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Vacuum Evaporators
in

Pollution Prevention and Control Technology for Plating Operations

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3.3 VACUUM EVAPORATORS

3.3.1 Overview

Vacuum evaporators are one of the earliest technologies used in the plating industry for chemical recovery. However, vacuum evaporators are currently used less frequently than some other recovery technologies, such as atmospheric evaporators (see Section 3.2). This is primarily due to the fact that the average vacuum evaporation unit costs approximately ten times more than the average atmospheric unit. Also, the vacuum units have more sophisticated and expensive operational and maintenance requirements. Of the 318 plating shops responding to the Users Survey, 23 shops (or 7.2%) have employed vacuum evaporators (30 total units of which approximately 80% were still in operation at the time of the survey) for chemical recovery, whereas, 71 shops (or 22.3%) have used atmospheric evaporators (86 total units). Another six shops (or 1.9%) use vacuum evaporators as end-of-pipe technologies to concentrate their wastes prior to off-site hauling and disposal. This section discusses recovery applications of this technology and Section 6.4.4 addresses end-of-pipe applications.

A vacuum evaporator is a distilling device that vaporizes water at low temperatures when placed under a vacuum.

The following explanation of the kinetic theory of liquids and in particular vapor pressure helps in understanding this phenomena.

Liquids as well as gases are in constant motion in varying degrees, depending upon the chemical composition of that matter and the temperature and pressure applied to it. Molecules near the surface have a tendency to escape into the surrounding atmosphere. In open systems, most of these molecules do not return to the liquid and the substance is said to vaporize. In a closed system, molecules return to the liquid in proportion to their concentration in the gaseous phase. Eventually a steady state is reached where the quantities of molecules leaving and returning to the liquid are equal. The vapor is then said to be saturated and the pressure exerted by these escaping molecules is referred to as vapor pressure (ref. 361). Since the kinetic energy of all molecules increases with increasing temperature, so does the vapor pressure. When a liquid reaches the temperature at which its vapor pressure becomes equal to that of the atmosphere above it, boiling occurs. This is the rapid evaporation from all parts of the liquid mass, with bubbles of vapor forming in the interior and rising to the surface. Liquids with appreciable vapor pressure may be caused to boil over a wide range of temperatures by decreasing or increasing the pressure of the atmosphere above it (ref. 362). For example, water boils at 212°F at sea level, but will boil at room temperature if the pressure above it is reduced to about 0.4 psia (ref. 361).

Vacuum evaporators depend on the fact that water, when introduced into a vacuum, tends to boil off, or vaporize. The rate of vaporization is directly related to the level of the vacuum and the temperature of the solution. In operation, heated solution is introduced into the vacuum chamber, the boiling point of the solution is reduced by the vacuum and the resultant vapor (distilled water) is removed from the chamber. The vapor can be either discharged or can be condensed for return to the process (e.g., as rinse water).

Vacuum evaporation systems are relatively complex and are therefore more expensive to construct and maintain than the more simple atmospheric systems discussed in Section 3.2. There are several types of vacuum evaporators used in the plating industry: rising film, flash type, and submerged tube. Generally, each consists of a boiling chamber which is under a vacuum, a liquid/vapor separator and a condensing system. Site-specific conditions and the mode of operation influence the selection of one system over another.

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 multiple-effect evaporator. Essentially, these are vacuum evaporators in series with different boiling points, made possible by varying the pressure between effects (subsequent effects have lower pressures). The driving force of a multiple effect system is the pressure drop from the first to the last effect. The solution to be concentrated is fed into the boiling chamber of the first effect and external heat is introduced to volatilize the water. The water vapor is then condensed at a different vacuum level and the energy is used to heat the subsequent vacuum chamber. Therefore, the same energy is used several times in multiple stages.

The second technique is to use a mechanical compressor. With this equipment, 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. Thus the latent heat of evaporation, normally lost to the condenser is recycled by the compressor, providing a temperature difference across the heat exchanger. The needed energy then comprises only the power for the pressure increase to provide the temperature difference.

There are a number of advantages accruing to vacuum systems. Among them are the fact that they are essentially independent of the requirement to heat and move large volumes of air, thus reducing the air pollution problem, at least when compared to atmospheric systems. Further, they are operated at relatively low temperatures, which could be of considerable importance in systems that handle temperature-sensitive products. Additionally, vacuum systems are advantageous with alkaline cyanide solutions which would build up carbonates more rapidly with atmospheric evaporators because the latter type aerates the solution.

3.3.2 Development and Commercialization

Evaporation has been used for centuries for food and beverage processing. Modern vacuum evaporator design for industrial use dates back to the early 1900's with the development of the rising film evaporator. Plating applications for vacuum evaporators began in approximately 1949, when systems were used to recover chromic acid (ref. 300). The early plating applications were purchased primarily to reduce operating costs through chemical *conservation.* Subsequently, evaporation was sporadically implemented as a pollution control method in response to local discharge standards. In some cases, this was a sufficient method of meeting the local standards for targeted pollutants such as cyanide and chromium. The early evaporators used for plating applications were the same types of units used by other industry segments (e.g., chemical processing, dairy, food and beverage industries). These units had large capacities, due in part because water conservation and pollution control were less important at the time, resulting in higher flow rates. Also, energy was much less expensive. In 1974, with the advent of rapidly rising energy costs, there began a movement to down-size recovery systems. Coupled with the Federal pollution control standards, first promulgated in 1979, plating shops turned to smaller and more energy efficient vacuum evaporators and the less expensive atmospheric evaporators for chemical recovery. Energy efficiency was achieved by the employment of multi-effect vacuum units and mechanical vapor compression. During the 1980's and early 1990's firms have sought methods of low or zero effluent discharge to reduce their regulatory requirements. As a result, the newer energy efficient vacuum evaporators were applied as end-of-pipe technologies (ref. 300, 375).

There are approximately 25 companies that manufacture and/or supply evaporative recovery equipment applicable to the plating industry. This includes vacuum and atmospheric evaporators for both chemical recovery and waste concentration (ref. 421). Of these companies, three firms have responded to the vendors survey (LICON, Inc., Calfran Int., and QPS Inc.).

3.3.3 Applications and Restrictions

Two common configurations for the application of vacuum evaporators to chemical recovery are shown in Exhibit 3-10. In configuration VE-1, a closed-loop process is achieved using a four stage rinse system with the feed from the first rinse being concentrated by the evaporator and directed to the plating bath. A solution purification step is shown, which removes bath contaminants that would buildup in the bath due to the closed-loop process. Typical solution purification technologies used for this purpose include ion exchange and/or carbon filtration. PS 125 employs this configuration using a cation exchange unit to remove contaminants from its decorative chromium plating rinse water/drag-out. PS 124 has a similar arrangement. PS 082 installed a cation exchange unit and electrolytic purification unit that are connected to a storage tank. The use of multiple-stage rinsing is nearly always required with evaporator applications in order to minimize the quantity of water to be evaporated. The survey respondents used a minimum of two and a maximum of four rinsing stations. The second configuration (VE-2) shows an open process, where a small portion of the drag-out is not recovered. Also shown in VE-2, is a direct bleed from the bath to the evaporator. This may be required for ambient or low temperature baths, where there is a limited surface evaporation rate and insufficient "head-room" in the plating tank to return the concentrated drag-out/rinse water.

Vacuum evaporators are applied to the recovery of a wide range of plating solutions. They are especially applicable in situations where atmospheric evaporators are either technically or economically impractical. This includes: (1) the recovery of heat sensitive chemicals (e.g., cyanide plating baths); (2) the recovery of chemicals that are sensitive to air oxidation (e.g., cyanide plating baths or the stannous tin bath); (3) low or ambient temperature plating solutions where there is no appreciable surface evaporation; (4) the recovery of solutions that contain volatile components; and/or (5) where high evaporation rates (e.g., >20 to 40 gph) are necessary to achieve recovery and atmospheric evaporators become too expensive (i.e., energy cost) to operate (ref. 299).

The results of the Users Survey and Vendors Survey showed that vacuum evaporators are applied to a range of plating and finishing solutions. These identified applications are shown in Exhibit 3-11.

