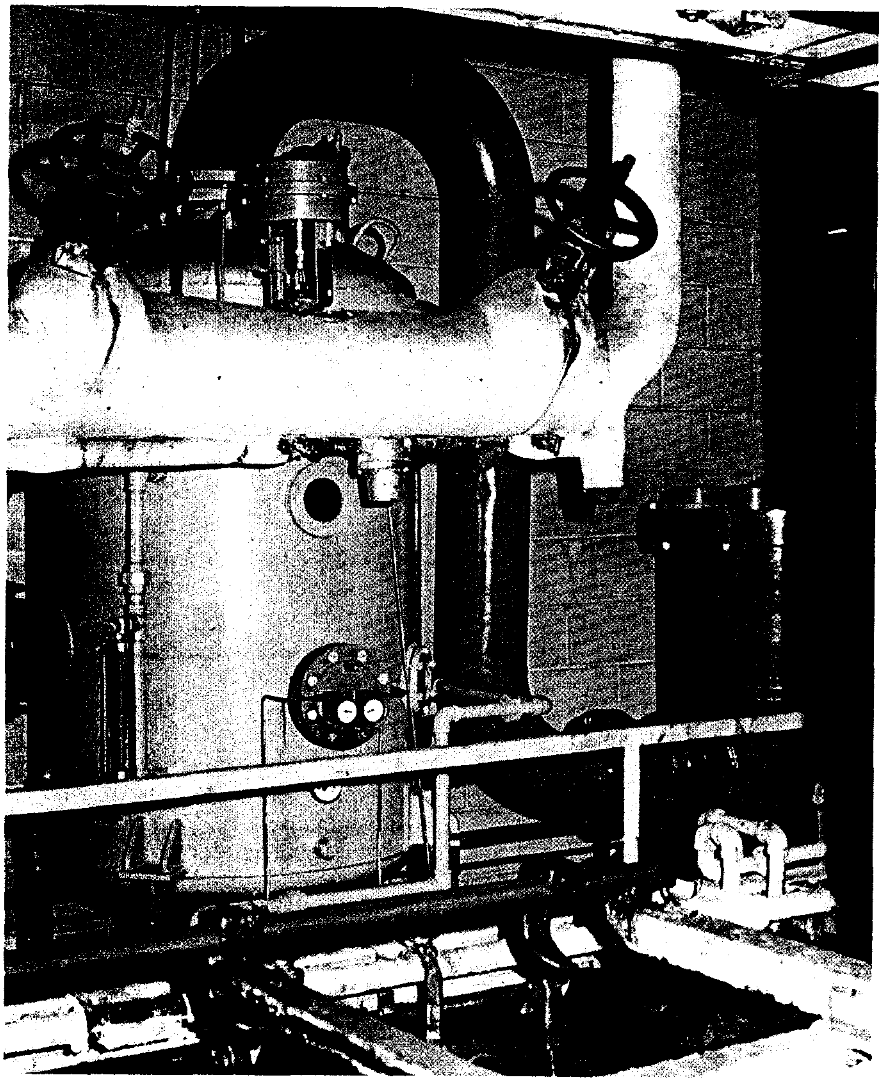
Determination of Plating Concentration in First Rinse Tank

Evaporation

Introduction

Evaporation, reverse osmosis, ion exchange, and electrodialysis are the common technologies for recovery of plating chemicals from rinse water. Evaporation achieves recovery by distilling the wastewater until there is a sufficient concentration of plating chemicals to allow reuse in the plating operation. Because of the thermal energy costs of operation, evaporators are not usually considered for recovery of plating chemicals from dilute wastewater. As discussed earlier, changes in the rinse systems can increase chemical concentrations in wastewater to a level where evaporative recovery can be considered.

Evaporation is becoming a popular method that can offer favorable returns on investment and can reduce the pollutant loading requiring treatment. The technology is proven and its application is expanding. The evaporation system shown in Figure 8 can be used to recover plating chemicals contained in the effluent from a three-stage countercurrent rinse. The feed to the evaporator is the discharge from the first rinse tank. The plating chemicals are concentrated in the evaporator and returned to the plating bath. The water vapor is condensed and returned to the rinse tanks.



Rising film evaporator: reboiler, vapor/liquid separator, and condenser

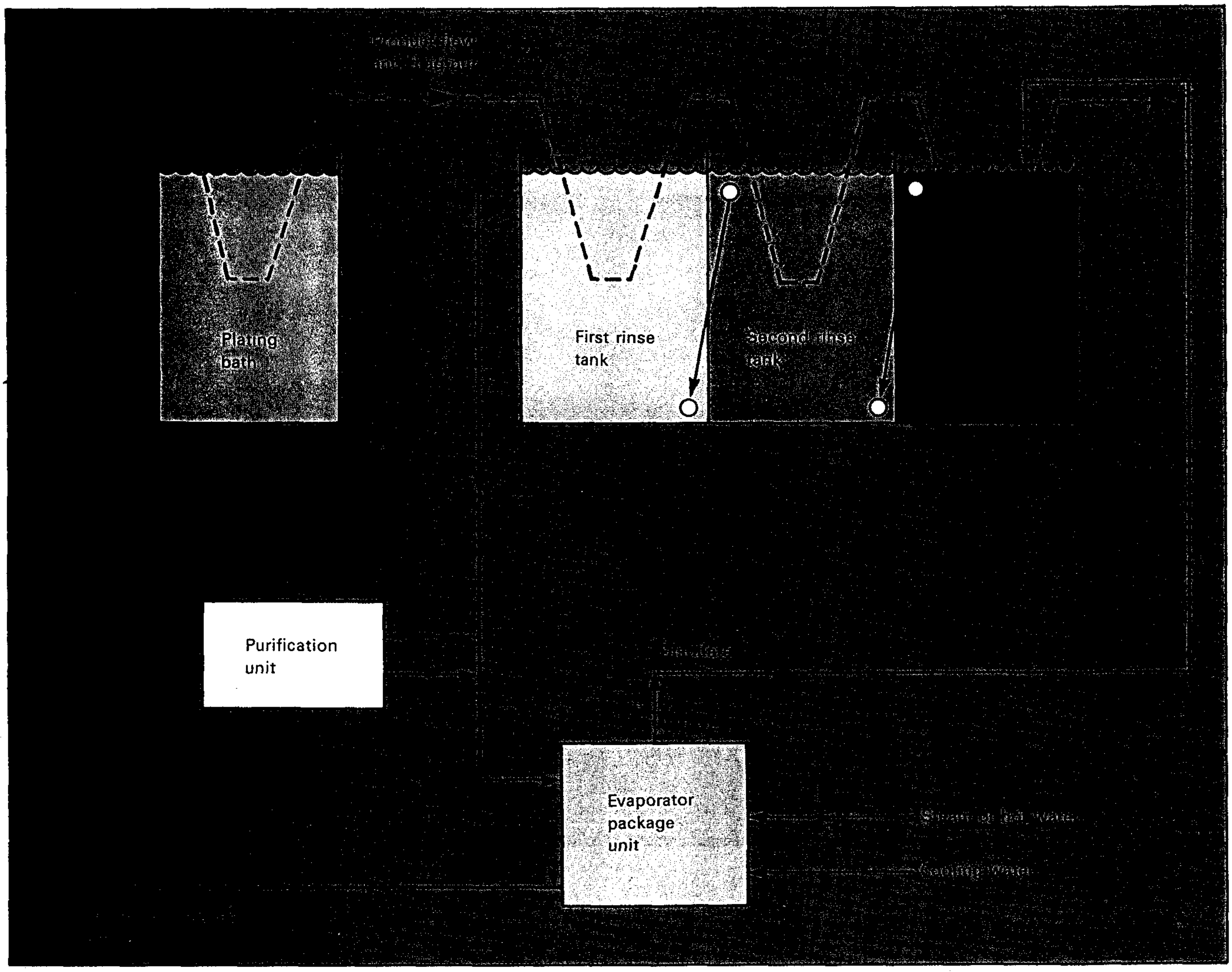


Figure 8.

Closed-Loop Evaporative Recovery of Plating Chemicals from Drag-Out

Four types of evaporators are used throughout the electroplating industry:

- Rising film evaporators
- Flash evaporators using waste heat
- Submerged tube evaporators
- Atmospheric evaporators

Site-specific conditions and the mode of operation determine construction materials and influence the selection of one system over another.

Types of Evaporators

Rising Film Evaporators. Rising film evaporators are built so that the evaporative heating surface is covered by a wastewater film and does not lie in a pool of boiling wastewater. A complete unit usually consists of a reboiler, separator, and condenser, as shown in Figure 9. The reboiler is a shell-and-tube heat exchanger in which the heat from low pressure steam—5 to 15 lb/in^2 gauge (1,018 to 1,536 mm Hg absolute)—or hot water is transferred to the wastewater. The wastewater may be circulated naturally or forced through the tubes, or it may be a rising film on the outside of the tubes, depending on the evaporator manufacturer. Because plating chemicals are susceptible to degradation at high temperatures, evaporation is accomplished at pressures of 1.3 to 7.5 lb/in^2 absolute (67 to 388 mm Hg absolute), thereby lowering the boiling point to 110° to 180° F (43° to 82° C). The operating pressure may vary among manufacturers and according to the type of plating chemicals handled. Reduced wall temperatures of the heat transfer surface will reduce scale and thermal breakdown of plating

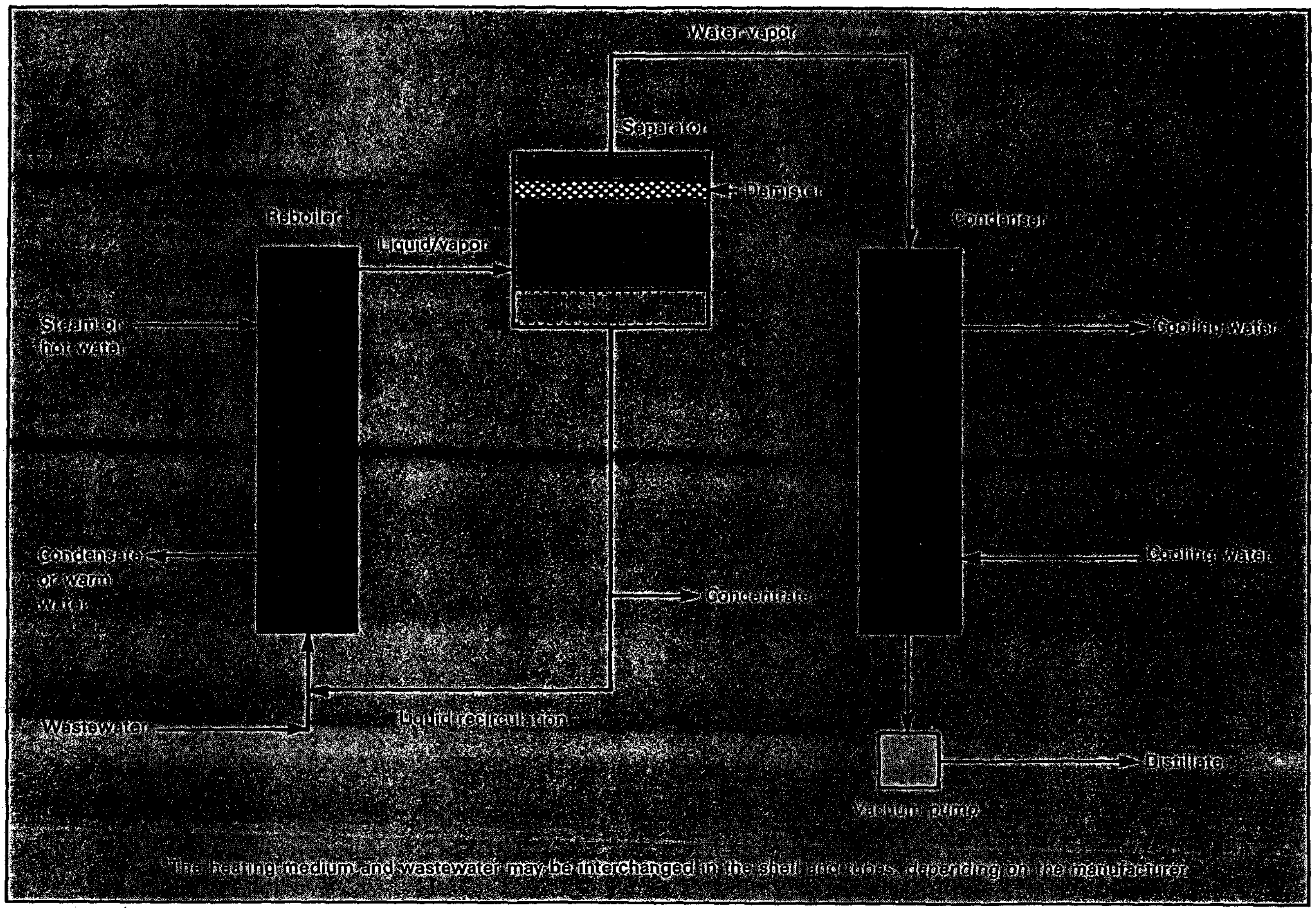


Figure 9.

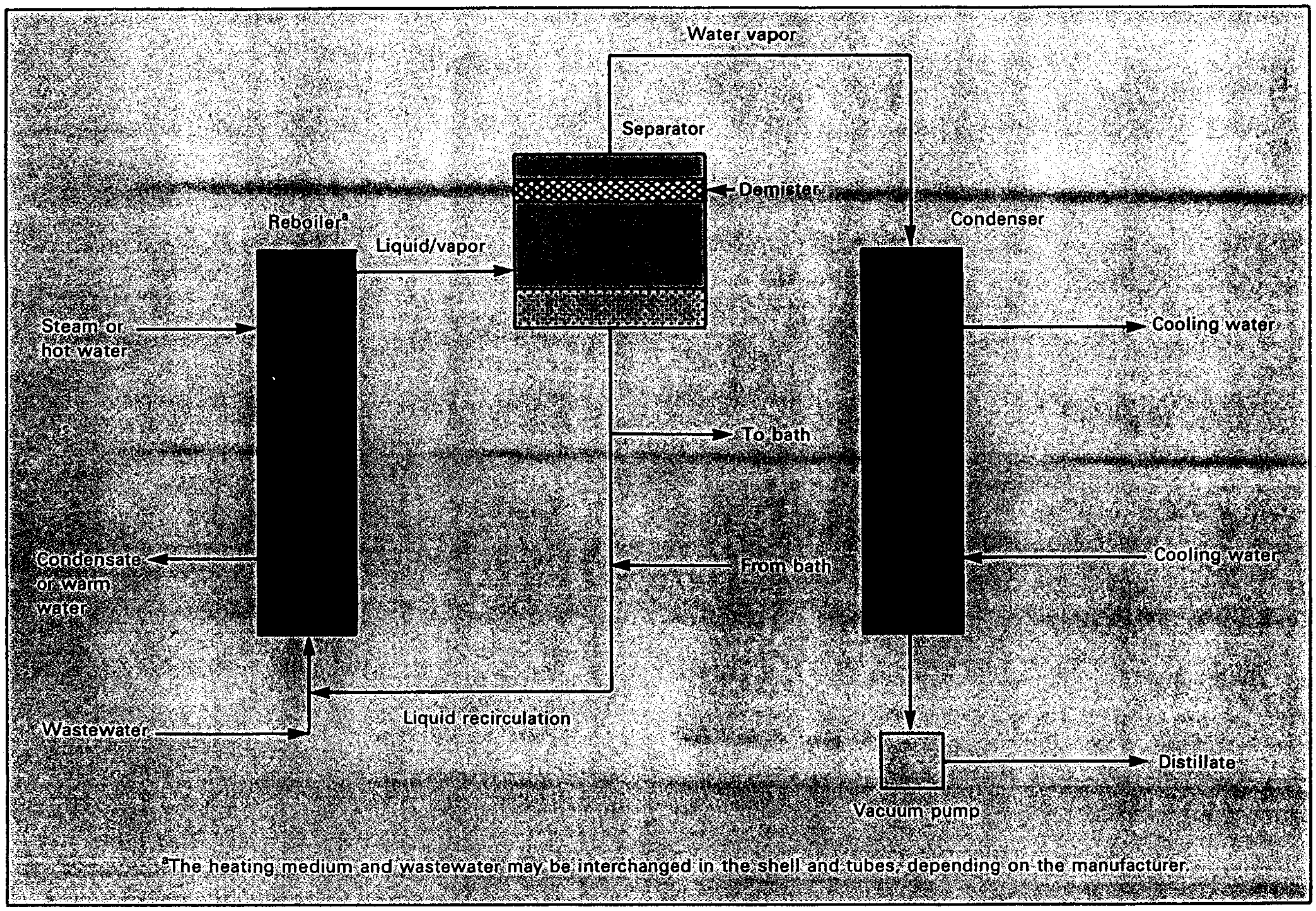
Rising Film Evaporation for Chemical Recovery

chemicals. The wastewater leaves the reboiler as a vapor/droplet mixture and enters the separator.