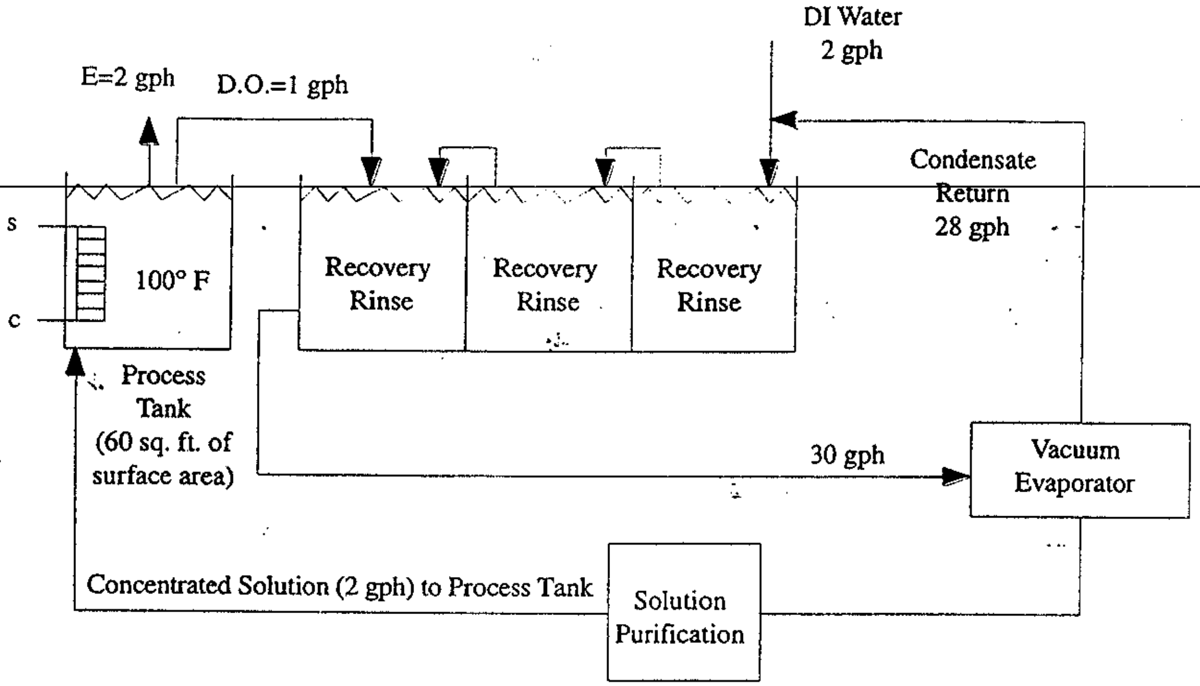
Although vacuum evaporators may provide an energy savings over the atmospheric types of evaporators, neither one is economically practical to purchase or operate where large volumes of low concentration solutions are involved. In those cases, ion exchange or reverse osmosis are the more cost effective methods of recovery (ref. 299).

3.3.4 Technology/Equipment Description

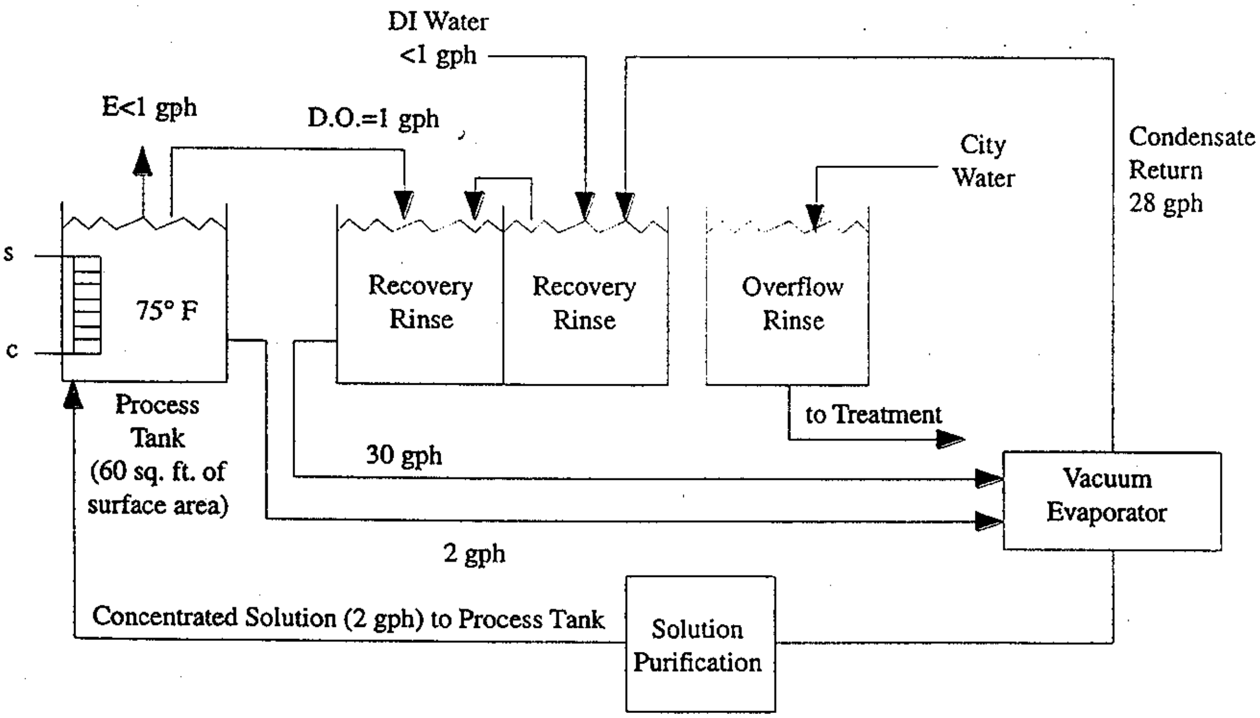
3.3.4.1 General

This subsection discusses commercially available vacuum evaporation equipment that is manufactured and/or sold by vendor survey respondents. This is intended to provide the reader with information and data on a cross section of available equipment. Mention of trade names or commercial products is not intended to constitute endorsement for use.

Exhibit 3-10. Two Configurations for the Application of Vacuum Evaporatrs for Chemical Recovery



Vacuum Evaporation Configuration VE-1: Closed-Loop System



Vacuum Evaporation Configuration VE-2: Open Rinse System

Exhibit 3-11. Applications of Vacuum Evaporation Identified During the Users and Vendors Surveys

	Number of Users Survey Applications[1]	Number of Vendors Survey Applications
Alkaline Cleaners	0	30
Brass, cyanide	0	25
Bronze	0	2
Cadmium, cyanide	3	8
Chromium, decorative (Cr^{+3})	1	0
Chromium, all Cr^{+6}	7	51
Copper, acid	0	11
Copper, cyanide	1	0
Gold	0	20
Lead-tin	1	20
Nickel, electroplating	3	58
Nickel, electroless	0	3
Phosphate	0	8
Silver, cyanide	0	10
Sulfuric acid	0	6
Zinc, acid	0	3
Zinc, alkaline (non-CN)	0	1
Zinc, cyanide	3	65
End-of-pipe concentration	5	80

[1] not all uses of vacuum evaporators by the Users Survey respondents were determined.

There is a wide range in design of vacuum evaporators, although the majority of these devices work on the principles described in Section 3.3.1. Vacuum evaporators are built by various manufacturers for different applications. Exhibit 3-12 classifies vacuum evaporators according to the way water is vaporized. This design element helps to differentiate between some of the commercial equipment available to the electroplater. It should be noted that not all manufacturers of plating evaporation equipment are represented in this exhibit.

As with any technology group, the vacuum evaporation industry has developed their own terminology for their equipment and its components. Some of their commonly used terms are defined in Exhibit 3-13.

The following subsections describe the types of vacuum evaporators that are applicable to the plating industry. Where information is available, specific commercial units are briefly described.

3.3.4.2 Submerged Tube Evaporators

The submerged tube evaporators, which includes the short and long tube vertical (LTV) types and the horizontal tube type, are termed natural circulation evaporators, because no pump or other recirculation device is employed. These units, which are older, but still widely used types of vacuum evaporators, are sometimes referred to as calandria type evaporators. With the basic design (short tube type), a vertical tube bundle is placed inside a vertical cylindrical evaporator shell. The tubes or tube sheets, usually two to six feet in length, span the body diameter. The liquid level in the body is typically maintained such that 50% of the tube sheets are immersed. Liquid circulates through the tubes at a rate many times greater than the feed rate. The liquor travels up through the tubes and down a central pipe called a "downcomer." Steam or water vapor condenses on the outside surface of the tubes and the liquor is heated and boiled inside the tubes. The circulation of the liquid is achieved because of the difference in specific gravity between the liquor and vapor in the tubes plus a vapor lift effect. This combined phenomenon is known as the thermosyphon effect and it is the design basis for all natural circulation evaporators, which includes the falling film types (ref. 376, 422, 423). In some cases, an agitator, located inside or beneath the downcomer, is used to increase circulation in salting-type applications.

Generally, the submerged tube evaporators are less expensive to purchase than rinsing film or flash units of equal capacity. Steam or thermal demand is the same as for rising film (ref. 376). The evaporators find application for processing mildly scaling liquors and relatively viscous solutions (ref. 422).

Exhibit 3-12. Classification of Commercially Available Evaporators for Plating Applications According to the Way Water is Vaporized

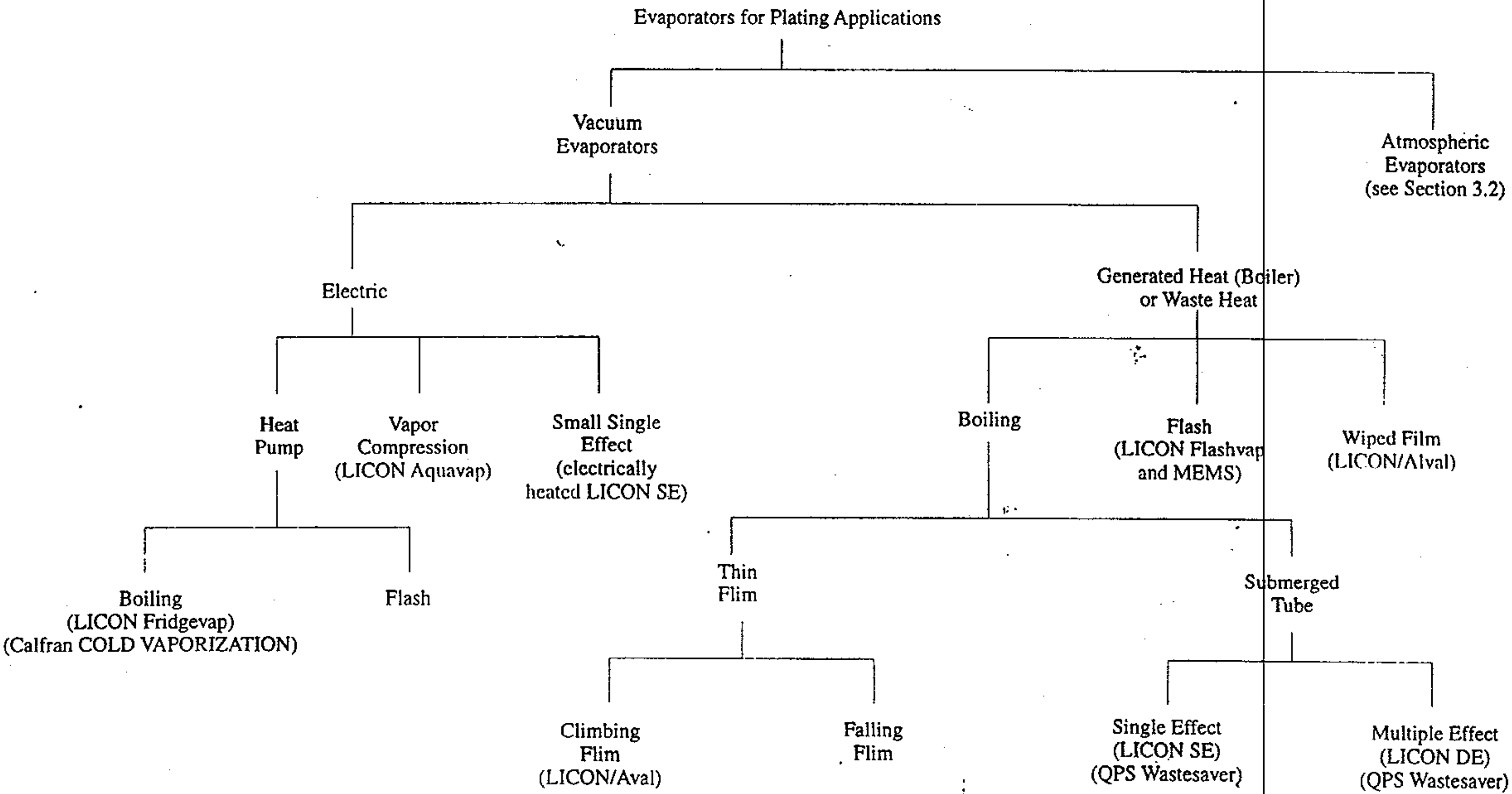


Exhibit 3-13. Common Vacuum Evaporator Terminology

Bodies	Also called vapor heads or flash chambers; the unit where vapor-liquid separation takes place. Also a label given to the basic module of an evaporator, comprising one heating element and one flash chamber.
Calandria	The unit in which heat transfer takes place.
Compression Evaporation	A process in which evaporated vapor is compressed to a higher pressure level and then condensed. The compressed vapor provides heat required for evaporation. Energy economy obtained by multi-effect evaporation can often be equalled in a compression evaporation system.
Condenser	Evaporator equipment used to condense the vapor from the last effect or used as an intercondenser in multi-stage vacuum producing systems.
Cooling Water	Water used in the condenser of an evaporator to condense the vapor phase that exists in the separator. Cooling water can come from cooling towers or reservoirs, or once-through process water can used.
Direct Contact Condenser	Condenses vapors as they are contacted with the cooling medium. There are no heat transfer surfaces and therefore the vapor pressure drop is low. Due to contact with the process solution, the cooling water will require waste treatment.
Effect	One or more bodies boiling at the same time.
Evaporator	The entire system of effects, not necessarily one body or one effect.
Fouling	Formation of deposits other than salt or scale.
Heat Pump	A device in which a refrigerant fluid is continuously circulated through a closed cycle. The gaseous refrigerant is first compressed and then allowed to condense by giving out heat to a cooler environment. The liquid refrigerant is then throttled to low pressure, by means of an expansion valve and allowed to evaporate in another heat exchanger, drawing in heat. The vapor is then circulated to the compressor to begin another cycle.
Intercondenser	A condenser within a multistage system that condenses some of the steam between stages and reduces steam consumption.
Mechanical Compression	Uses a compressor driven by a mechanical drive to compress all the overhead vapors.
Mechanical Pumps	One of two devices (see steam jet ejectors) used to produce a vacuum. More energy efficient than steam jet ejectors but less reliable due to the number of moving parts involved.
Precondenser	A condenser that removes process vapors and permits the use of smaller vacuum pumps.
Refrigeration	Systems that absorb heat not wanted or needed and reject it elsewhere. Heat is removed from the system by evaporation of a liquid refrigerant and is rejected by condensation of the refrigerant vapor.
Scaling	Growth or deposition on heating surfaces of a material that is either insoluble or has a solubility that decreases with an increasing temperature.
Staging	Two or more sections of a single effect evaporator operating at different concentrations.
Steam Jet Ejectors	One of two devices (see mechanical pump) used to produce a vacuum. Jet ejectors usually have lower initial costs, lower maintenance costs (fewer moving parts) but higher operating costs (less energy efficient) than mechanical systems. Multistage jet ejectors (connected in series) improve thermodynamic efficiency.
Surface Condenser	A condenser with a heat transfer surface on which condensing occurs. The heat transfer surface is subject to fouling, corrosion and plugging. Generally more expensive than direct contact condensers. Cooling water is not contaminated with the process solution.
Thermal Compression	Uses a steam jet to compress a fraction of the overhead vapors with high pressure steam.
Thin Film	Thin films of solution are created in evaporators to maximize the liquid surface area per unit volume of flow and therefore facilitate rapid evaporation.

Sources: ref. 373, 374, 423.

LICON Inc., a manufacturer of electroplating evaporation equipment and a Vendors Survey respondent, manufactures single effect and double effect submerged tube evaporators. These devices have been applied to the concentration of chromium (Cr^{+3} and Cr^{+6}), zinc chloride, nickel chloride, nitric acid, and sulfuric acid bearing waters as well as mixed wastestreams (ref. LICON file).