The separator can serve two functions: it can separate the water vapor from the heavier plating solution and it can provide a reservoir for the concentrated plating solution to collect until returned to the bath. One manufacturer employs a separate concentration tank to serve the same function as the reservoir in the separator. The water vapor exits through the top of the separator. A recirculation loop continuously recirculates the separated plating solution through the reboiler and separator until the concentration increases to a preset level. At this point, the wastewater flow is momentarily valved off, allowing the concentrated plating solution to return to the bath or hold tank. This step takes only a few minutes, then the wastewater flow to the reboiler is resumed. Some systems operate with a continuous feed and do not require this valve cycling.

The vapor leaving the separator is condensed in a shell-and-tube heat exchanger and the distillate is returned to the rinse tanks or to other plant uses. Cooling water can come from cooling towers or reservoirs, or once-through process water can be used.

Flash Evaporators Using Waste Heat. Flash evaporators, as shown in Figure 10, are of the same basic design as the rising film evaporators. The main difference is that plating solution from the bath is recirculated continuously through the evaporator. This recirculation reduces overall energy requirements for evaporation and cools the bath solution as well.



[a]The heating medium and wastewater may be interchanged in the shell and tubes, depending on the manufacturer.

Figure 10.

Flash Evaporation for Chemical Recovery

During the plating operation, the temperature of the plating bath increases because of the electrolytic process. Cooling coils are installed to maintain the bath temperature. An alternative approach for high temperature baths is to withdraw a part of the plating solution for feed to flash evaporators. The plating solution from the bath is at a temperature above its boiling point at the pressure maintained in the evaporator. A small part of the plating solution therefore vaporizes in the separator, and thus reduces the temperature of the solution and provides heat to the wastewater being evaporated. If the evaporator is operating at a pressure of 1.3 lb/in^2 absolute (67 mm Hg absolute) and the temperature of plating bath is 135° F (57° C), the plating solution will flash cool to 110° F (43° C). The 110° F (43° C) plating solution is recycled to the plating bath to maintain the bath temperature at 135° F (57° C).

To save 1 pound (0.45 kg) of steam in the flash evaporator, approximately 5 gallons (19 liters) of plating solution must be flash cooled by 25° F (14° C) in the evaporator. If a rising film evaporator required 1,000 lb/h (454 kg/h) of steam, a flash evaporator could achieve the same concentration rate using 800 lb/h (363 kg/h) of steam if 1,000 gal/h (3,785 l/h)—based on 5 gal/lb steam × 200 lb/h (91 kg/h × 41.85 l/kg steam)—of plating solution is fed to the unit. The amount of heat removed from the bath cannot exceed the cooling duty. Therefore, the plating bath cooling requirements are at least 200,000 Btu/h (50,400 kcal/h)—200 lb/h (91 kg/h) steam × 1,000 Btu/lb (555 kcal/kg) steam. Because the quantity of heat provided by the flash cooling of the plating bath solution is small compared to the latent heat provided by steam heating, flash evaporation usually is limited to large, high temperature plating installations.

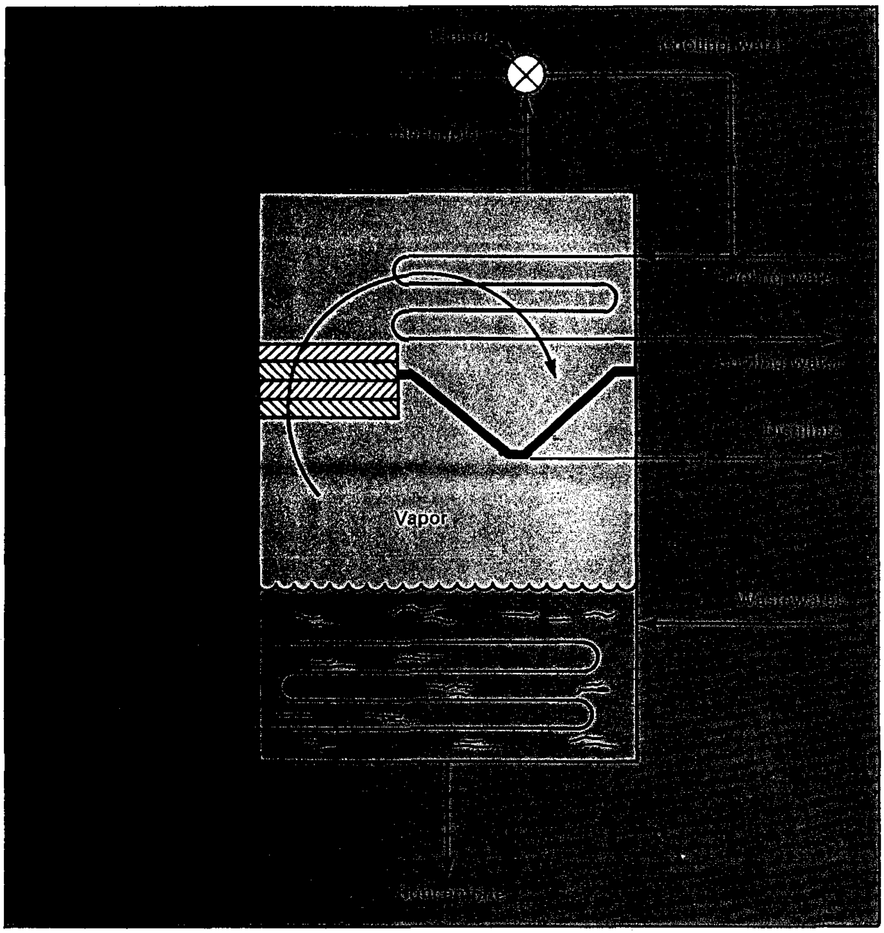


Figure 11.

Submerged Tube Evaporation for Chemical Recovery

Submerged Tube Evaporators. Submerged tube evaporators operate on a slightly different principle from that of film or flash evaporators for supplying thermal energy to the wastewater. As shown in Figure 11, steam, at 5 to 15 lb/in^2 gauge (1,018 to 1,536 mm Hg absolute), or hot water, at approximately 160° F (71° C), is supplied to heating coils that are immersed in the boiling wastewater. A single-effect unit consists of one vessel that includes internal heating coils for evaporation, a moisture separator, and cooling coils for condensing water vapor. The wastewater is not recirculated, unlike that of rising film and flash evaporators.

Submerged tube units are designed to operate under a pressure as low as 0.7 to 1.3 lb/in^2 absolute (36 to 67 mm Hg absolute). This pressure is created by diverting part of the cooling water through an eductor external to the unit. The distillate is recycled to the rinse tanks or for other plant uses. The plating solution is recycled to the plating tanks after the desired concentration is reached.

The cost for submerged tube evaporators usually is lower than that for rising film or flash units, primarily because of the integrated evaporation/condensation single-unit design. The steam or thermal demand is the same as that for rising film evaporators.

Atmospheric Evaporators. Atmospheric evaporators, as shown in Figure 12, do not recover the distillate for reuse and do not operate under a vacuum. Wastewater is evaporated by using it to humidify air flowing through a packed tower. The humidified air is exhausted to the atmosphere; this procedure eliminates the need for cooling water and a condenser. The concentrate from the reservoir is circulated continuously through the packed tower at a rate of approximately 50 gal/min (189 l/min). Contaminated rinse water enters the system and mixes with the concentrate in the reservoir. The wastewater is recirculated through the shell-and-tube heat exchanger, where steam is used to raise the temperature of the solution to approximately 160° to 170° F (71° to 77° C). Ambient air is drawn in through the packed tower, where it becomes saturated with water vapor and is exhausted to the atmosphere. Because the exhaust air removes some of the heat supplied by the wastewater heat exchanger, this type of unit requires approximately 20 percent more steam than do evaporators of other designs.

Deionized water is added to the rinse tanks to make up for all of the water lost to the humidified air. Deionized water is required to minimize the scale deposit from evaporation.

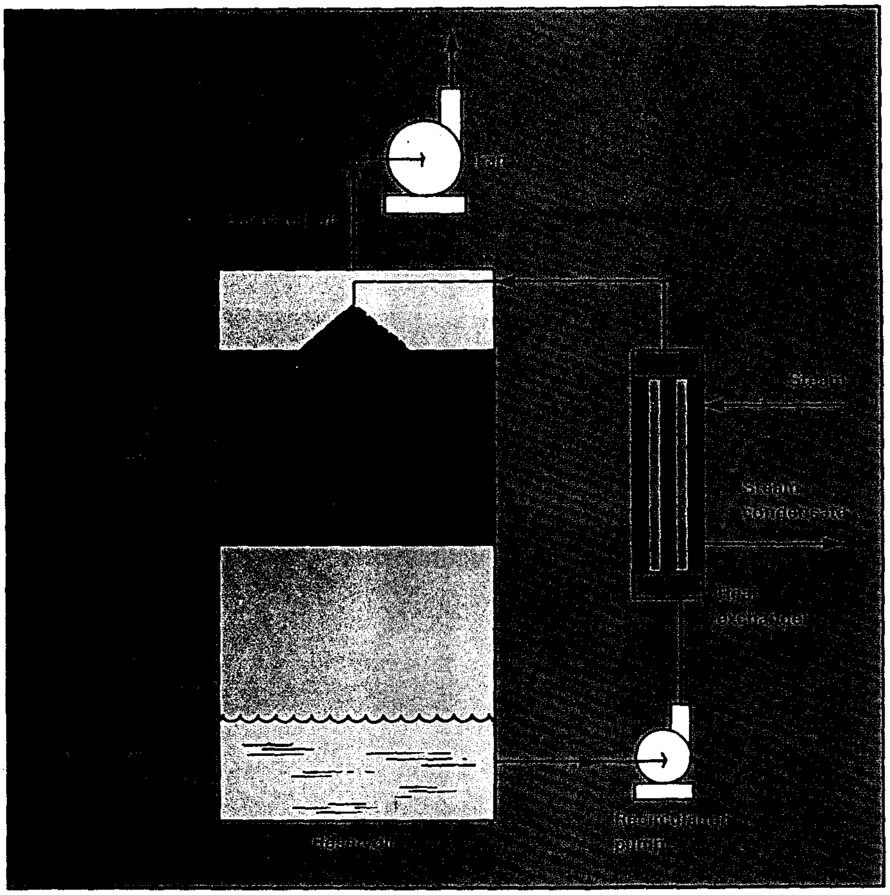


Figure 12.

Atmospheric Evaporation for Chemical Recovery

Operating Requirements for Evaporators

Introduction. The major operating costs for evaporators include operating labor, maintenance, and utilities. The utility requirements include steam or hot water, cooling water, and electricity. Instrumentation and controls may be electrical or pneumatic; if pneumatic, an air supply will be required. Fixed costs, such as depreciation and interest on borrowed capital, also are incurred.

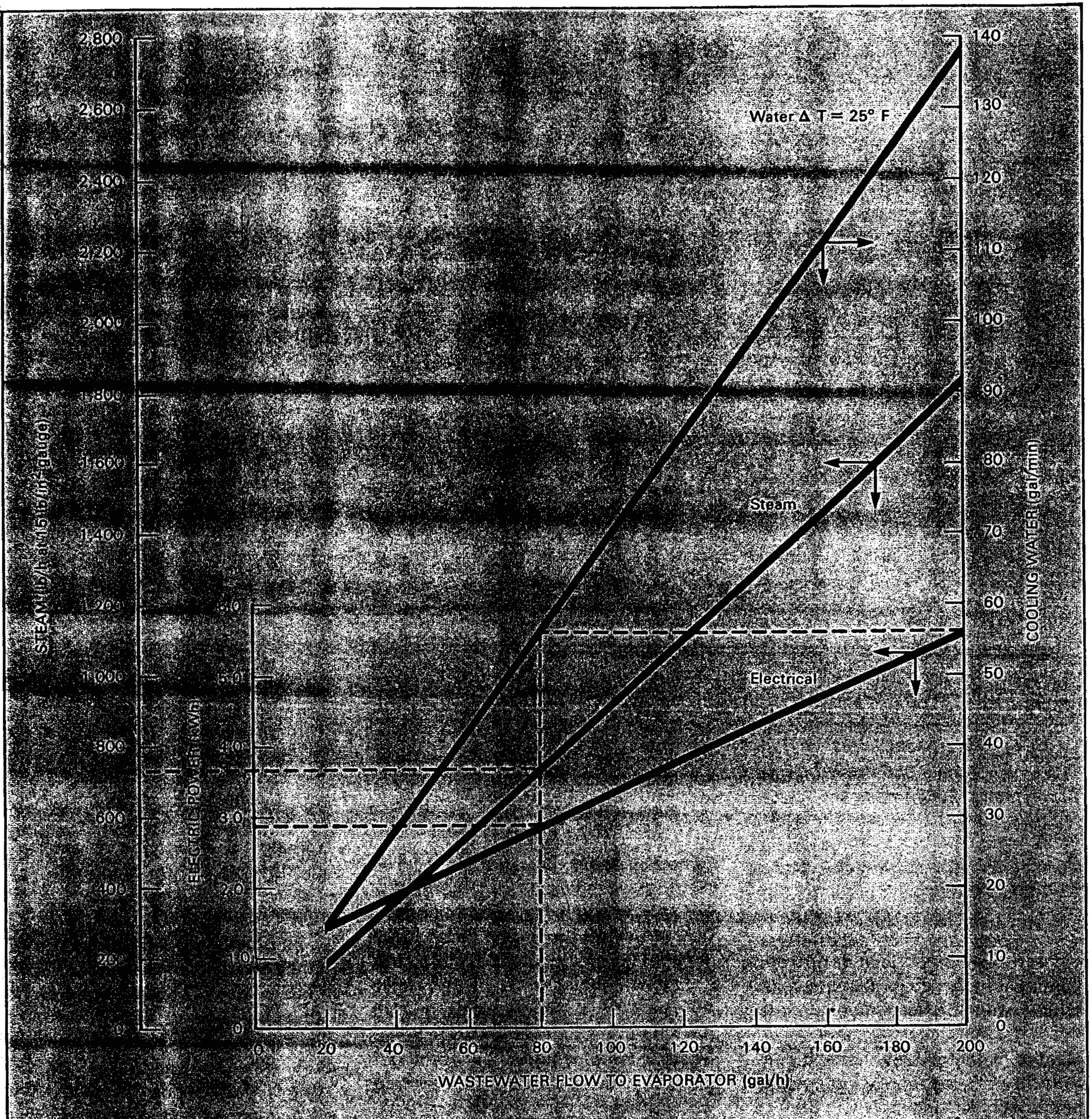
Operating Labor. Evaporators usually are trouble-free systems that require, typically, less than one-half hour per shift of operator attention. Evaporator operation may be manual or automatic.

A manual system is started up by opening the steam supply and the wastewater inlet valves and starting the recirculation, vacuum, and cooling water pumps. In some systems, the vacuum pump and distillate pump are the same; in others, the cooling water pump also creates the vacuum through an eductor. The system is shut down by closing the wastewater inlet and steam supply valves.