QPS manufactures the Wastesaver® submerged tube evaporator, which is available with either single, double or triple effects. Their newer units have a pumpless liquid transfer system that reportedly eliminates problems commonly associated with mechanical liquid transfer equipment (e.g., pumps, seals, impellers, etc.). These units are manufactured with capacities ranging from 25 gph to 1,500 gph. The basic units are manufactured from stainless steel with titanium offered as an option.

3.3.4.3 Rising Film (Climbing Film)

The basic rising film evaporator consists of an evaporator body, separator and condenser. The evaporator body is a shell-and-tube heat exchanger. Liquid feed enters the bottom of the heat exchanger, it is preheated until it reaches the boiling point and it then moves up the tube. The vapor generated occupies the center of the tube and the liquid is forced to the tube wall. As the fluid travels up the tube, more vapor is formed resulting in a higher central core velocity. The upward velocity of the vapor forces any remaining liquid to the tube wall and continues to provide an upward motion. As the process continues, the higher vapor velocities result in thinner and more rapidly moving liquid films. This design provides a high heat transfer coefficient and relatively short residence time (ref. 373, 375, 376).

Evaporation is typically accomplished at pressures of 1.3 to 7.5 psia (67 to 388 mm Hg absolute), thereby lowering the boiling point to 110° to 180°F (43° to 82°C). The wastewater leaves the body and enters the separator where the water vapor is separated from the heavier plating solution. The plating solution is either returned directly to the bath or held in an integral reservoir. The vapor leaving the separator is condensed in a shell-and-tube heat exchanger and the distillate is directed to the rinse tanks (ref. 376).

Commercially available rinsing film evaporators used in the plating industry are manufactured by LICON/Aval and Corning. Several existing plating applications of rinsing film evaporators identified in the Users Survey were manufactured by the Pfaudler Company.

3.3.4.4 Falling Film

Liquid enters the top of the evaporator and a liquid film is formed by gravity, which then flows down the heat transfer surface. During evaporation, vapor fills the center of the channel and as the momentum of the vapor accelerates, the film becomes thinner. Also, the solution accelerates in velocity as it descends inside the tubes because of gravity and the drag of the vapor. Since the vapor is working with gravity, a falling film evaporator produces thinner films than a rising film evaporator for any given set of conditions. This gives rise to shorter residence times and a further improvement over the rising film types in heat transfer. With these devices, liquid is usually separated from the vapor in the bottom liquid chamber of the body.

The falling-film evaporator is particularly useful in applications involving heat sensitive chemical solutions. This is due to a low "driving force" or temperature difference between the heat-transfer medium and the liquid (ΔT's less than 15°F compared to 25°F or more for the rising film) (ref. 375, 377).

No commercial electroplating applications of the falling film evaporator were identified during the Users or Vendors Surveys, although they presumably exist due to the widespread commercialization of these devices (ref. 373, 377).

3.3.4.5 Wiped Film Evaporator

Feed is introduced at the top of the evaporator and is spread by wiper blades on to the vertical cylindrical surface inside the unit. Evaporation takes place as the thin film moves down the evaporator wall. The heating medium is usually high pressure steam. Use of the wiped film evaporator is limited primarily to highly viscous liquids and the stripping of solvents. The high number of moving parts, such as the rotor and wiper blades, may result in higher maintenance costs than other types of evaporators (ref. 375).

LICON Inc. manufactures a wiped film evaporator (Stratavap) with capacities from 5 to 700 gph, but no plating shop applications were identified in the Users or Vendors Surveys for this device or other wiped film evaporators.

3.3.4.6 Flash Evaporators

Unlike with thin film types (e.g., falling film or wiped film), with flash evaporators, vaporization does not occur on the heat exchanger surfaces. Instead, liquor flashes as it enters a separator, crystallization takes place, and a suspended slurry results. Since evaporation does not take place on a heat transfer surface, the tendency for scale to deposit is significantly reduced. The flash evaporation system can be used in single or multiple effects.

The LICON Inc. Flashvap is sold as an end-of-pipe industrial waste concentrator.

3.3.4.7 Thermal Compressor Evaporators

The thermal compressor evaporators are not, by themselves, a separate category of evaporator. Rather, they are evaporators, such as a rising film type, that uses a steam jet ejector or thermocompressor in order to increase steam economy. They can be designed with either single or multiple effects, although the thermocompressor is normally used on a single effect evaporator or only on the first effect of a multiple effect evaporator. Typically, the addition of a thermocompressor will provide an improved steam economy equal to the addition of another effect, but at lower cost. They should be considered only when high pressure steam is available. Because of their smaller size in comparison to an additional effect, they are favored in applications where space limitations exist. A disadvantage of these units is that the condensate is sometimes contaminated with product traces and may have to be treated, rather than reused as rinse water.

No applications of thermal compression evaporators were identified during the Users Survey or Vendors Survey.

3.3.4.8 Heat Pump Evaporator

A heat pump is a device that upgrades a heat source to a higher temperature, thus rendering it more useful. With conventional evaporator/heat pump operation, a refrigerant, upon boiling, absorbs the heat that would otherwise be rejected in a condenser. The refrigerant vapor is compressed to a pressure adequate to permit the vapor to be condensed in the calandria, thereby providing the heat needed for evaporation. The condensate from the calandria is flashed into the condenser, thereby completing the cycle (ref. 373). The heat pump eliminates the waste of single and double effect designs, but does cost electrical power to operate the heat pump. Therefore, it is not applicable to plating shops where waste heat is available. Also, it is generally confined to small flows ($\leq$ 100 gph) due to the range of heat pumps available.

LICON Inc. manufactures the Fridgevap (3 to 100 gph) heat pump evaporator, in which the solution is evaporated at around 100°F (40°C). This unit finds application where heat sensitive chemicals are involved.

Calfran, Int. manufactures a line of heat pump evaporators that they term COLD VAPORIZATION™. These include the PTU series (immersion coil design) and STU series (reaction vessel type) for applications of 1,000 gpd or less and greater than 1,000 gpd, respectively and the VTU series designed for low solids feed streams (75 to 1,000 gpd). Their basic materials of construction include 316 stainless steel heat exchangers and PVC shells. Their units are also available in all stainless steel design and heat exchangers are available in titanium and Hastelloy.

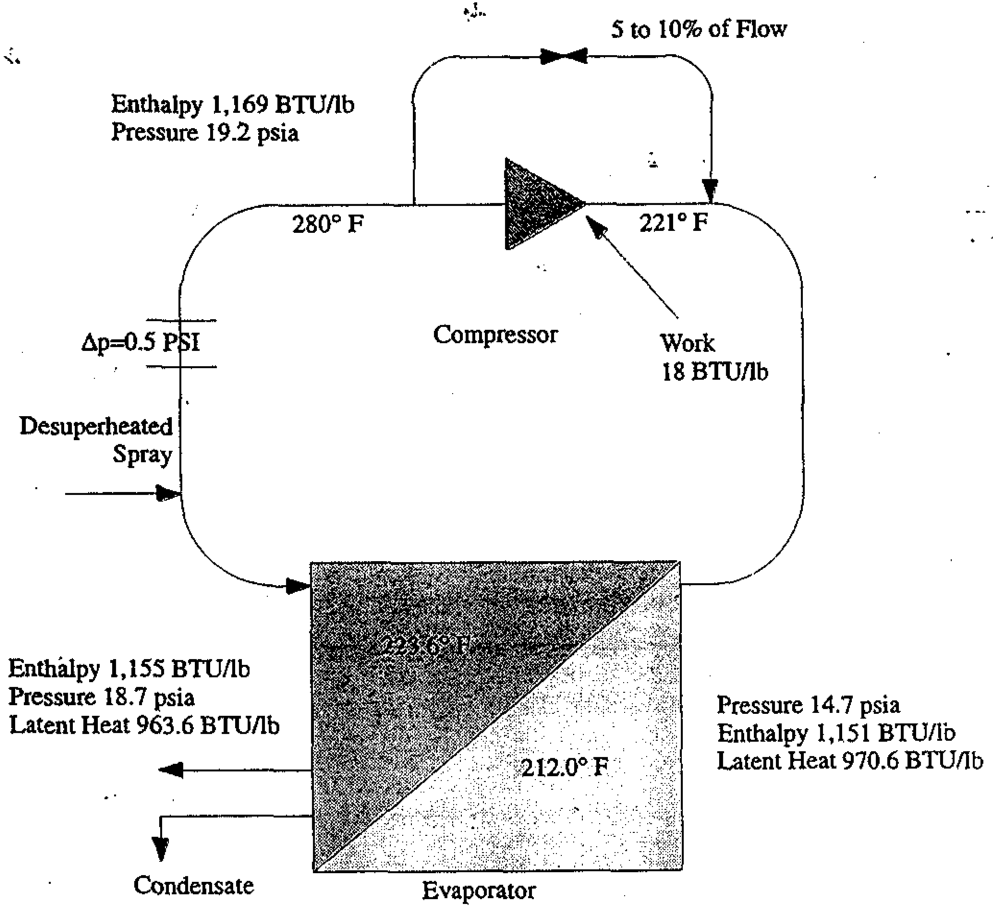
3.3.4.9 Mechanical Vapor Recompression (MVR)

The MVR evaporator is the highest priced evaporator type used in the electroplating industry and it is also the most energy efficient. The MVR evaporator is similar to a conventional single-effect evaporator, except the vapor released from the boiling solution is compressed (adds energy) in a mechanical compressor. This compressed water vapor condenses and gives up its latent heat, which is used to vaporize more water from the liquid that is being concentrated. The following example from the literature shows the potential operating cost savings from using the MVR evaporator (ref. 375).