Some automatically controlled systems are equipped with concentration sensor/controllers that monitor the plating concentration. When the desired concentration is reached, the automatic controls close the wastewater inlet valve and return the concentrate to the plating bath or holding tank. The systems are sized so that the return of the plating chemicals to the bath occurs approximately once per shift. Other systems are designed to operate continuously with no interruption to the wastewater feed.

Single-Effect Evaporators: Utility Requirements. Most evaporators used in the plating industry are single-effect units, as illustrated earlier. Single-effect evaporators operate with one reboiler or evaporator section. The water vapor is condensed or exhausted to the atmosphere. Approximately 1.1 pound (0.5 kg) of steam is consumed in evaporating each pound of water from the plating solution. Various methods can be employed for reusing the thermal energy of the water vapor to reduce the thermal energy demand; however, additional capital investment is required.

Figure 13 shows the utility requirements for single-effect evaporators as a function of wastewater flowrates to the evaporator. Because the typical application requires evaporation of over 98 percent of the water, the evaporator ratings are based on wastewater flowrates. Changes in concentration of the plating chemicals do not affect the utility demand significantly if the flowrate remains constant; however, the plating chemical concentration will have a significant effect on the economics and cost savings.



Notes: — Evaporation at 1.3 lb/in² absolute. Wastewater feed at 100° F. Cooling water supply at 70° F. Steam supply at 15 lb/in² gauge. Rising film or submerged tube. Example: A single effect evaporator boiling 80 gal/h of wastewater at 1.3 lb/in² absolute pressure has the following utility requirements: steam (15 lb/in² gauge), 730 lb/h; electric power, 2.9 kWh; cooling H_2O at Δ T = 25° F, 56 gal/min.

Figure 13.

Utility Requirements for Single-Effect Evaporation

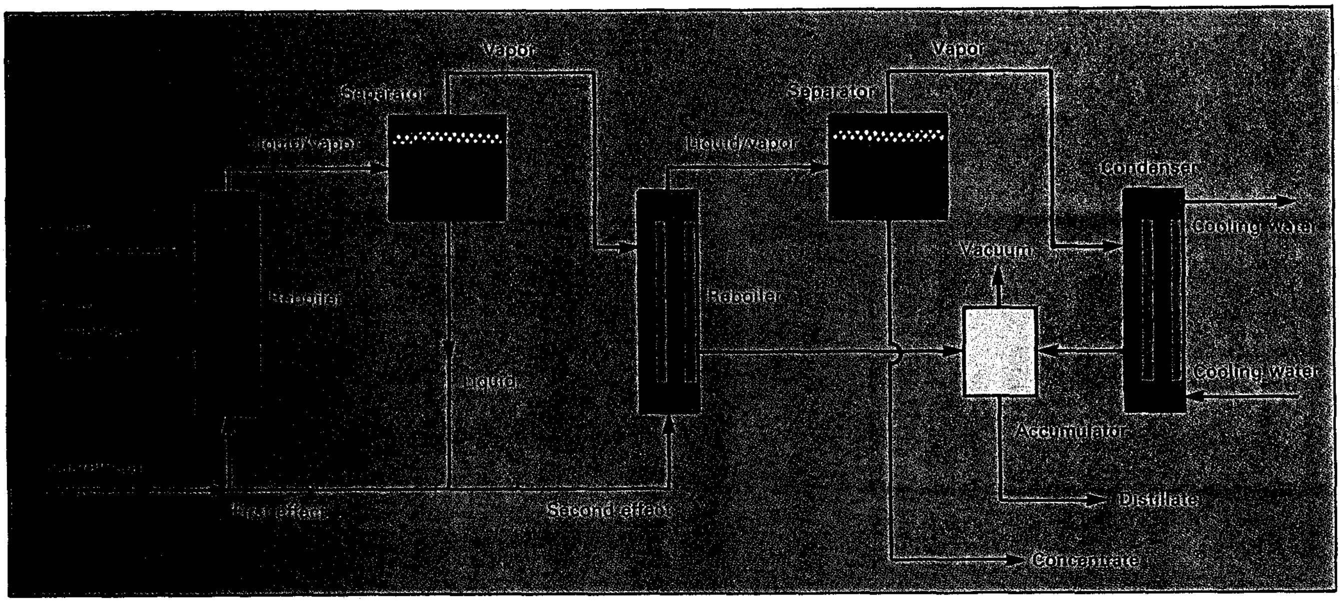


Figure 14.

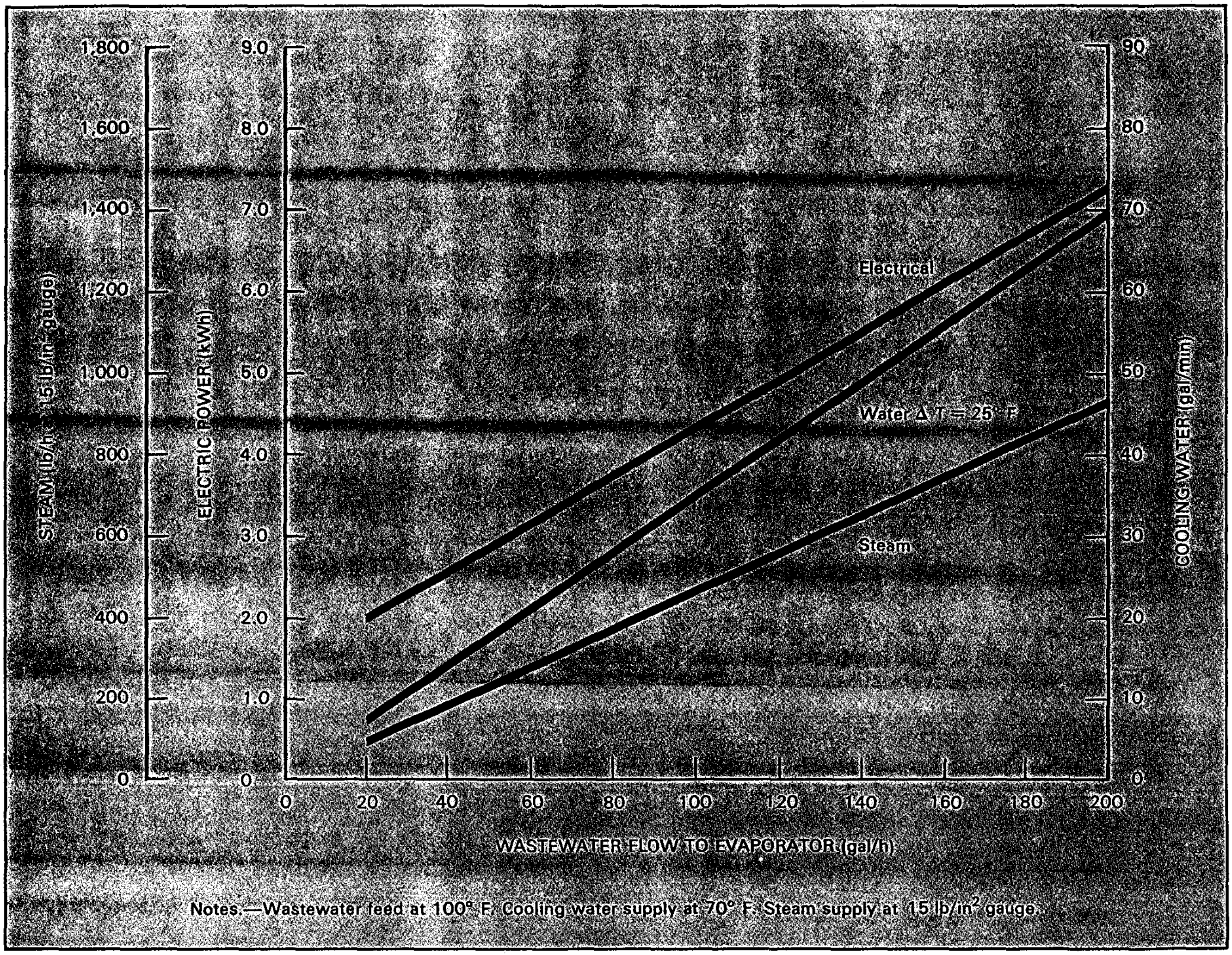
Double-Effect Evaporation for Chemical Recovery

The electrical demand is associated with power requirements of the vacuum pump, recirculation pump, and feed pump. As a rule, the cooling water rates are based on a temperature rise of 25° F (14° C) across the condenser.

For example, from Figure 13, if the wastewater flowrate to the evaporator is 80 gal/h (303 l/h), the steam rate is 730 lb/h (331 kg/h) for 15 lb/in^2 gauge (1,536 mm Hg absolute) steam. The electrical demand is 2.9 kWh and the cooling water rate is 56 gal/min (212 l/min). For atmospheric evaporators where no cooling water is used, the steam rate would be at least 20 percent higher.

Methods for Reducing Steam Rates. Two techniques have been applied successfully to reduce steam demand for evaporation; both involve reusing the heat value contained in the vapor from the separator.

The most common technique is to use a double-effect evaporator, as shown in Figure 14. In this system, approximately 50 percent of the wastewater is concentrated in the first effect using steam. The vapor from the separator of the first effect enters the second-effect reboiler and condenses to provide the thermal energy required to reach the final concentration of the plating solution. Rising film, flash, and submerged tube evaporators can be employed in this manner; however, the capital costs are significantly increased because of the need for an additional reboiler and separator. The



Notes.—Wastewater feed at 100° F. Cooling water supply at 70° F. Steam supply at 15 lb/in² gauge.

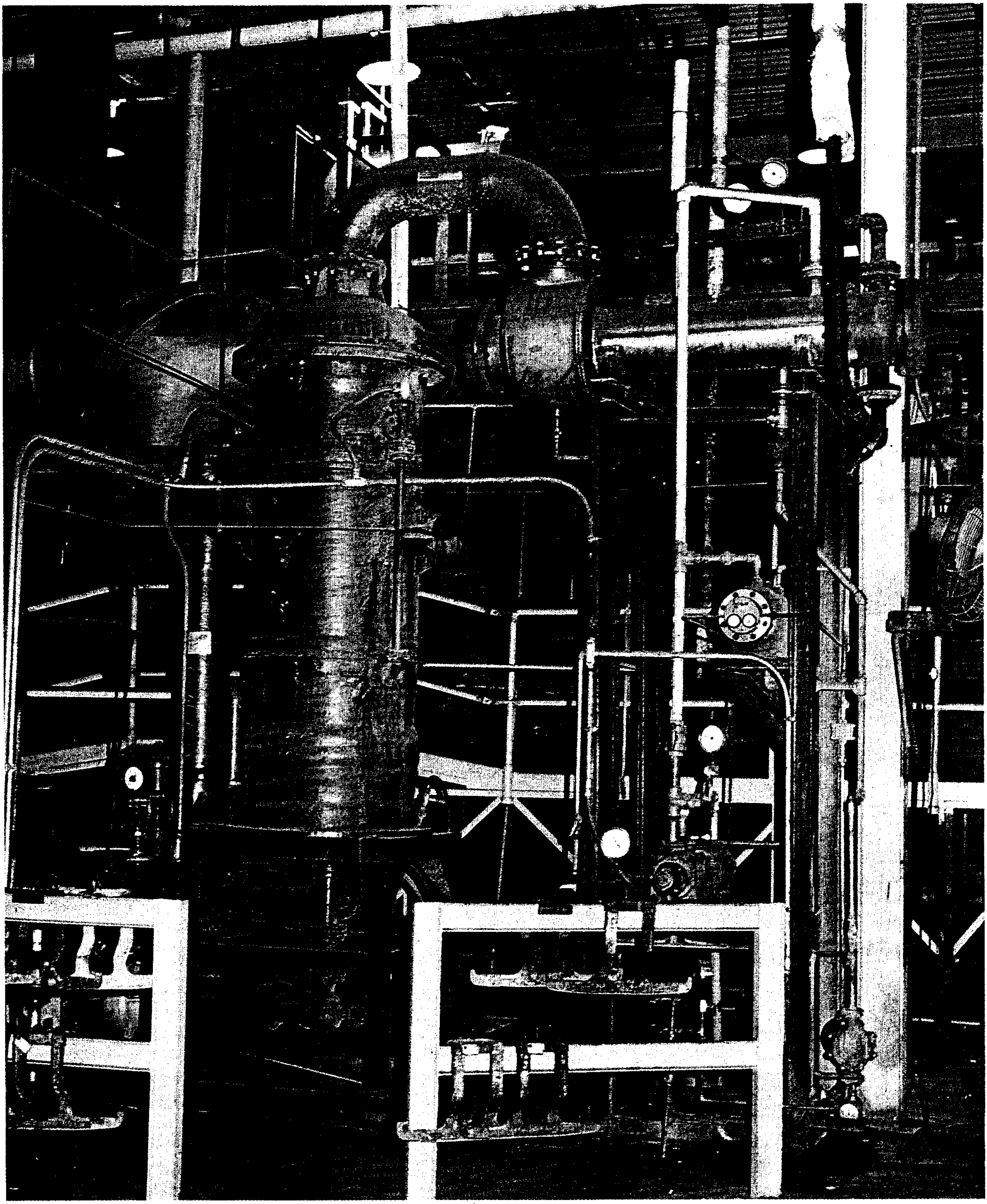
Figure 15.

Utility Requirements for Double-Effect Evaporation

steam and cooling water rates for the double-effect unit (Figure 15) are approximately 50 percent of those required for the single-effect unit (see Figure 13).

Some platers using double-effect units achieve an additional benefit by recovering two different plating baths simultaneously. Care should be taken in employing this arrangement however, because there is a possibility of cross-contaminating baths.

The second technique is to use a mechanical compressor (Figure 16). The water vapor from the separator enters the suction of the compressor where its temperature and pressure are increased. The vapor is then desuperheated and enters the reboiler. The mechanical vapor recompression system requires no external steam or cooling water; this characteristic eliminates the need for capital investment in boilers and cooling towers. Currently the application of this system is limited to alkaline plating solutions because acid carryover can cause corrosion damage to the compressors.



Double-effect evaporator: first-effect vapor separator and second-effect reboiler

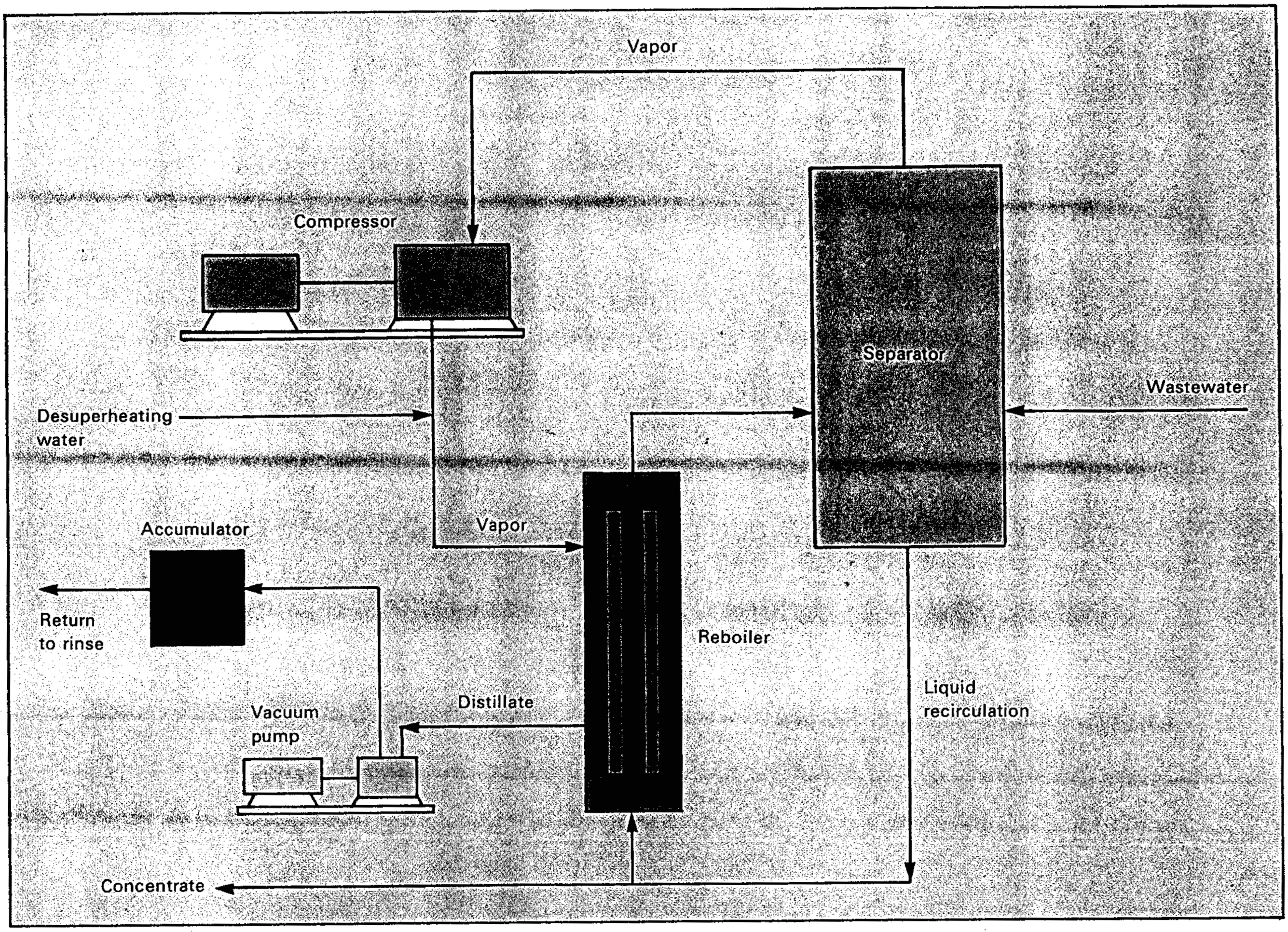


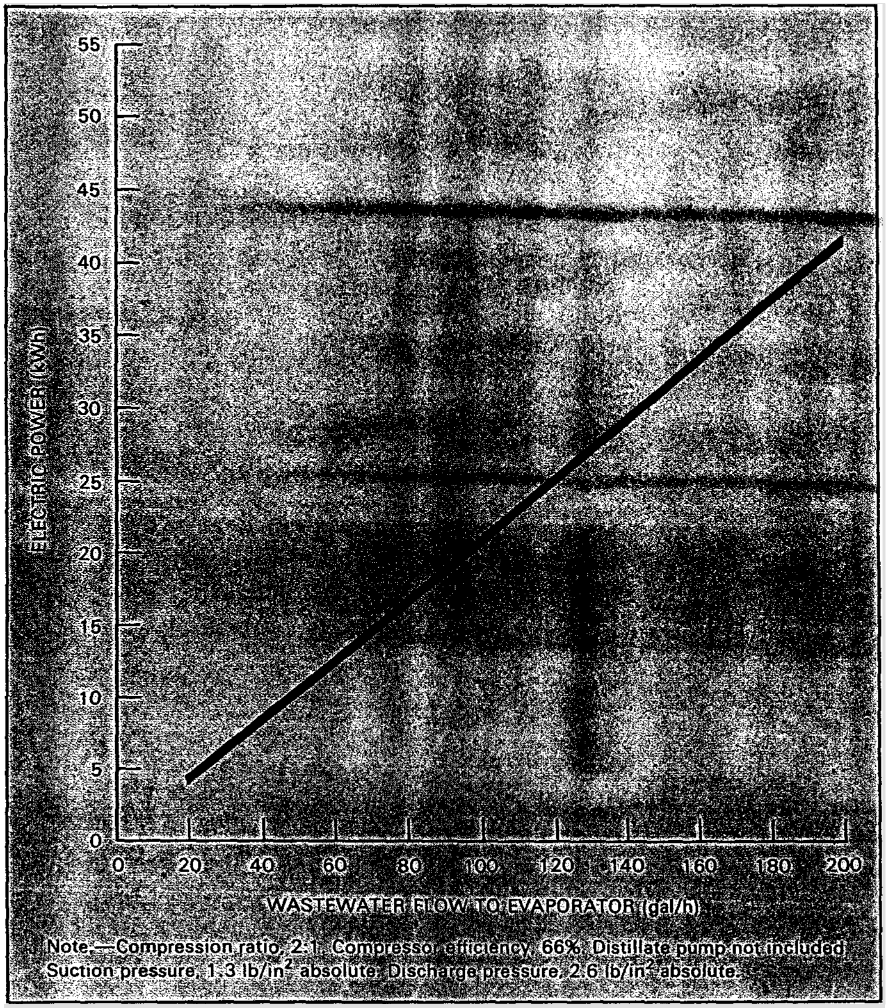
Figure 16.

Mechanical Vapor Recompression Evaporation for Chemical Recovery

The initial investment cost for mechanical vapor recompression is the highest among equivalent capacity single- and double-effect units; however, this technique has the lowest operating cost.

Figure 17 shows the electric utility requirements for mechanical vapor recompression units as a function of capacity.

The application of mechanical vapor recompression and multiple-effect evaporators should be considered when the additional investment costs can be economically justified by the reduced operating costs.



Note.—Compression ratio, 2:1. Compressor efficiency, 66%. Distillate pump not included. Suction pressure, 1.3 lb/in^2 absolute. Discharge pressure, 2.6 lb/in^2 absolute.

Figure 17.

Utility Requirements for Mechanical Vapor Recompression Units

Closed-Loop and Open-Loop Systems for Evaporation

The capacity of the evaporator will depend on the rinse flow rates and the level of recovery desired. As discussed earlier, the mass flow rate of the plating chemicals entering the rinse tank is based on drag-out. This rate sets the total raw material savings. The concentration of the plating chemicals entering the evaporator will depend on the rinse ratio and the number of rinse tanks for a fixed drag-out concentration and rate. Because the utility requirements and evaporator capacity are primarily a function of rinse water flowrate, it is important to reduce the flowrate to the evaporator by using multiple rinse tanks, thereby increasing the concentration of plating chemicals. An optimum closed-loop or open-loop system can be developed to reduce the costs for evaporation.

If three or more rinse tanks are used, the rinse ratio usually will be low enough to make closed-loop recovery economical. The closed-loop system allows maximum recovery of plating chemicals. For example, if a plant operating a chromium plating bath at a concentration of 45 oz/gal (337 g/l) and having a three-tank rinse system maintains the final rinse concentration at 0.002 oz/gal (15 mg/l), the required rinse ratio would be 28 (Figure 5). If the drag-out rate were 1 gal/h (3.78 l/h), then a closed-loop evaporator system would require a minimum capacity of 28 gal/h (106 l/h). Recovery of 99 percent of the drag-out would be possible.

A similar plant having the same plating bath and final rinse tank concentrations, but having only two rinse tanks, would require a rinse ratio of 150 (Figure 5). At the drag-out rate of 1 gal/h (3.78 l/h), the minimum evaporator capacity would be 150 gal/h (568 l/h), or a little greater than five times the capacity of a three-tank rinse system. The same 99 percent plating recovery would result.

The plant with the two-stage rinse system would have two alternatives: it could install another rinse tank or it could operate the two rinse tanks as an open-loop recovery system (Figure 18). The disadvantage of an open-loop system is that the rinse water rate of the final rinse tank (which requires chemical treatment) will increase considerably. The overall recovery of the two-stage system, however, will be only slightly lower than that achievable with the three-tank rinse system.

At a rinse ratio of 28 in the first rinse tank, there is 96.5 percent recovery of plating chemicals from drag-out. The rinse ratio for the second tank is set to maintain the final rinse concentration of 0.002 oz/gal (15 mg/l). This rate is calculated by determining the concentration in the first rinse tank (from Figure 7), which, at a rinse ratio of 28 and a plating bath concentration of 45 oz/gal (337 g/l), is 1.6 oz/gal (12 g/l). Figure 5 will give the rinse ratio

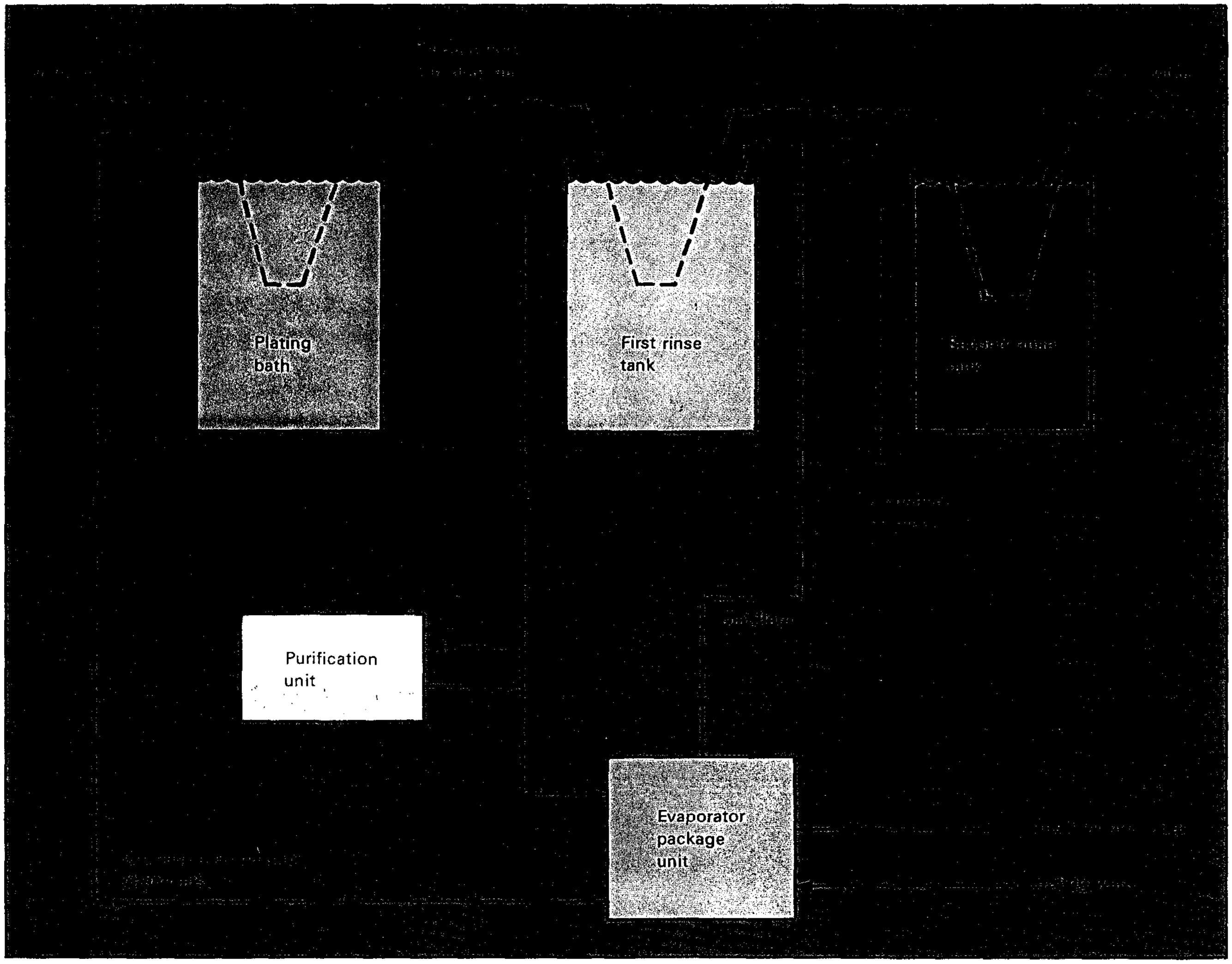


Figure 18.

Open-Loop Evaporative Recovery of Plating Chemicals from Drag-Out

required in the second tank to achieve a dilution ratio of 800 ($C_p/C_n = 800$). If the drag-out rate were 1 gal/h (3.78 l/h), the rinse water flowrate needed in the second tank to achieve the final discharge concentration of 0.002 oz/gal (15 mg/l) would be 800 gal/h (3,028 l/h).

If an open-loop system with a two-stage rinse is used, the volume of wastewater processed by the evaporator is the same as the volume processed in a three-stage closed-loop system—28 gal/h (106 l/h). Although the utility requirements are the same for evaporation, the open-loop system will result in slightly less chemical recovery and in increased rinse water and chemical treatment costs.

For plants that cannot reduce the rinsing rates, open-loop systems provide the opportunity to use evaporative recovery in an economically feasible manner. As a rule, the most economical approach is to add additional rinse tanks to minimize the rinse rate required in a recovery rinse and in a free rinse, where chemical treatment of the rinse water is required.