Exhibit 3-14 shows an evaporator with a liquid boiling point of 212°F (atmospheric pressure). All of the water vapor that is boiled off passes to a compressor. In order to keep the energy input to the system as low as possible, the pressure boost across the compressor is limited. In the majority of cases, this pressure boost will correspond to a saturated temperature rise in the region of 15°F or less. In this example, there is a pressure boost of 4.5 psi across the compressor. Assuming that there is a pressure loss of 0.5 psi in the system, the effective pressure on the steam side of the evaporator is 18.7 psia. This compressed water vapor condenses and gives up its latent heat, which is used to vaporize more water from the liquid that is being concentrated. The latent heat of vaporization of water at atmospheric pressure is 970 Btu/lb. Note that it only requires a theoretical energy input of 18 Btu/lb to raise the water vapor from 14.7 to 19.2 psia. The theoretical steam economy, therefore, is 970/18 = 54. When compressor efficiency is taken into account, this figure is brought down to between 32 and 35 which is another way of saying that the MVR system is equivalent to an evaporator with 32-35 effects (see definitions in Exhibit 3-13). However, when the electricity cost for the compressor drive is taken into account, the MVR system then becomes the economic equivalent of just under a 19 effect evaporator.

The MVR has another definite advantage over steam. The condensate is available at high temperature and is ideal for evaporator feed preheating, particularly if the condensate rate is as high as 90% of the feed rate, i.e., a 10:1 concentration ratio within the evaporator. There are many such evaporators in operation where the sole energy input to the system is through the compressor with steam

Exhibit 3-14. Mechanical Vapor Recompression Evaporator/Condensor Schematic



Effective Steam Economy:	970 +18 = 54
Efficiency of Drive & Compressor:	65 ---> 72%
Inefficiency due to By-Pass:	5 ---> 10%
Actual Effective Steam Economy:	32 ---> 35 Effects

Effective Steam Economy:	970 + 18 = 54
Efficiency of Drive and Compressor:	65 → 72%
Inefficiency due to By-Pass:	5 → 10%
Actual Effective Steam Economy:	32 → 35 Effects

Source: ref. 375

requirements limited to approximately 15 minutes during start up (ref. 375).

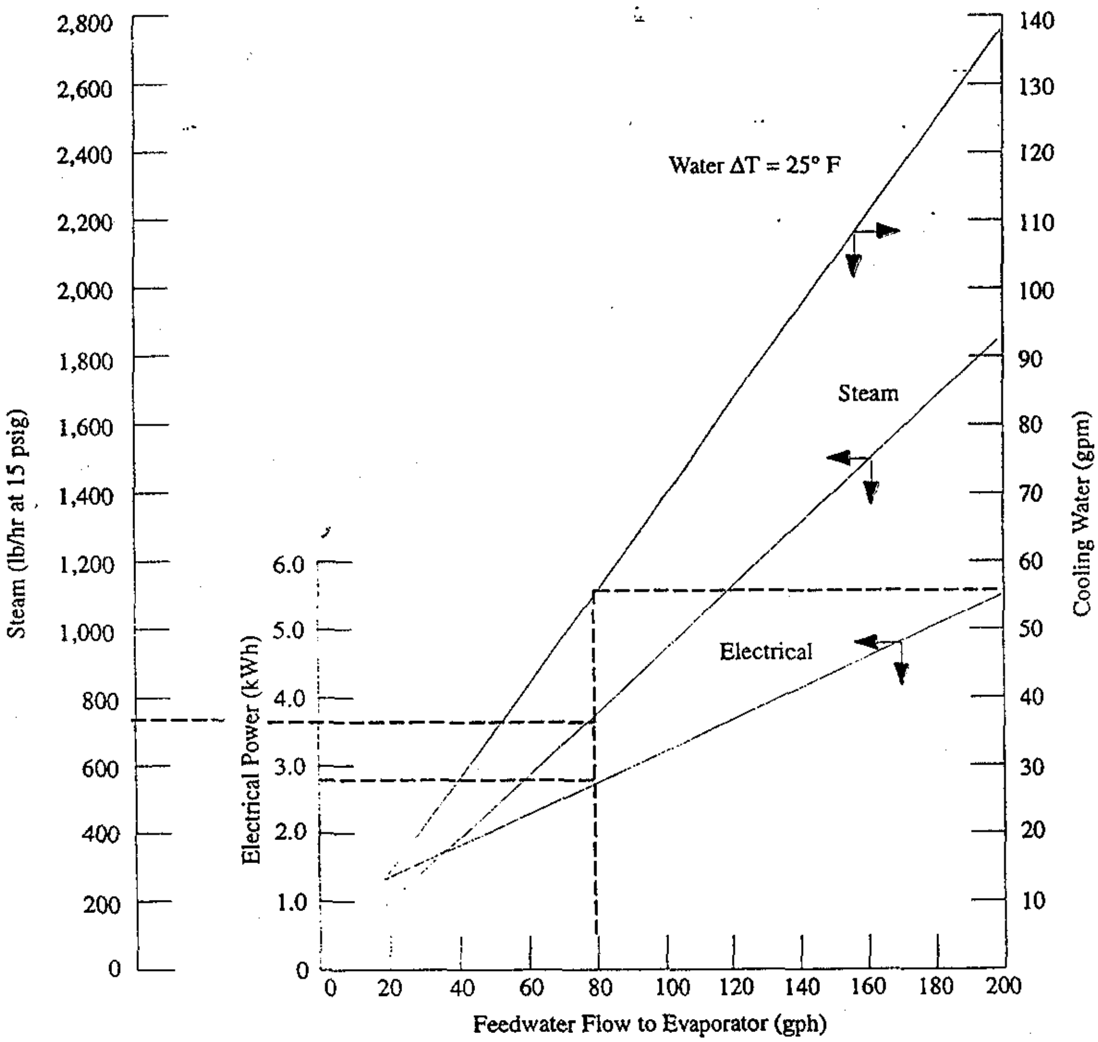
An example of a commercial MVR evaporator used by the plating industry is the LICON Inc. Aquavap. This evaporator has an auxiliary flash stage and is capable of achieving concentrations of 500,000 mg/l or more. Evaporative capacities for the Aquavap range from 50 to 600 gph. Existing plating applications include: concentrations of zinc phosphate rinses (multiple units totaling 1,800 gph), concentration of RO reject (300 gph), and end-of-pipe wastewater concentration (50 to 600 gph) (ref. LICON Inc. file).

3.3.4.10 *Multiple Effect Evaporators*

Multiple effect evaporators are not a specific type of evaporator, but rather a design element employed to improve the energy efficiency of the evaporation process.

Most evaporators used in the plating industry are single-effect units. Single-effect evaporators operate with one boiler or evaporator section. The water vapor is condensed or exhausted to the atmosphere. Approximately 1.1 pounds (0.5 kg) of steam is consumed in evaporating each pound of water from the plating solution (ref. 376).

Exhibit 3-15. Utility Requirements for Single-Effect Evaporators



Notes: Evaporation at 1.3 psia. Wastewater feed at 100°F. Cooling water supply at 70°F. Steam at 15 psig. Rising film or submerged tube. Example: A single effect evaporator boiling 80 gph of wastewater at 1.3 psia pressure has the following requirments – steam (15 psig), 730 lb/hr; electric power, 2.9 kWh; cooling water at ΔT = 25°F, 56 gpm.