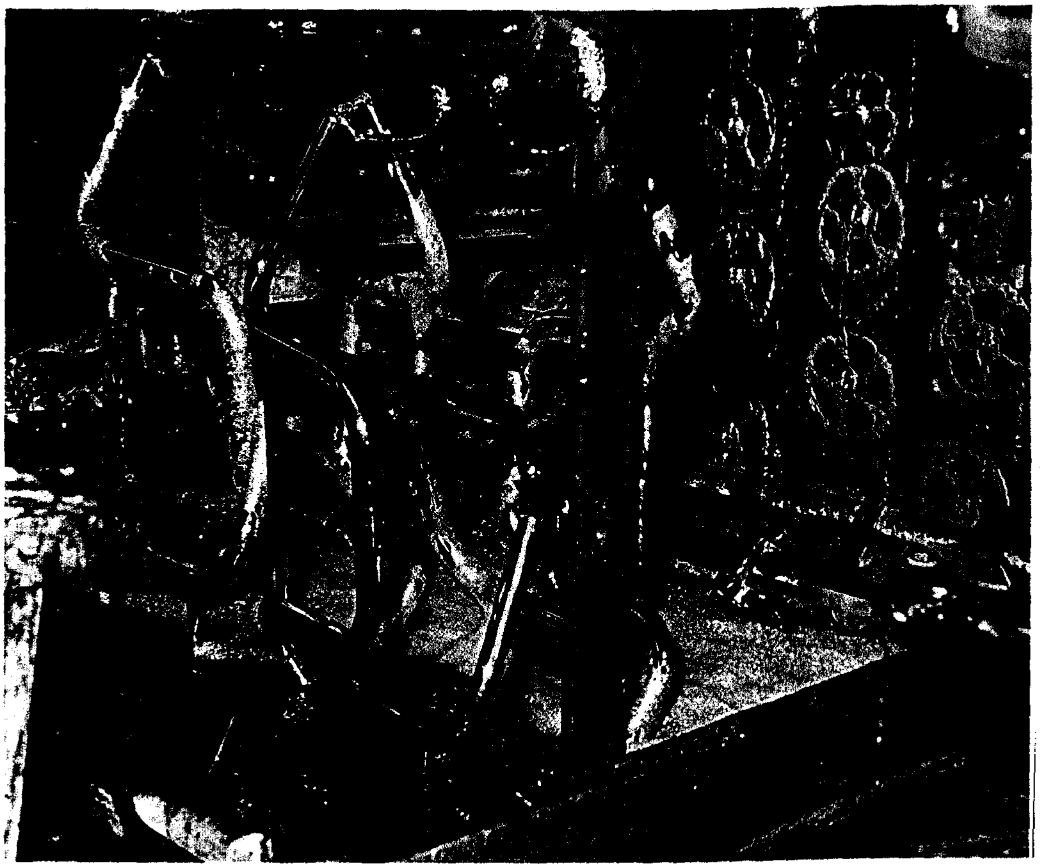
Economics

Investment Costs for Evaporators

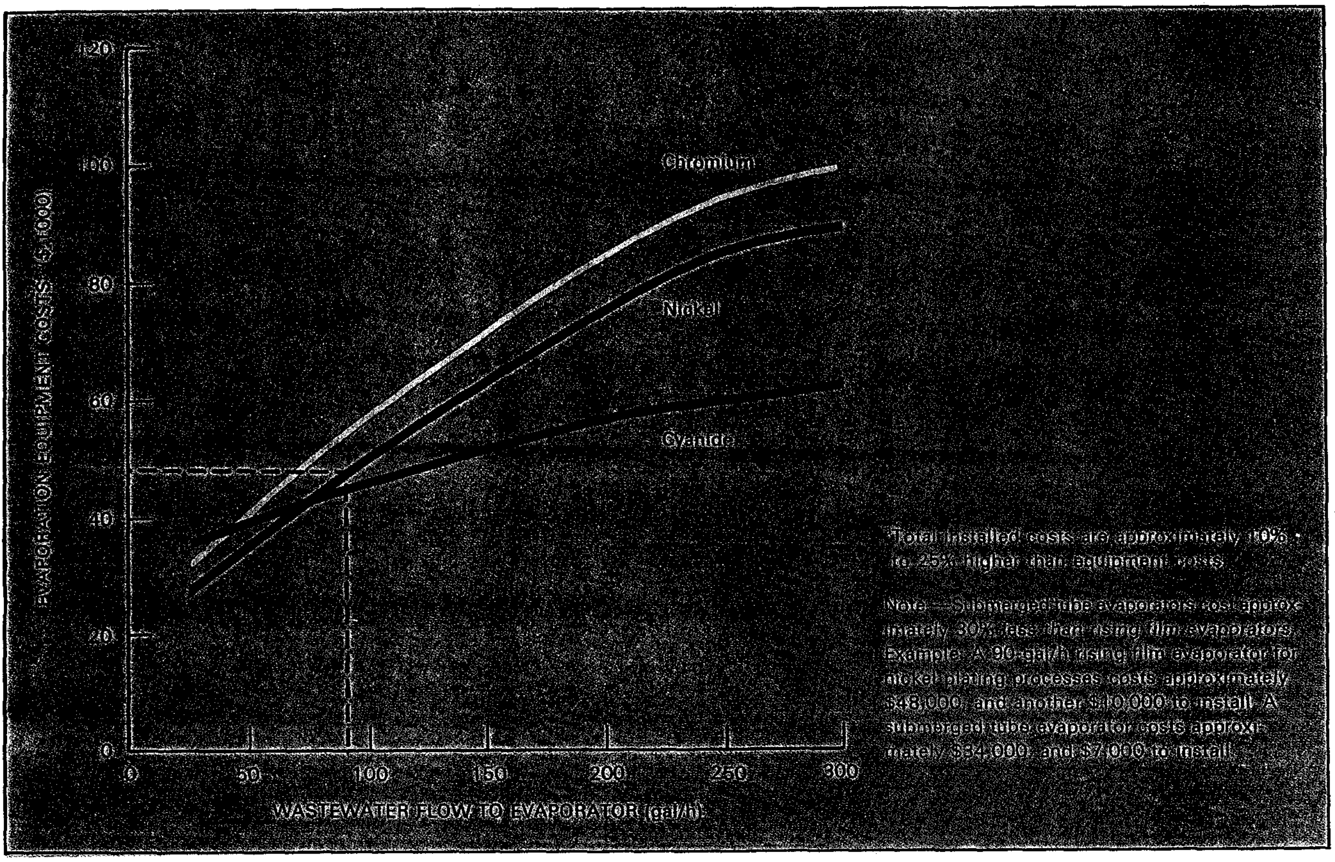
The investment costs for evaporators depend on the capacity, design, and materials of construction. For each type of evaporator, the major difference in investment costs depends on the materials of construction. Most evaporators are supplied as package units and only require the hook-up of utilities before startup.

Evaporators currently are marketed with a wide range of construction materials to resist the corrosiveness of many of the plating chemicals. The more popular materials include titanium, tantalum, borosilicate glass, fiberglass-reinforced plastic (FRP), stainless steel, and polyvinyl chloride (PVC). Carbon steel can be used for condensers when there is no chance for rust contamination of the distillate.

Figure 19 shows the approximate installed costs for complete package, single-effect, rising film evaporators excluding a bath purification system. The investment costs for submerged tube evaporators are approximately 30 percent lower, primarily because of the integrated evaporation/condensation single-unit construction.



Chromium plating of bicycle parts



Total installed costs are approximately 10% to 25% higher than equipment costs.

Note — Submerged tube evaporators cost approximately 30% less than rising film evaporators. Example: A 90-gal/h rising film evaporator for nickel plating processes costs approximately $48,000, and another $10,000 to install. A submerged tube evaporator costs approximately $34,000, and $7,000 to install.

Figure 19.

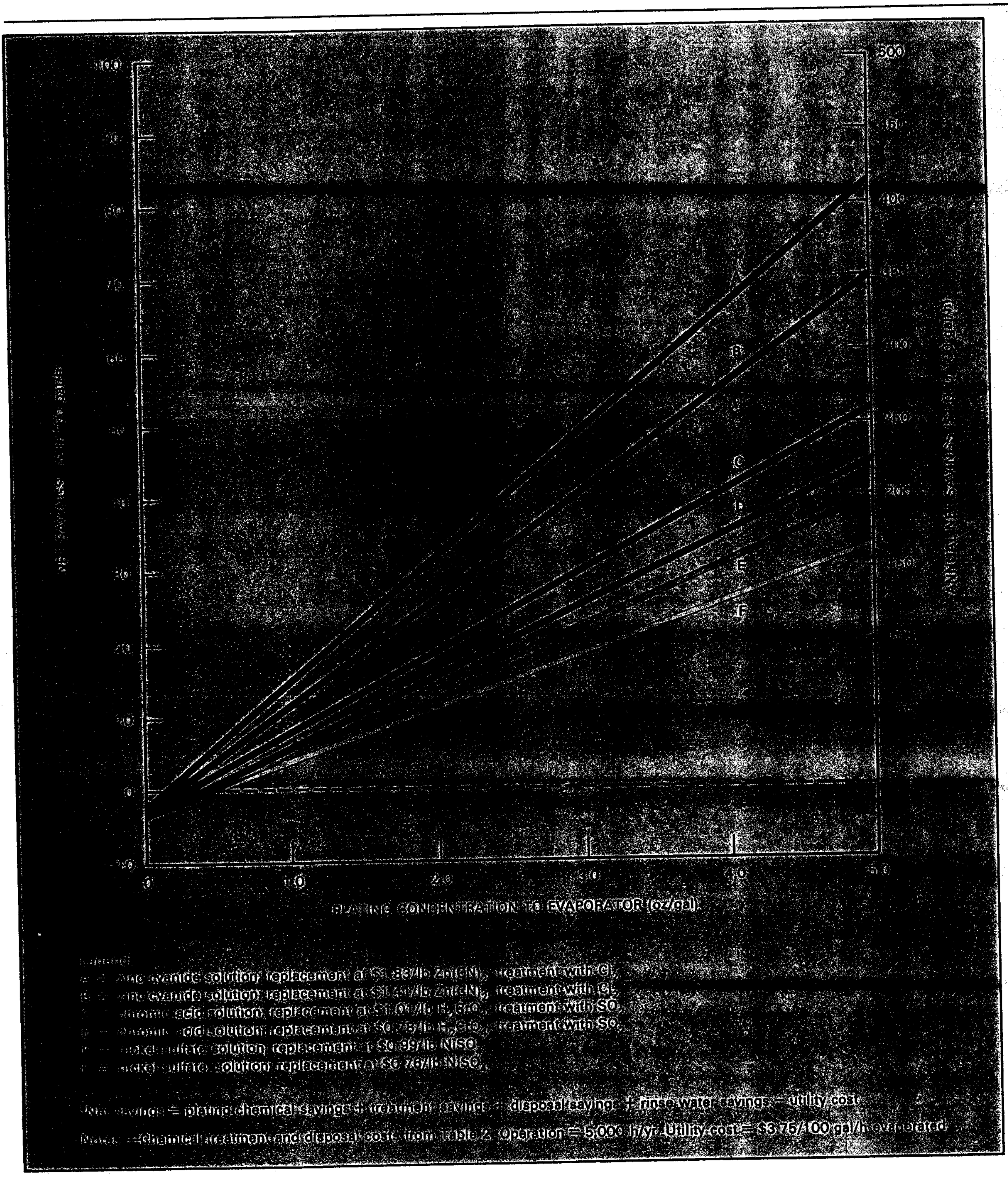
Capital Cost of Single-Effect Rising Film Evaporators

For rising film evaporator capacities above 100 gal/h (378 l/h), the investment costs for double-effect units will be approximately 30 percent higher than for single-effect systems. The investment costs for mechanical vapor recompression evaporators are approximately 50 percent higher than for single-effect units. Maintenance costs also are higher for mechanical vapor recompression units. The costs for installation of package evaporators range from 10 to 25 percent of the hardware costs. Installation costs for larger evaporators will be a lower percentage of the hardware costs because essentially the same utility hook-ups are required and only line sizes will change. The economics for evaporative recovery systems depend primarily on savings in plating chemicals and wastewater treatment costs. These savings will be used with the investment costs for rising film evaporators to illustrate the economics.

Chemical and Treatment Cost Savings

Figures 20 and 21 show the net savings attributable to recovery of three typical plating solutions, using the cost basis of Tables 1 and 2, for each 100 gal/h (378 l/h) of wastewater concentrated in single-effect and double-effect evaporators. Net savings is determined by adding the raw materials savings for plating chemical replacement and the reduction in chemical treatment costs, including costs for sludge disposal, and then subtracting the utility costs (electricity, steam, and cooling water) of the evaporator. The figures also show the impact on net savings of different plating chemical costs.

To illustrate the effects of the concentration and the evaporator capacity on net savings, assume that a chromium plating line has a drag-out rate of 1.5 gal/h (5.7 l/h), a closed-loop rinse system with a rinse ratio of 100, and a plating bath concentration of 50 oz/gal (375 g/l). From Figure 7, the concentration of rinse water entering the evaporator is 0.5 oz/gal (3.7 g/l) and the flowrate is 150 gal/h (568 l/h)—1.5 gal/h (5.7 l/h) drag-out × rinse ratio of 100. From Figure 20, the net savings is approximately $1.50/h ($1/h × 150/100), assuming a plating replacement cost of $0.78/lb, curve D. Approximately 1.5 gal/h (5.7 l/h) of plating chemicals are returned to the bath. If the rinse system is modified to reduce the rinse ratio to 20, the concentration of plating chemicals entering the evaporator increases to



Legend:

A = zinc cyanide solution; replacement at $1.83/lb $Zn(CN)_2$, treatment with Cl_2

B = zinc cyanide solution; replacement at $1.49/lb $Zn(CN)_2$, treatment with Cl_2

C = chromic acid solution; replacement at $1.07/lb H_2CrO_4, treatment with SO_2

D = chromic acid solution; replacement at $0.78/lb H_2CrO_4, treatment with SO_2

E = nickel sulfate solution; replacement at $0.99/lb $NiSO_4$

F = nickel sulfate solution; replacement at $0.76/lb $NiSO_4$

Net savings = plating chemical savings + treatment savings + disposal savings + rinse water savings − utility cost

Notes: Chemical treatment and disposal costs from Table 2. Operation = 5,000 h/yr. Utility cost = $3.75/100 gal/h evaporated.

Figure 20.

Plating Chemical and Wastewater Treatment Savings for Single-Effect Evaporative Recovery Systems

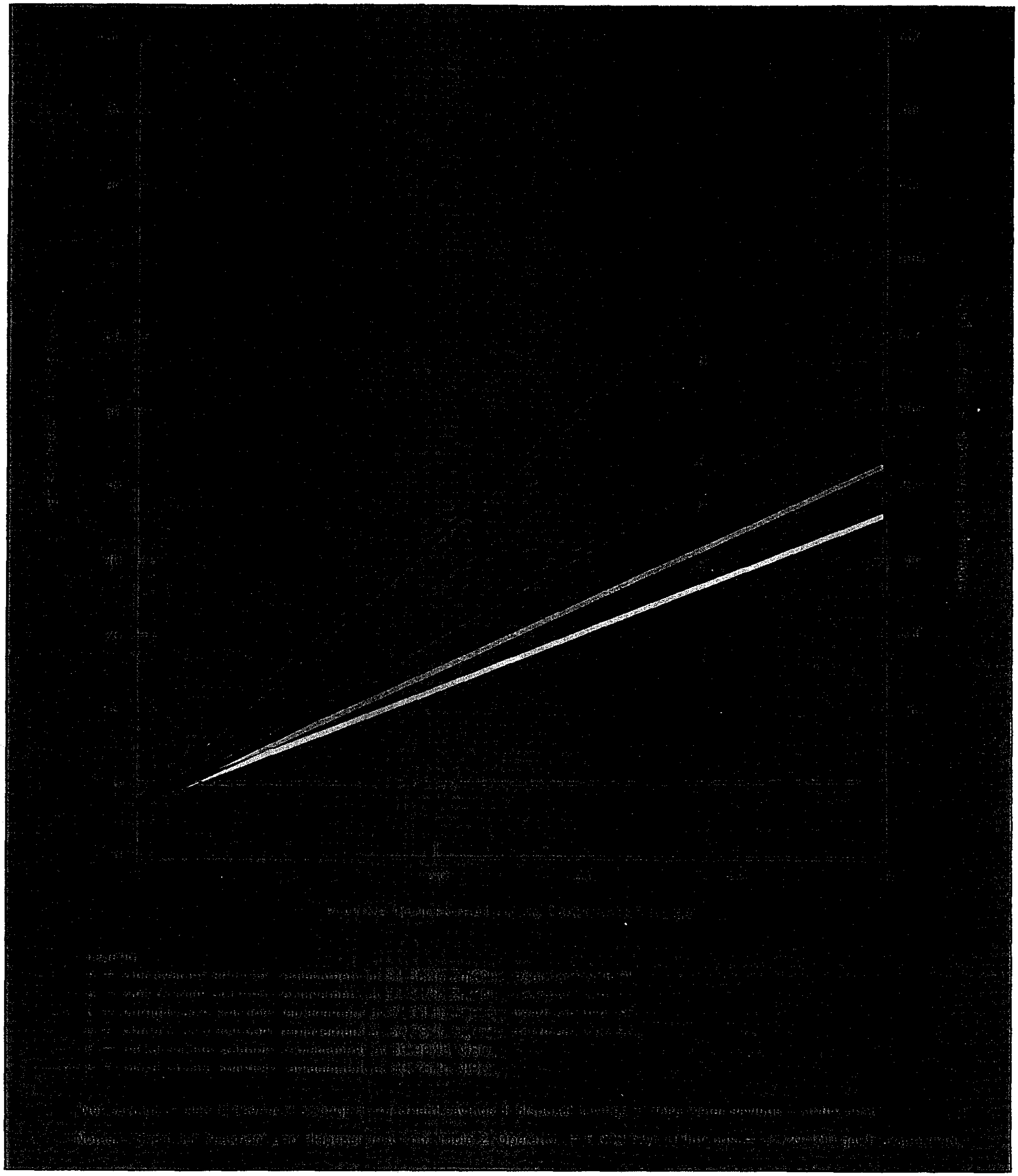


Figure 21.

Plating Chemical and Wastewater Treatment Savings for Double-Effect Evaporative Recovery Systems

2.5 oz/gal (18.7 g/l), Figure 7, and the feed rate decreases to 30 gal/h (114 l/h)—1.5 gal/h (5.7 l/h) drag-out × rinse ratio of 20). From Figure 20, the net savings for recovery increases to \$6.30/h (\$21/h × 30/100). Approximately 95 percent of the plating chemicals contained in the drag-out is returned to the plating bath at 1.5 gal/h (5.7 l/h), but the utility costs for the evaporator are reduced because the evaporation rate is decreased by approximately 120 gal/h (454 l/h). The installed cost for a rising film evaporator to recover the drag-out is decreased from \$90,000 for a 150-gal/h (568-l/h) unit to \$42,500 for a 30-gal/h (114-l/h) unit, as shown in Figure 19.

In Figures 20 and 21, the intersection of plating solution curves with the vertical axis gives the utility cost of evaporating 100 gal/h (378 l/h) of water, based on the fuel and utility costs presented in Table 1. The intersection of the plating solution curves with the horizontal axis gives the minimum plating concentration necessary for the cost savings to equal the evaporator utility costs. At plating solution concentrations lower than the minimum needed to offset evaporator operating cost, the recovery system will yield a net operating loss.

Because steam requirements are approximately 50 percent lower for the double-effect units, the increased investment, maintenance cost, and operating complexity sometimes can be justified from net savings. For example, from curve D in Figures 20 and 21, at a chromic acid concentration of 1.0 oz/gal (7.5 g/l), the double-effect evaporator would have a net savings of \$7.50/h compared with \$5.50/h for a single-effect unit for each 100 gal/h (378 l/h) of wastewater evaporated. By comparison, a mechanical vapor recompression unit evaporating 100 gal/h (378 l/h) would have a utility cost of approximately \$1/h as determined from Figure 17—21 kWh (75,600 kJ) × \$0.045/kWh. Because of the lower operating cost, the net savings would be \$2.75/h (\$3.75 − \$1.00) greater than that of a single-effect unit.

Table 3.

Basis for Estimating Costs for Investment Options and Economics

Item	Basis
Operating expenses:	
Operating labor[a]	\$8/h
Supervision[b]	\$10/h
Maintenance	6% of total investment cost
General plant overhead	0.58 × (operating labor + supervision + maintenance labor); *maintenance labor* = 0.37 × maintenance cost
Depreciation (10-yr straight line)	10% of total investment
Taxes and insurance	2% of total investment
Federal taxes	48% of annual before-tax profit
Interest on borrowed capital	10% on unpaid balance
Utility charges:	
Electricity	\$0.045/kWh
Cooling water:	
Once through city water	\$0.50/1,000 gal
Cooling tower	\$0.10/1,000 gal
Steam, based on No. 2 fuel oil	\$3.50/1,000 lb
Annual operating time	5,000 h
Annual profit before tax (\$/yr)	Operating cost reduction (savings) resulting from investment minus increase in fixed and operating cost for new system
Annual profit after tax (\$/yr)	Annual *before-tax profit* × 0.52
ROI	Annual profit after taxes divided by total installed investment
Cash flow (\$/yr)	Annual profit after taxes plus depreciation
Payback period (yr)	Total installed investment divided by cash flow
DCF rate of return (%)	Interest rate on capital recovery for the total investment based on the annual cash flow

[a] Evaporator operating labor requirement assumed at 0.5 h per shift (average expense \$2,500/yr).

[b] Taken at 50% of operating labor cost, or \$1,250.

Return on Investment

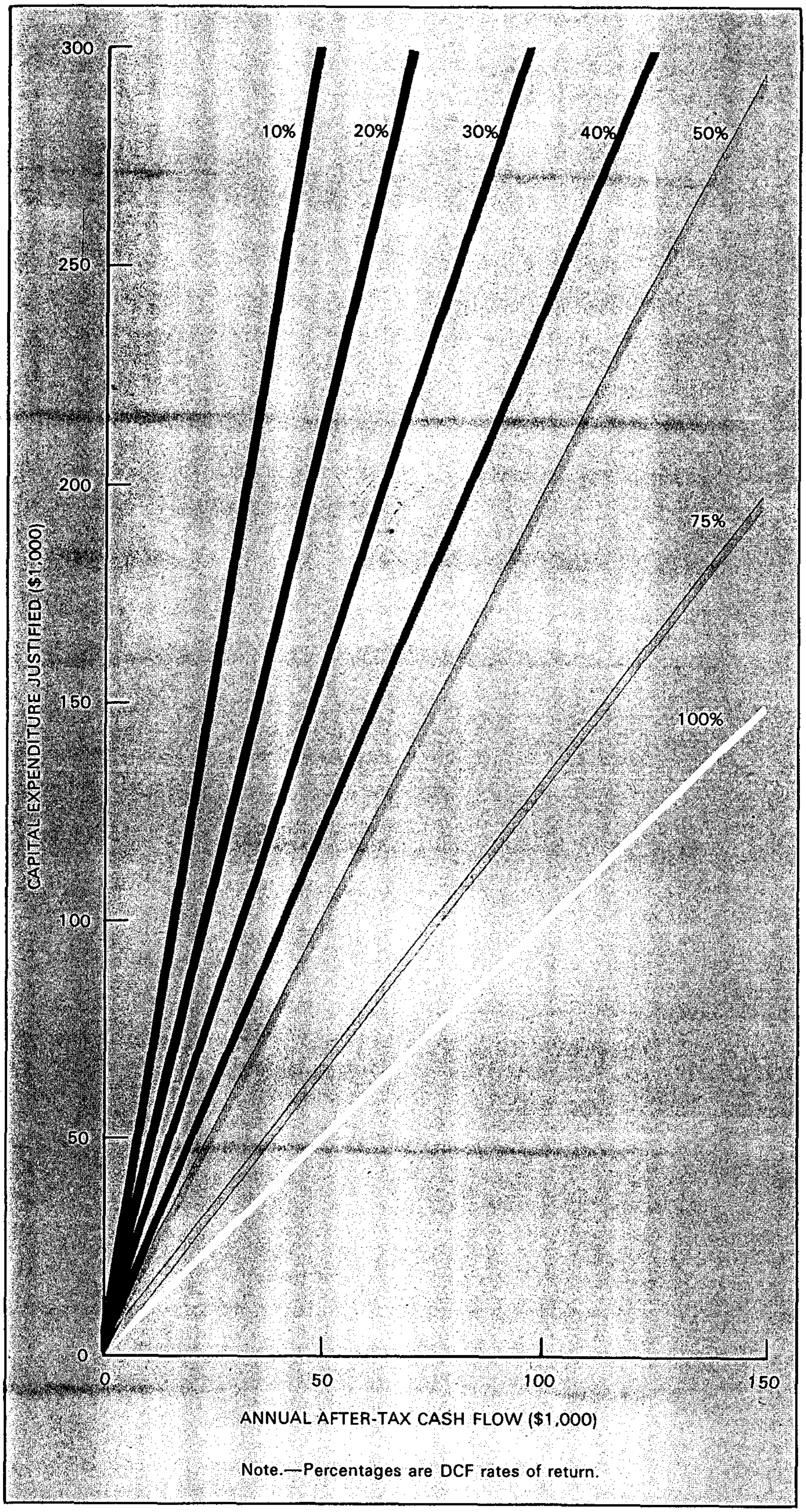
The economics for recovery can be based on the net savings including chemical recovery and reduction in wastewater treatment costs, as illustrated in Figures 20 and 21. Moreover, if the recovery system can reduce the investment cost in waste treatment hardware, then this savings should be factored into the economic analysis.

In addition to utility costs, operating labor and fixed costs such as depreciation, taxes, and insurance will be incurred by the plant. Table 3 shows the basis for the derivation of the return on investment (ROI).

There will be two situations to consider when the potential economic benefits of evaporative recovery are evaluated. In the first case, where a closed-loop evaporative recovery system is installed in a chromic acid or zinc cyanide plating line, the investment cost for treatment hardware can be reduced or possibly eliminated (Figures 3 and 4). The second case assumes that the chromium and cyanide treatment systems also must be installed or already have been installed. In the second case the economics must be based on the total investment costs for the evaporator; in the first case the economics can be based on the investment costs for the evaporators minus any investment cost savings for waste treatment hardware resulting from installation of the evaporator. For nickel sulfate recovery, the investment in an evaporative recovery system will not result in any significant reduction in the investment required for neutralization and clarification hardware.

Before-tax profit is calculated by determining the net savings, as illustrated in Figures 20 and 21, and subtracting the additional costs, such as operating labor, maintenance labor, and depreciation (Table 3). The annual after-tax cash flow then may be estimated by subtracting 48 percent Federal taxes from the before-tax profit and adding the depreciation expenses.

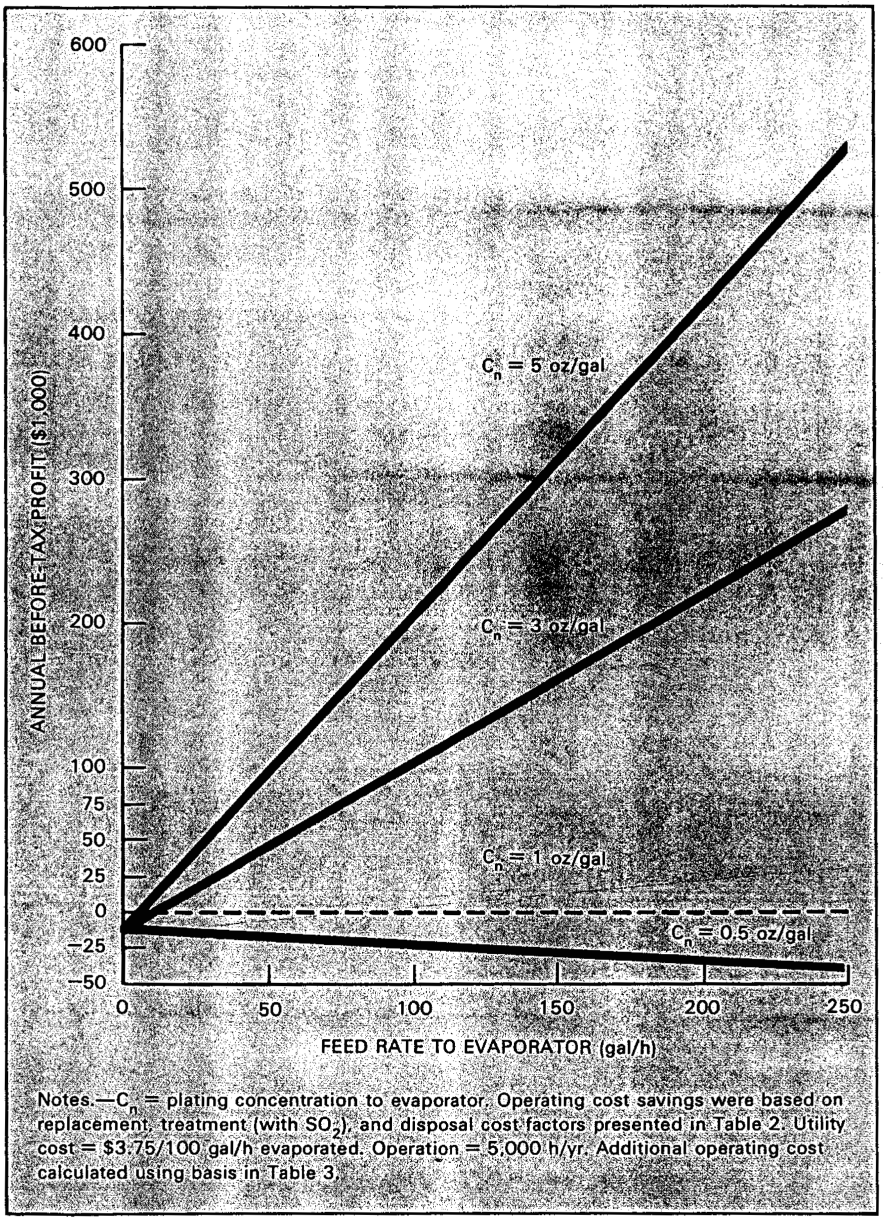
Once the annual after-tax cash flow is known, the capital expenditure justified for a desired discounted cash flow (DCF) rate of return can be obtained from Figure 22. Or, if the total



Note.—Percentages are DCF rates of return.

Figure 22.

Capital Expenditures Justified at DCF Rates of Return for Annual After-Tax Cash Flow



Notes.—C_n = plating concentration to evaporator. Operating cost savings were based on replacement, treatment (with SO_2), and disposal cost factors presented in Table 2. Utility cost = $3.75/100 gal/h evaporated. Operation = 5,000 h/yr. Additional operating cost calculated using basis in Table 3.

Figure 23.

Annual Before-Tax Profit for Single-Effect Evaporative Recovery of Chromic Acid

installed investment cost and annual after-tax cash flow are already known, the resulting rate of return can be obtained from Figure 22. For example, if the capital cost were $75,000 and the annual after-tax cash flow were $25,000, then a 30 percent rate of return would be possible. If the company were to desire a minimum of 20 percent rate of return on its investment, and the annual after-tax cash flow were already calculated to be $25,000, then the maximum capital investment would be $105,000.

Figures 23 through 25 show the annual before-tax profit for evaporative recovery for the three plating solutions typically processed as a function of concentration and flow rates entering single-effect evaporators. The total operating time is set at 5,000 hours. The before-tax profit for recovery of 100 gal/h (378 l/h) of a rinse water containing 1 oz/gal (7.5 g/l) of chromic acid is $5,000 annually (see Figure 23).