Source: ref. 376

Exhibit 3-15 shows the utility requirements for single-effect evaporators as a function of liquid flow rates to the evaporator. 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 (ref. 376). For example, from Exhibit 3-14, if the wastewater flow rate to the evaporator is 80 gal/hr (303 l/hr), the steam rate is 730 lb/hr (331 kg/hr) 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 (ref. 376).

A general application of a double-effect evaporator, is shown in Exhibit 3-16. The basic principle is to use the heat given up by condensation in one effect to provide the reboiler heat for another effect. In the system shown in Exhibit 3-16, 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.

The steam and cooling water rates for the double-effect unit in Exhibit 3-17 are approximately 50 percent of those required for the single-effect unit.

Some platers using double-effect units achieve an additional benefit by recovering two different plating baths simultaneously. However, care should be taken in employing this arrangement however, because there is a possibility of cross-contaminating baths (ref. 376).

Multiple effect evaporation, when used in the plating industry, is most often applied to submerged tube evaporators, rinsing film and flash types (ref. 376). An alternative method for reusing the heat value contained in the vapor from the separator is to employ a mechanical compressor (see Section 3.4.2.9).

3.3.5 Costs

3.3.5.1 Capital Costs

The basic equipment costs and installed costs for vacuum evaporators are indicated in Exhibits 3-18 and 3-19 for heat generated (steam) and electric types. Equipment costs will vary depending on the materials of construction; costs shown are for the basic materials offered by the manufacturer. Evaporators are currently marketed with a wide range of construction materials to resist the corrosiveness of various plating chemicals. The more popular materials include titanium, tantalum, borosilicate glass, stainless steel and carbon steel. Most evaporators are supplied as package units and only require the hook-up of utilities before start-up. However, some ancillary equipment is required (e.g., tanks), which are reflected in the installed costs. The installed cost estimate (140% of basic equipment cost) is based on Users Survey data.

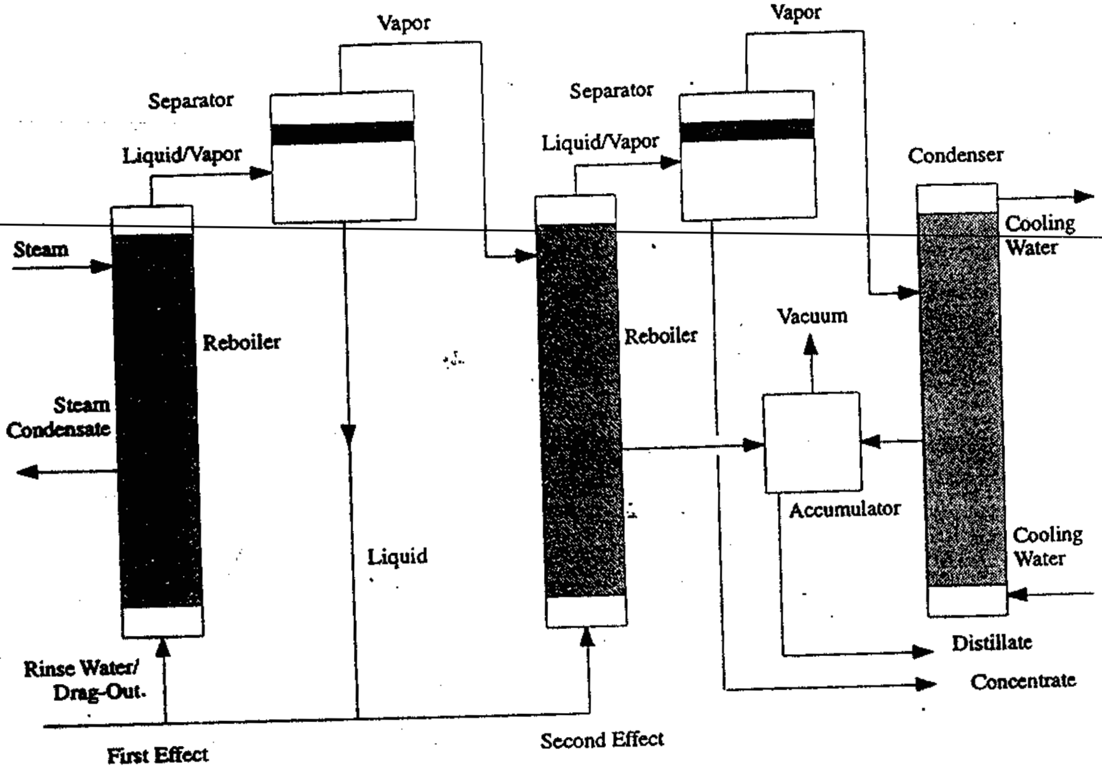
Due to the capital intensive nature of this technology, it is prudent that the buyer make every effort to reduce the flow rate of the feed stream by employing pollution prevention measures. Methods of flow reduction are discussed in Section 2.

When selecting a vacuum evaporator, the plater should consider, in addition to costs, the following: (1) availability, quantity and quality of steam, hot water or waste heat (i.e., if unavailable or insufficient, then choose one of the electric units); (2) cooling water requirements; (3) electrical power requirements; (4) maximum temperature that can be applied to the feed stream (i.e., concern for heat sensitive chemicals); (5) expected feed rate; (6) required solids concentration of product (i.e., how concentrated must the plating solution be before it can be returned to the bath); (7) anticipated use of distillate; (8) materials of construction (depends on both the type and maximum concentration of chemicals); (9) controls (most units have microprocessor controls for automatic operation and manual override); (10) auxiliary equipment requirements (e.g., bath maintenance technologies for removal of contaminants that will be returned to the bath by the evaporator); and (11) O & M requirements (level of expertise required and number of man-hours per year).

3.3.5.2 Operating Costs

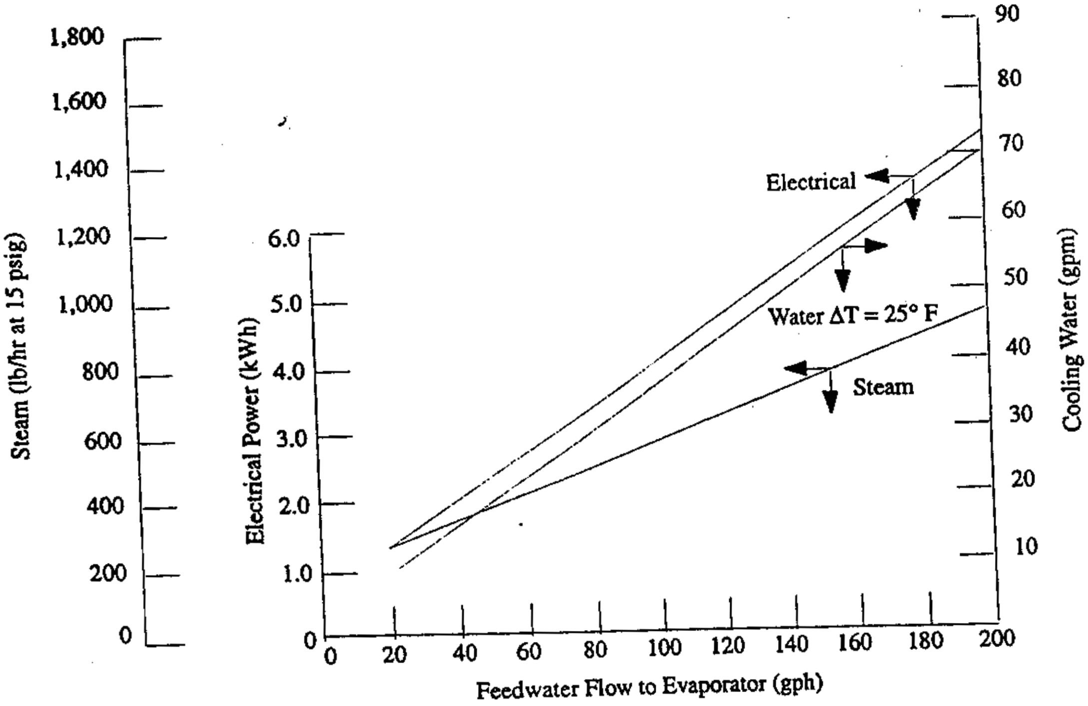
The primary operating costs for vacuum evaporators are labor, energy and cooling water. Energy and operating labor costs per gallon evaporated are shown in Exhibit 3-20. In this exhibit, a distinction is made between operating costs for segregated recovery and the concentration of mixed waste streams (e.g., end-of-pipe). Higher O&M costs can be expected for end-of-pipe applications because the solutions are evaporated to higher solids levels, which increases fouling and scaling.