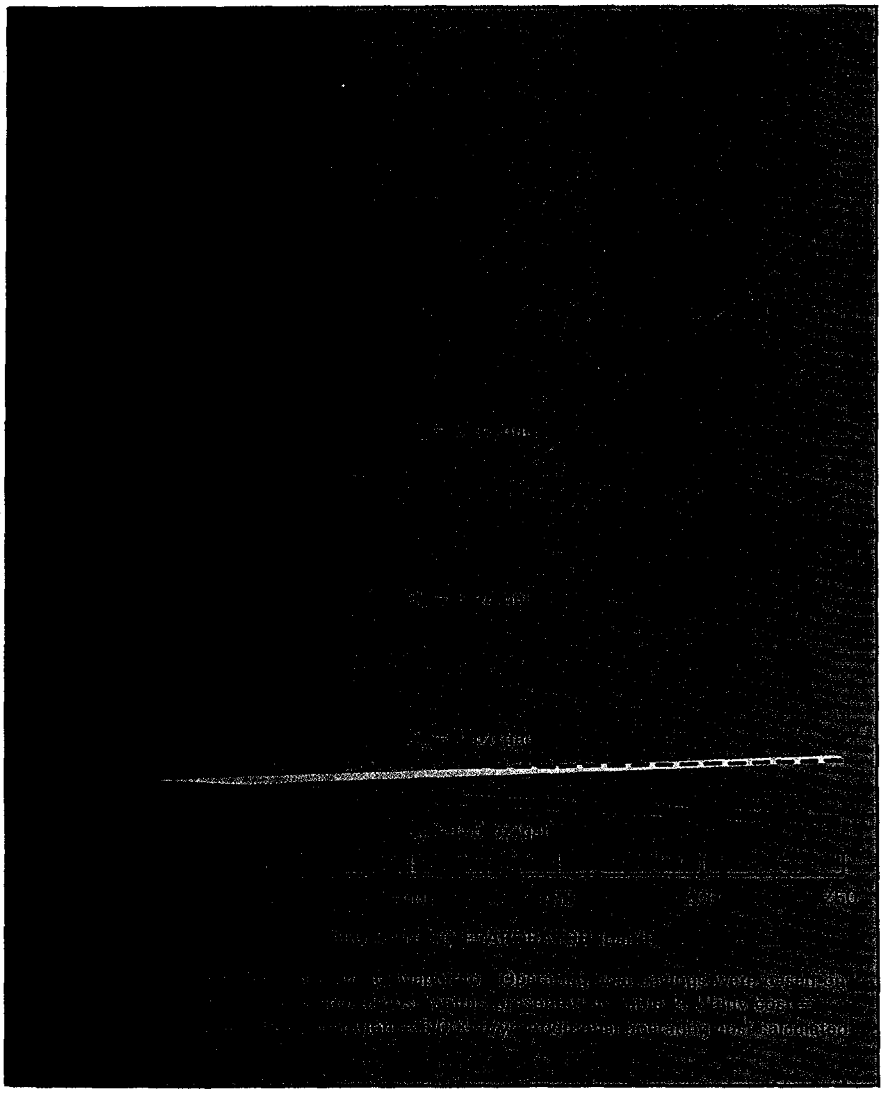
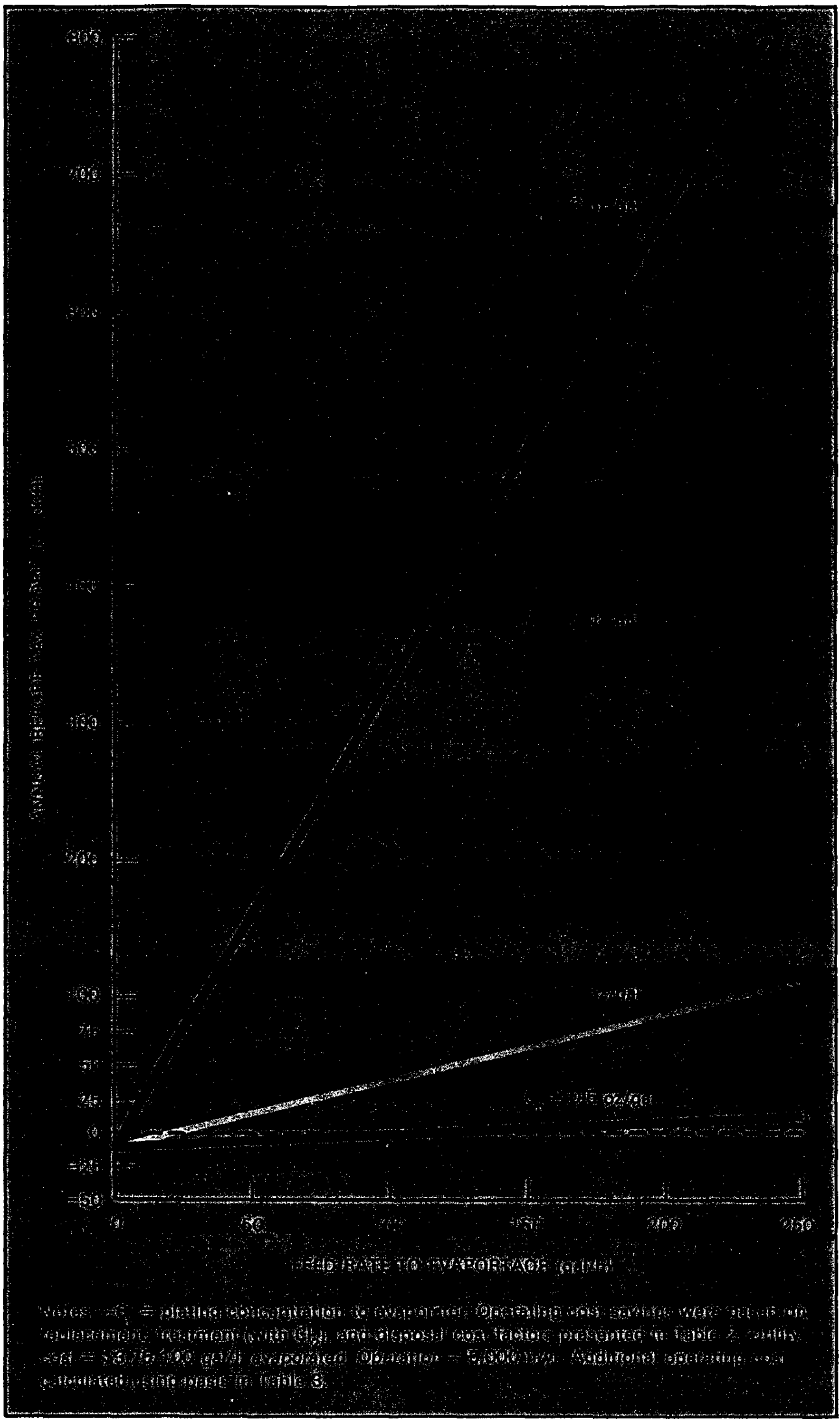


Figure 24.

Annual Before-Tax Profit for Single-Effect Evaporative Recovery of Nickel Sulfate Solutions

If another plant with the same drag-out rate had a rinse ratio that increased the evaporator feed rate to 200 gal/h (757 l/h), the chromic acid concentration would reduce to 0.5 oz/gal (3.7 g/l). The annual before-tax profit would then become a negative $30,000.

With a given quantity of plating chemicals in a rinse stream, minimizing the volume of rinse water that must be evaporated is critical in justifying the recovery system investment. As a rule, if the flowrate to the evaporator is too high and cannot be reduced by installing additional rinse tanks, it will be advantageous to consider an open-loop system and to accept a lower percentage of recovery.

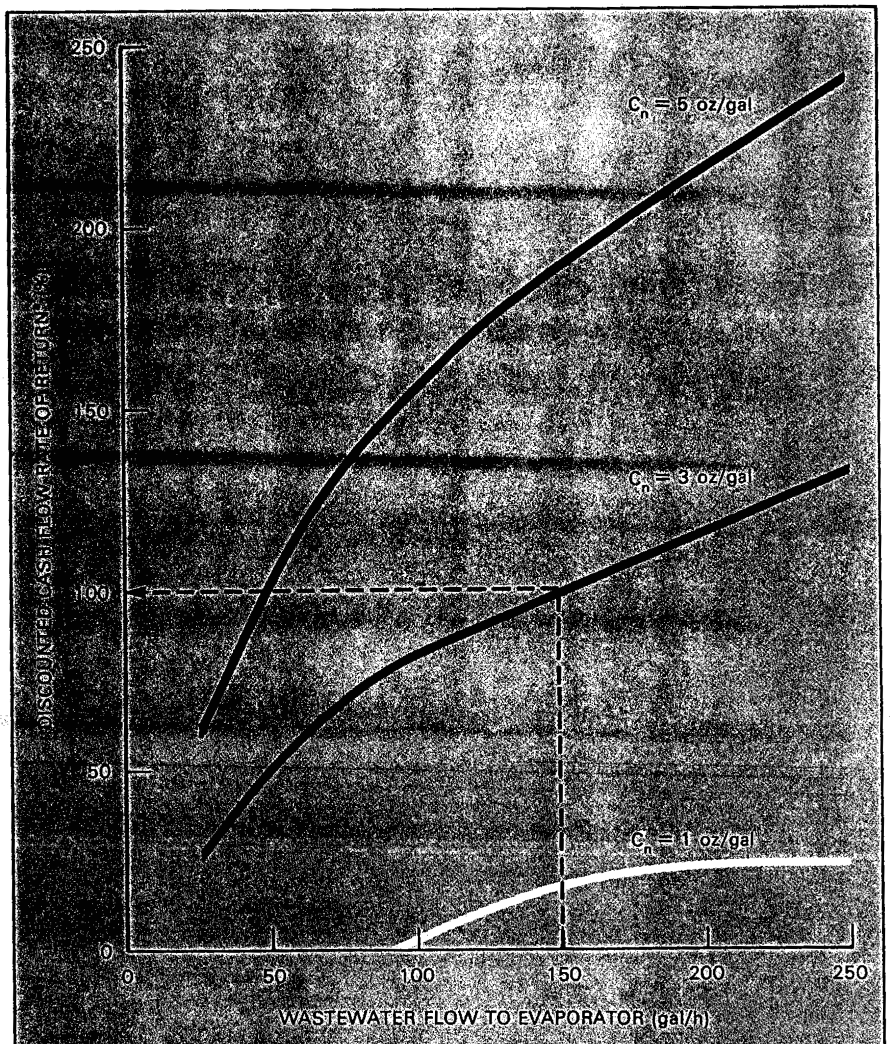


Notes: C_i = plating concentration to evaporator. Operating cost savings were based on replacement, treatment (with Cl_2), and disposal cost factors presented in Table 2. Utility cost = $3.75/100 gal/h evaporated. Operation = 5,000 h/yr. Additional operating cost calculated using basis in Table 3.

Figure 25.

Annual Before-Tax Profit for Single-Effect Evaporative Recovery of Zinc Cyanide Solutions

Figures 26 through 28 show the after-tax DCF rate of return for recovery for single-effect, rising film evaporators. For example, if 150 gal/h (567 l/h) of wastewater flow were to contain 3 oz/gal (22.5 g/l) of chromic acid, then the installation of a single-effect, rising film evaporator to process this flow would result in a DCF rate of return of 100 *percent* (Figure 26). The ROI's would be similar for submerged-tube and flash evaporators. Site-specific economics for these evaporators and for double-effect and mechanical vapor recompression systems can be estimated by following the procedures given in the case study in Section 5.



*Rate of return after taxes; Federal tax at 48%.

Notes.—C_n = plating concentration to evaporator. Pretax savings from Figure 23. Investment cost for single effect evaporator from Figure 19.

Figure 26.

DCF Rates of Return for Evaporation Equipment to Process Chromic Acid Wastewater

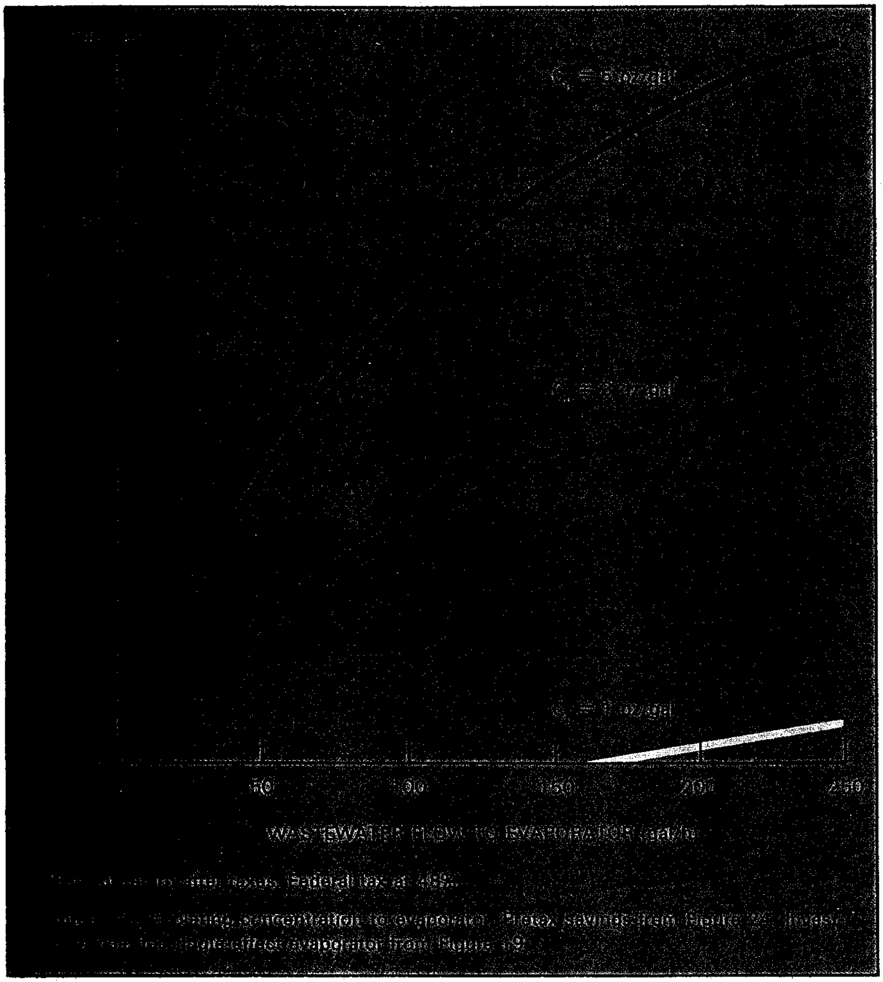
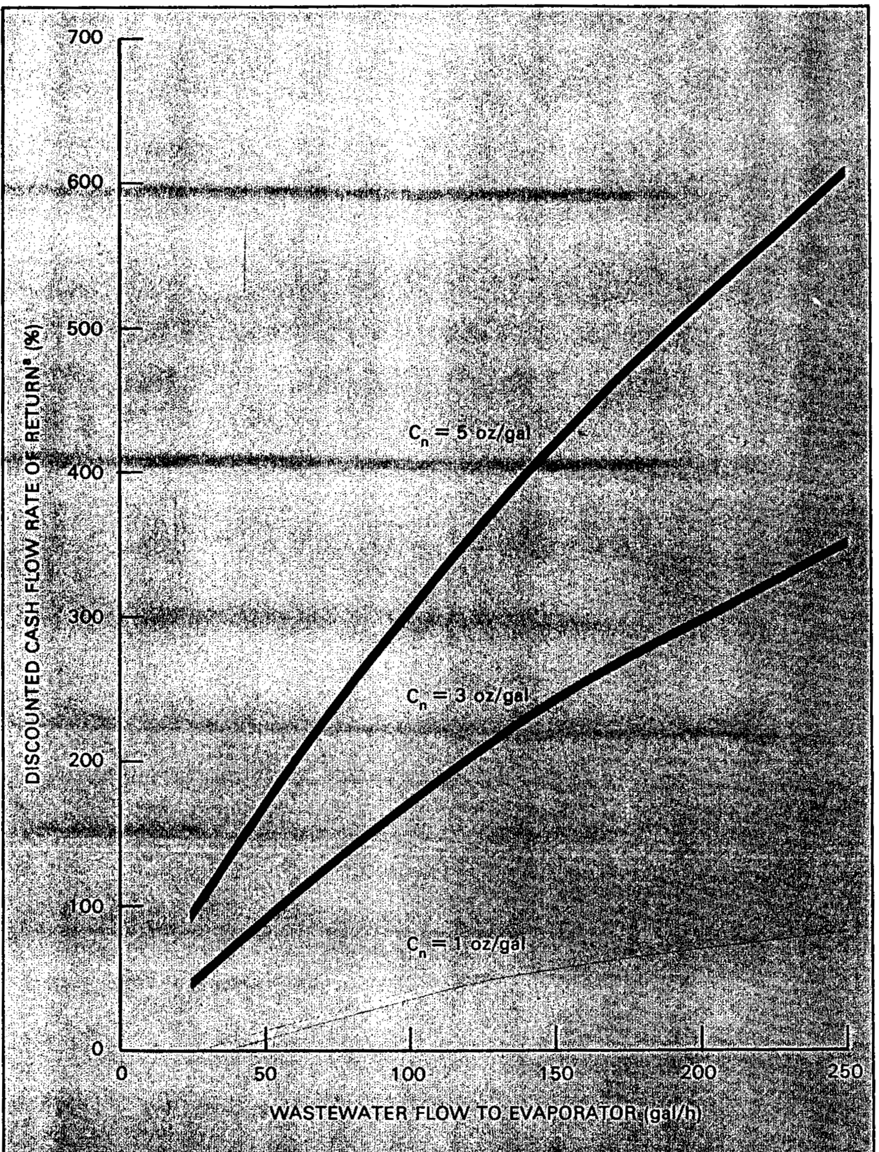


Figure 27.

DCF Rates of Return for Evaporation Equipment to Process Nickel Sulfate Wastewater



^aRate of return after taxes; Federal tax at 48%.

Notes.—C_n = plating concentration to evaporator. Pretax savings from Figure 25. Investment cost for single-effect evaporator from Figure 19.

Figure 28.

DCF Rates of Return for Evaporation Equipment to Process Zinc Cyanide Wastewater

Case Study

Plant Situation

An electroplater operates a chromic acid bath at a concentration of 40 oz/gal (300 g/l). The drag-out rate from the plating bath is 2 gal/h (7.57 l/h). Three rinse tanks are used, and the rinse water flow is adjusted so that the concentration in the final rinse tank is 0.003 oz/gal (22.5 mg/l). The plant operates 5,000 hours annually. The economics for installing an evaporator in a closed-loop system are compared to that of an open-loop system. A 25-gal/h (94.6-l/h) evaporator is evaluated for the open-loop system based on the electroplater's limited budget.

Case 1: Closed-Loop System

Figure 29 diagrams evaporative recovery in a closed-loop system.

The rinse ratio (r) required to obtain $C_3 = 0.003$ oz/gal is determined using Equation 1:

$$\frac{C_p}{C_n} = r^3$$

$$r = \left(\frac{40}{0.003}\right)^{1/3} = 24$$

Figure 5 also may be used to determine r, at $n = 3$ and $C_p/C_n = 13{,}333$.

The rinse rate (evaporator feed rate) is determined as follows:

$$\begin{aligned}\text{Rinse rate} &= r \times \text{drag-out}\\ &= 24 \times 2 \text{ gal/h}\\ &= 48 \text{ gal/h}\end{aligned}$$

The percent recovery of plating chemicals from drag-out is determined using Equation 2:

Percent recovery

$$= \left(1 - \frac{C_n}{C_p}\right) \times 100\%$$

$$= \left(1 - \frac{0.003 \text{ oz/gal}}{40 \text{ oz/gal}}\right) \times 100\%$$

$$= 99.99\%$$

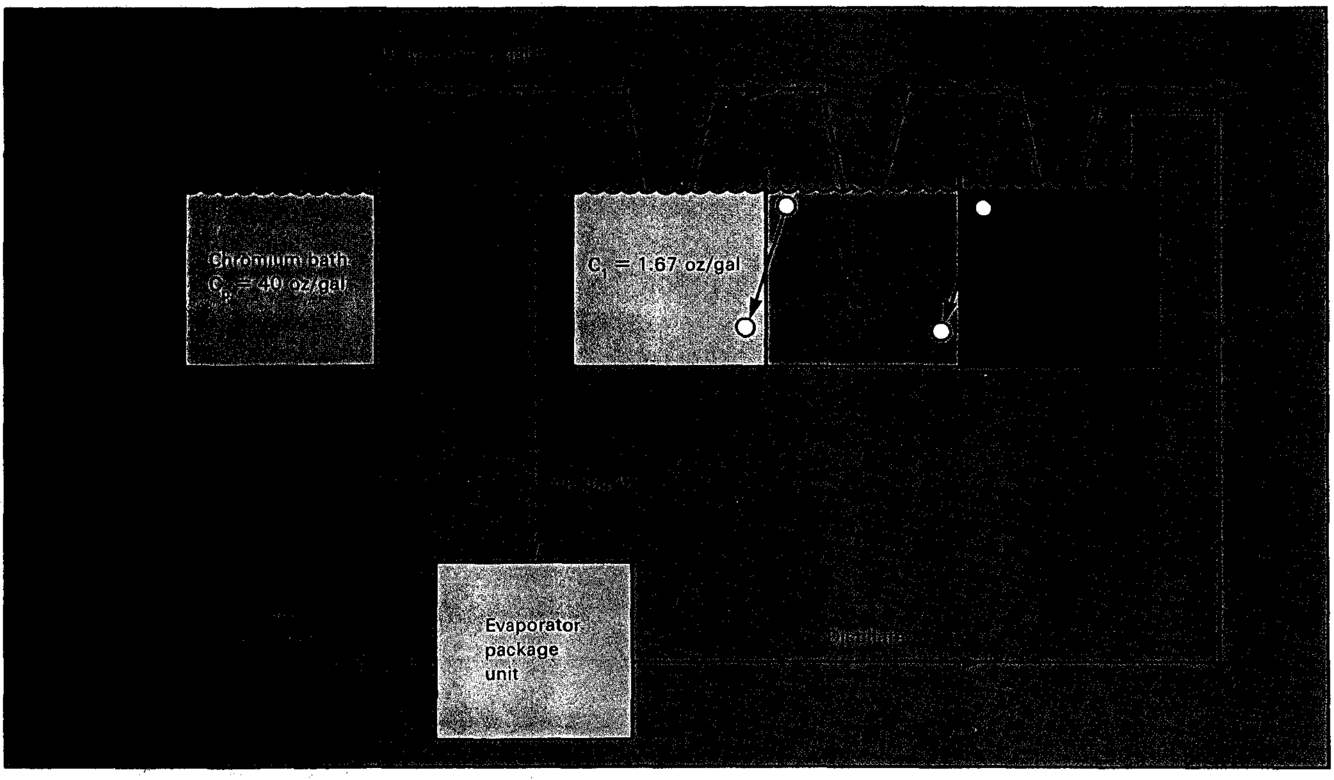


Figure 29.

Case 1: Evaporative Recovery in a Closed-Loop System

The plating concentration in the first rinse tank (concentration to the evaporator) is determined using Figure 5, where n = 1 and r = 24,

$$\frac{C_p}{C_n} = 24$$

$$C_n = \frac{40 \text{ oz/gal}}{24} = 1.67 \text{ oz/gal}$$

For a single-effect, rising film evaporator, from Figure 19, total installed cost = hardware cost × 1.25 = \$40,000 × 1.25 = \$50,000.

Using curve D in Figure 20, the net savings for *evaporation is determined*: annual net savings = (\$12.50/h) × (48/100) × 5,000 h/yr = \$30,000/yr.

Determined from Figure 23, the annual *before-tax profit* = \$9,600/yr.

The DCF rate of return for the *investment is determined* using Figure 22. For a capital expenditure of \$50,000 and an annual after-tax cash flow of \$10,000 (after-tax profit + depreciation), the DCF rate of return is 15 percent. (After-tax profit = 0.52 × before-tax profit.)

From Table 3, the payback period is determined as: payback = \$50,000/(\$10,000/yr) = 5 yr.

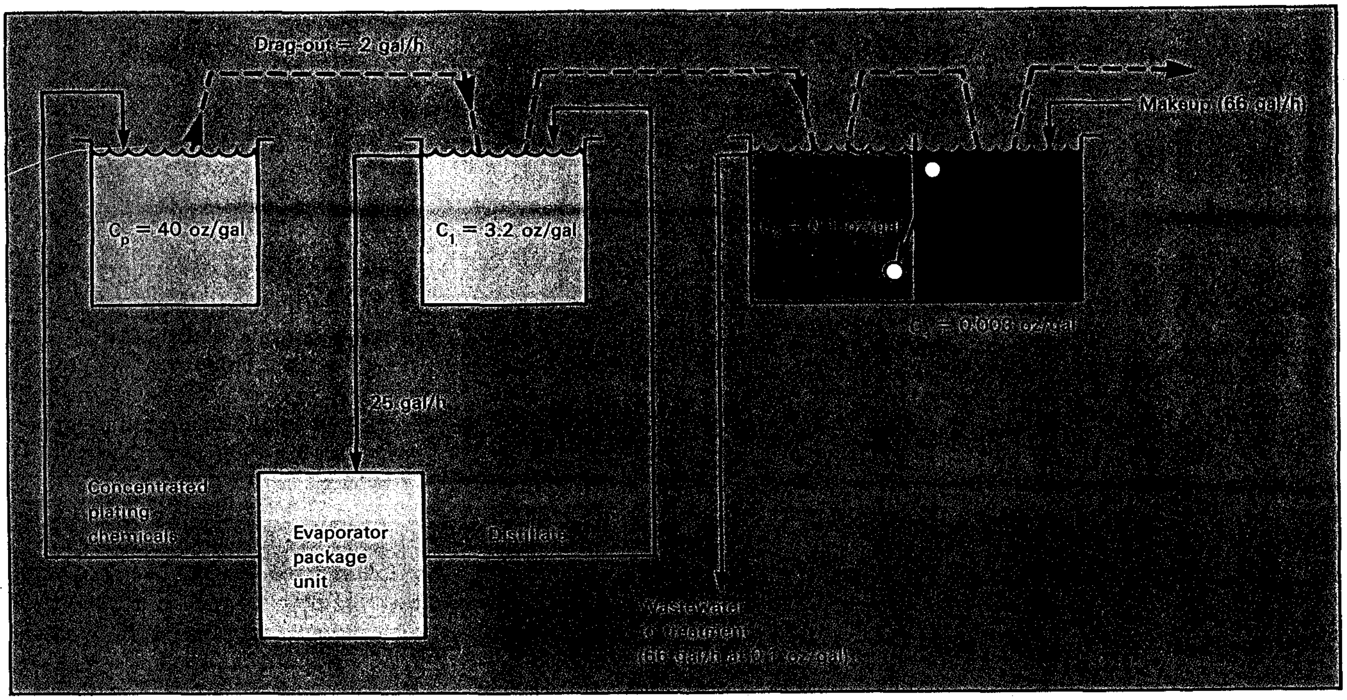


Figure 30.

Case 2: Evaporative Recovery in an Open-Loop System

Case 2: Open-Loop System

Figure 30 diagrams evaporative recovery in an open-loop system.

The rinse ratio (r) is determined for the first rinse tank, given a rinse rate of 25 gal/h (evaporator feed rate) and a drag-out rate of 2 gal/h:

$$\begin{aligned} r &= \frac{\text{rinse rate}}{\text{drag-out rate}} \\ &= \frac{25 \text{ gal/h}}{2 \text{ gal/h}} \\ &= 12.5 \end{aligned}$$

The concentration of the first rinse tank (also the concentration entering the evaporator) is determined as follows:

$$\begin{aligned} C_n &= \frac{C_p}{r} \\ &= \frac{40 \text{ oz/gal}}{12.5} \\ &= 3.2 \text{ oz/gal} \end{aligned}$$

For a 25-gal/h single-effect, rising film evaporator, from Figure 19, total installed cost = hardware cost × 1.25 = \$32,000 × 1.25 = \$40,000.

Using curve D in Figure 20, the net savings for evaporation is determined. Hourly net savings = \$27.50/h at 100 gal/h × (25 gal/h ÷ 100 gal/h) = \$6.88/h. Annual net savings = \$6.88/h × 5,000 h/yr = \$34,400/yr.

Determined from Figure 23, the annual before-tax profit for the evaporator = \$15,000/yr.

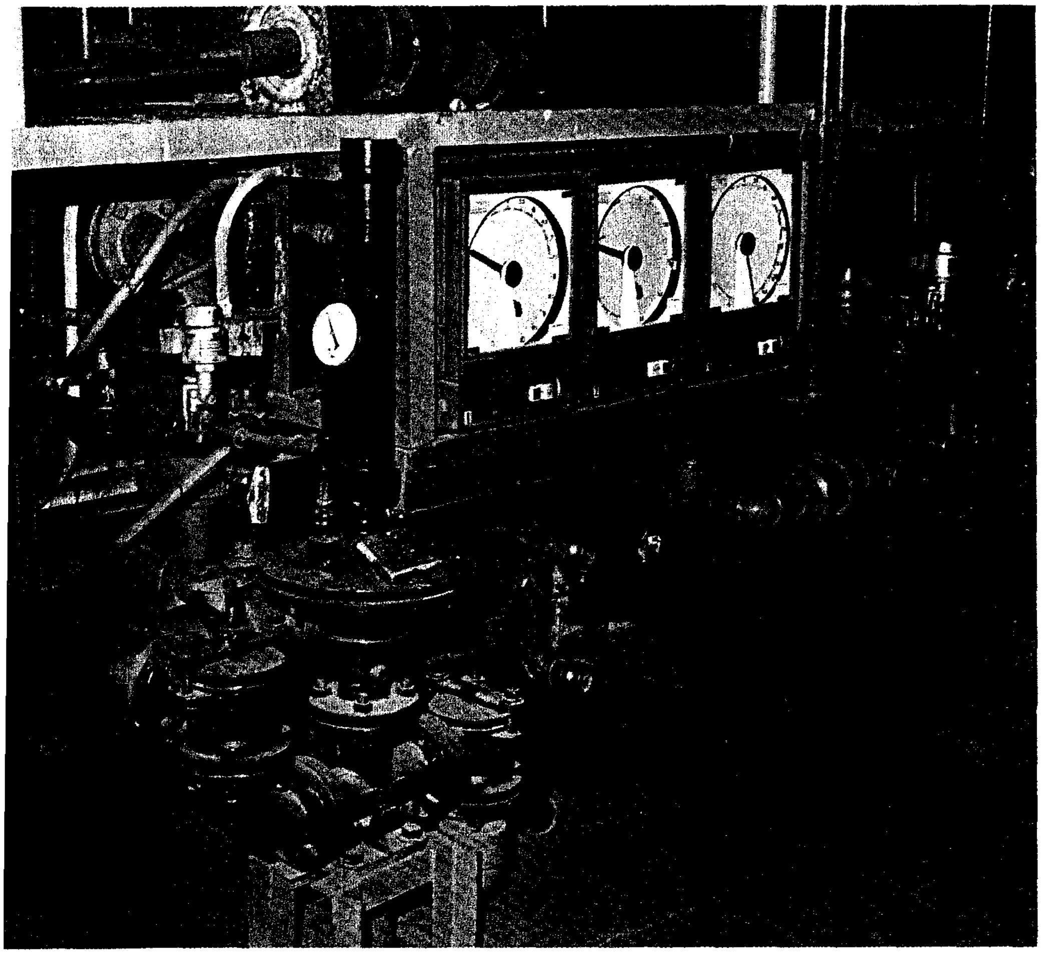
The rinse ratio (r) is determined for the second and third (final) rinse tanks, given C_p = 3.2 oz/gal and C_3 = 0.003 oz/gal:

$$\begin{aligned} r^2 &= \frac{C_p}{C_n} \\ r &= \left(\frac{3.2 \text{ oz/gal}}{0.003 \text{ oz/gal}}\right)^{1/2} \\ &= 33 \end{aligned}$$

For the last two rinse tanks,

$$\begin{aligned} \text{Rinse rate} &= r \times \text{drag-out} \\ &= 33 \times 2 \text{ gal/h} \\ &= 66 \text{ gal/h} \end{aligned}$$

Therefore, 66 gal/h of wastewater must be treated.



Wastewater discharge flow and pH recorders

The concentration of chromic acid to be treated (also the concentration of the second rinse tank) is calculated by:

$$C_n = \frac{C_p}{r}$$

$$= \frac{3.2 \text{ oz/gal}}{33}$$

$$= 0.10 \text{ oz/gal}$$

The DCF rate of return for the investment of $40,000 for the evaporator, and a before-tax profit of $15,000/yr, is determined as follows: After-tax profit (before-tax profit − tax at 48 percent) = $15,000/yr − $7,200/yr = $7,800/yr. After-tax cash flow (after-tax profit + depreciation) = $7,800/yr + (0.1 × $40,000) = $11,800/yr. From Figure 22, the DCF rate of return for $40,000 investment and $11,800/yr after-tax cash flow is 25 percent.

From Table 3, the payback period is determined as: payback = $40,000/($11,800/yr) = 3.4 yr.

Summary

The economics of the open-loop recovery system are superior to the economics of the closed-loop recovery system for the following reasons:

- The investment cost of evaporation equipment for the open-loop recovery system is $10,000 less than that for the closed-loop recovery system because of the difference in flowrates.
- The ratio of profit to investment cost of evaporation equipment is greater for the lower capacity system.

The use of an open-loop evaporation system has the advantage of reducing the volumetric flowrate of the rinse water stream to be evaporated. The result is a higher concentration in the first rinse tank (feed to evaporator), with the further benefit of a lower utility cost for the evaporator (utility cost is proportional to the total volume of liquid evaporated).

Although the closed-loop evaporator recovers all the chromic acid, the incremental savings is not great enough to offset the advantages of the open-loop configuration. If evaporative recovery is not used, then the cost of wastewater treatment by chemical destruction, in addition to chromic acid replacement, would be $40,000 annually.

Abbreviations

actual ft^3	actual cubic feet
Btu	British thermal unit
°C	degree centigrade
°F	degree fahrenheit
ft^3	cubic feet
g	grams
gal.	gallons
Gg	gigagrams (10^9 g)
GJ	gigajoules (10^9 J)
gr	grains (1.4×10^{-4} lb)
hm^3	cubic hectometer (1×10^6 m^3)
h	hour
J	joule
kg	kilogram (10^3 g)
kW	kilowatt (10^3 watt)
kWh	kilowatt-hour
l.	liter
lb	pound
m	meter
Mg	megagrams (10^6 g)
MW.	megawatt (10^6 watt)
normal m^3	normal cubic meter (0° C)
Pa	pascal
ppm	parts per million (wt)
ppmv	parts per million (volume)
stdft^3.	standard cubic foot (60° F)
stdft^3/min.	standard cubic feet per minute (60° F)
Tg	teragrams (10^{12} g)
TJ	terajoules (10^{12} J)
yr.	year

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