Exhibit 3-16. Double-Effect Evaporation for Chemical Recovery



Source: ref. 376

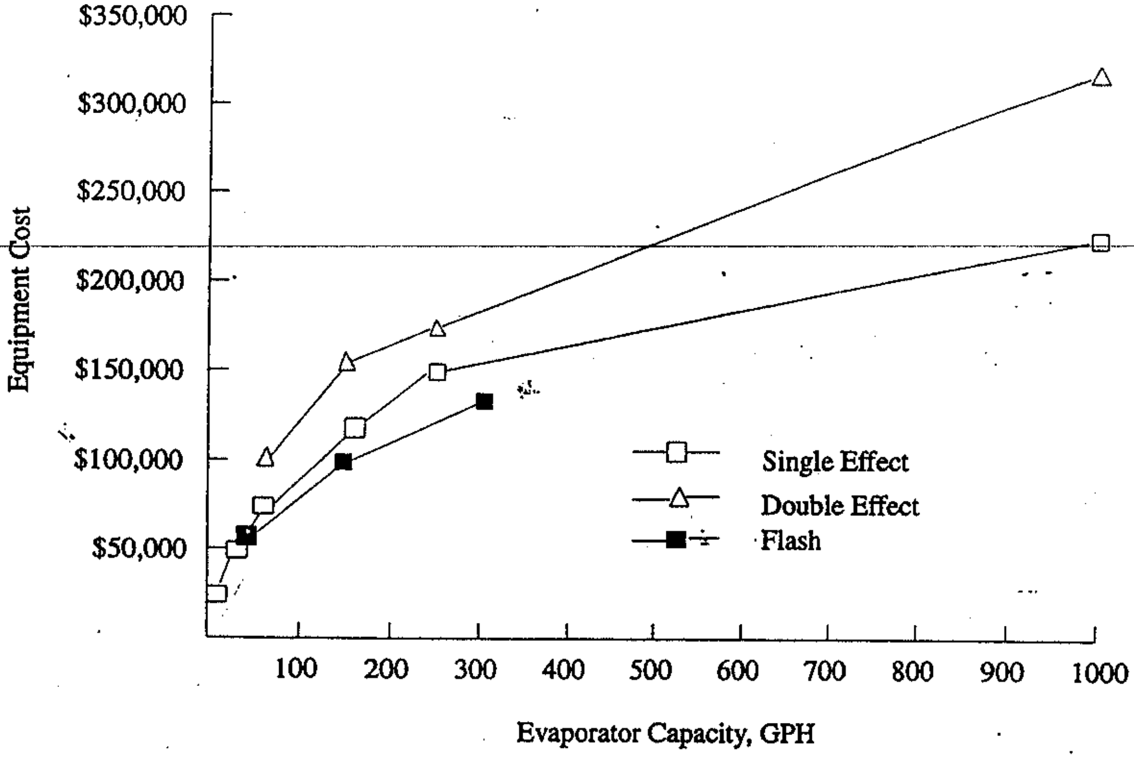
Exhibit 3-17. Utility Requirements for a Double-Effect Evaporator



Notes: Wastewater feed at 100°F; cooling water supply at 70°F; and steam supply at 15 psig.

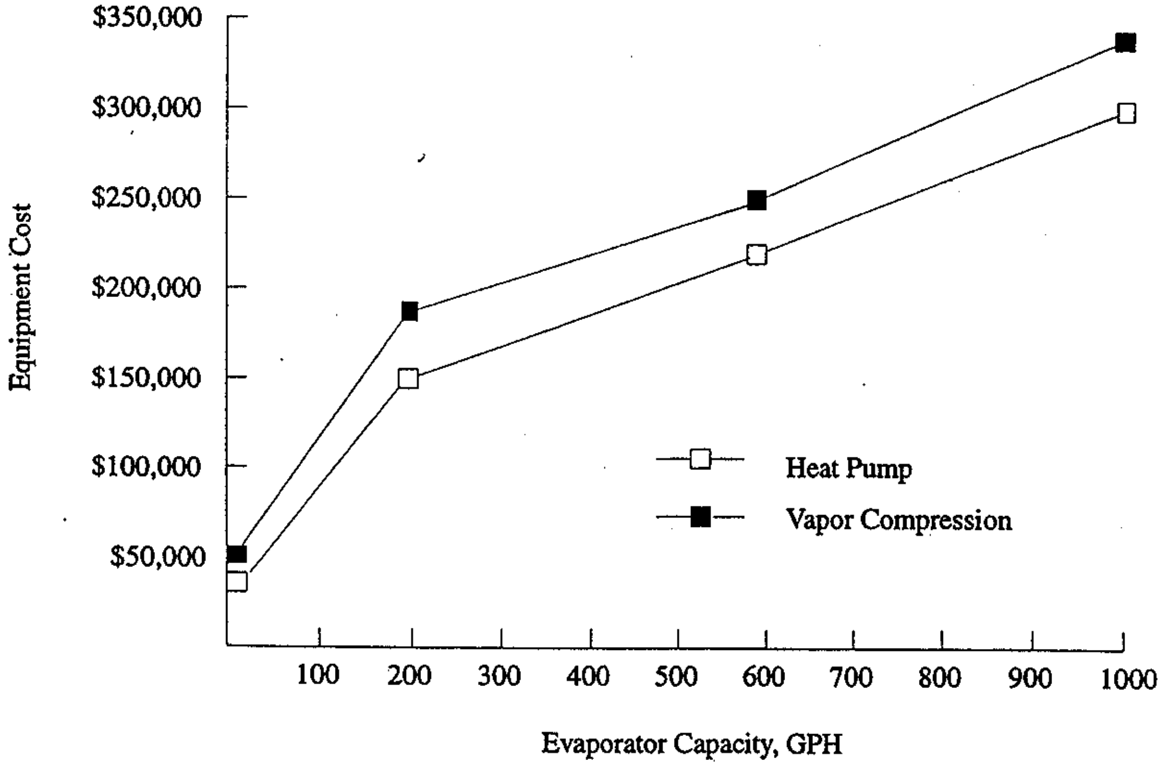
Source: ref. 376

Exhibit 3-18. Equipment Costs for Steam Type Vacuum Evaporators



Note: Total installed costs (includes basic equipment, auxillary equipment and installation costs) are approximately 140% of equipment costs.

Exhibit 3-19. Equipment Costs for Electric Type Vacuum Evaporators



Note: Total installed costs (includes basic equipment, auxillary equipment and installation costs) are approximately 140% of equipment costs.

Exhibit 3-20(a). Operating and Maintenance Costs for Vacuum Evaporators (Segregated Recovery)

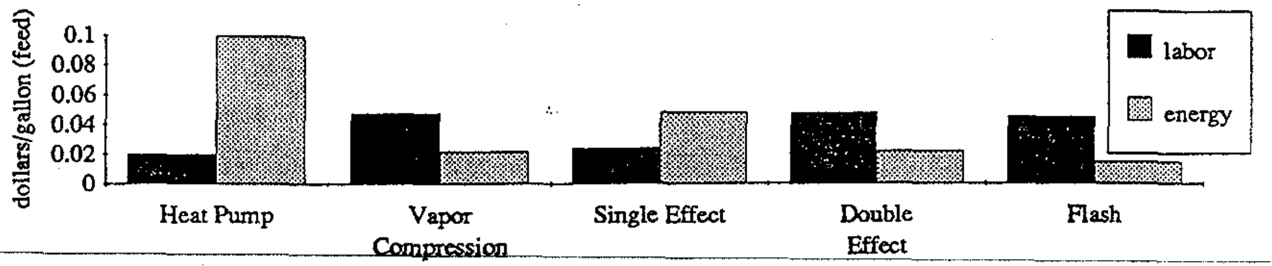
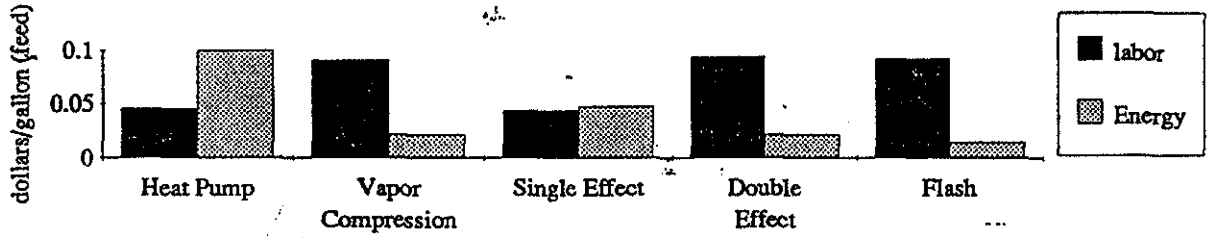


Exhibit 3-20(b). Operating and Maintenance Costs for Vacuum Evaporators (Mixed Waste Concentration)



3.3.6 Performance Experience

A partial summary of the user data relative to vacuum evaporation is presented in Exhibit 3-21. There are a number of observations that can be made from these data and other data contained in the database and literature:

- The average satisfaction level for chemical recovery applications is 3.5 (on a scale of 1 to 5, with 5 being most satisfactory), which higher than the average rating for all recovery technologies. Seventy-five percent of the shops using vacuum evaporation for chemical recovery indicated that this technology satisfied the need for which it was purchased. The following is a breakdown of the reasons why shops purchased this technology:

To meet of help meet effluent regulations:	14
To reduce plating chemical purchases:	12
To reduce the quantity of waste shipped off-site:	12
To reduce wastewater treatment costs:	11
To improve product quantity:	0
To close-loop a particular process:	1

- Vacuum evaporators were successful for most applications identified in the Users Survey except for zinc-cyanide plating solution recovery. The average annual savings from using vacuum evaporators exceeded the sum of the average capital cost plus the average annual operating cost. The most significant savings were derived from reductions of bath chemical and treatment chemical usage.

- The use of vacuum evaporation as a recovery technology generally did not impact production quality or the rate of production for the survey respondents. The following responses were provided:

	Product Quality	Production Rate
Improved	1	1
No Change	13	13
Decreased	2	0

- PS 298 indicated that use of their evaporator decreases product quality because their distillate is contaminated and not adequate for good rinsing. PS 102 also indicated that their unit decreases product quality.

- The respondents indicated, that based on their experience with this technology and, if given the opportunity, they would:

Purchase the same technology from the same vendor:	12
Purchase the same technology from a different vendor:	4
Purchase a different technology:	3
Do nothing:	0

- Two of the respondents indicated that their vacuum evaporation system was the cause of an effluent compliance excursion (PS 039 and PS 088). PS 280 did not respond to the ques-

Exhibit 3-21. Summary of Users Survey Data for Vacuum Evaporators

Shop Code	Application	Vendor	Year Purchased	Equipment Costs			Annual Operating Costs				Annual Savings					Use Code	Sat. Level	Future Decision	Shop Code
				Equip.	Other Cap.	Total	Non-Labor	Hrs	Labor	Total	Bath Chem.	Treat. Chem.	Disposal	Other	Total				
034	Zinc, Cyanide	McDermit	1980	$35,000	$8,000	$43,000	ND	250	$5,000	$5,000	$500	$200	$1,000	$2,500	$4,200	3	2	2	034
039	Zinc, Cyanide	Waste Saver	1975	$50,000	$4,000	$54,000	$9,000	400	$2,400	$11,400	$5,000	$0	$0	$0	$5,000	2	1	2	039
082	Cr+6, Decorative	Pfaudler	ND	$150,000	$25,000	$175,000	$50,000	1,000	$15,000	$65,000	$130,000	$115,000	$30,000	$0	$275,000	1	4	1	082
088	Cadmium, Cyanide	Pfaudler	1982	$23,000	$2,050	$25,050	$10,000	500	$6,000	$16,000	$9,900	$15,000	$5,000	$0	$29,900	1	4	1	088
102	Copper, Cyanide	McDermid	1972	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2	4	3	102
123	Lead-Tin	Calfran	1991	$60,000	$2,000	$62,000	$6,912	2,080	$14,560	$21,472	$214,700	$0	$34,260	$0	$248,960	1	4	1	123
124	Cr+6, Decorative	Corning	1980	$108,210	$0	$108,210	ND	ND	ND	ND	ND	ND	ND	ND	ND	1	4	1	124
125	Cr+6, Decorative	In-House	1985	$35,000	$10,000	$45,000	ND	200	$2,600	$2,600	$18,500	$0	$0	$0	$18,500	1	4	1	125
125	Nickel, Watts	In-House	1985	$70,000	$210,000	$280,000	$15,000	200	$2,600	$17,600	$38,000	$0	$0	$0	$38,000	1	4	1	125
132	Cadmium, Cyanide	Corning	1981	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2	1	3	132
143	Cadmium, Cyanide	Water Vap	1992	$10,000	$500	$10,500	$3,000	ND	ND	$3,000	$0	$0	$500	$1,000	$1,500	1	4	1	143
196	Cr+3, Decorative	Corning	ND	$240,000	$25,000	$265,000	$10,000	200	$2,000	$12,000	$450,000	$15,000	$12,000	$18,000	$495,000	1	4	1	196
197	Cr+6, Decorative	Macdermid Inc.	1979	$44,646	$56,890	$101,536	$28,565	2,920	ND	$28,565	ND	ND	ND	ND	ND	1	4	1	197
197	Nickel, Watts	Macdermid Inc.	1978	$41,521	$56,950	$98,471	$40,017	2,920	ND	$40,017	ND	ND	ND	ND	ND	1	4	1	197
197	Nickel, Watts	Macdermid Inc.	1979	$54,172	$56,960	$111,132	$40,016	2,920	ND	$40,016	ND	ND	ND	ND	ND	1	4	1	197
213	Chromium Etch	Corning	1988	$80,557	ND	$80,557	ND	ND	ND	ND	ND	ND	ND	ND	ND	2	5	1	213
275	Cr+6, Decorative	Corning	1984	$75,000	$6,500	$81,500	$10,000	250	$4,250	$14,250	$200,000	$200,000	$38,000	$0	$438,000	1	4	2	275
280	Chromium Etch	Corning	1990	$90,000	$8,000	$98,000	ND	ND	ND	ND	$16,400	$80,700	$10,000	$0	$107,100	1	4	3	280
298	Zinc, Cyanide	Wastesaver Corp	1991	$43,000	$29,000	$72,000	$15,600	780	$7,800	$23,400	$31,000	$13,000	$0	$3,000	$47,000	1	2	2	298
	Average		1983	$71,183	$31,303	$100,644	$19,843	1,125	$6,221	$21,451	$92,833	$36,575	$10,897	$2,042	$142,347		3.5		

PS 082 purchased their unit used.
PS 088 purchased their unit second hand, but unused.
Notes:
(1) Other capital costs include installation and ancillary equipment.
(2) Use Codes: 1-currently operating; 2-not currently operating and no intension for future use; 3-not currently in use, but intend to use in future.
(3) Satisfaction levels (manufacturer and technology) 1 to 5, with 1=lowest and 5=highest.
(4) Future decision codes: 1-purchase the same technology from the same vendor; 2-purchase the same technology from a different vendor; 3-purchase a different technology; 4-do nothing.
(5) "√" indicates that a savings was realized, but not quantified.
(6) ND = no data

tion. All other respondents indicated that their vacuum evaporation system was not the cause of an effluent compliance excursion.

- Several respondents provided the following quantitative performance data:
    - PS 082 indicated that the supplier stated capacity of their unit is 300 gph and that the actual capacity is 175 gph.
    - PS 123 has an evaporation rate of only 6 gph. It is used to make head-room in their tin-lead plating tank so that recovery rinsing can be used. The feed to their unit (tin-lead plating solution), has a concentration of 16 to 18 oz/gal and the concentrated return has a concentration of 32 to 36 oz/gal.
    - PS 088 indicated that the capacity of their unit is 60 gph and that they are able to operate their cadmium plating process on a closed-loop basis. Their drag-out rate is 1.5 gph and they have a three stage counterflow rinse system feeding the evaporator. The cadmium bath is operated at 75°F and there is essentially no surface evaporation.
    - PS 124 indicated that their unit has a capacity of 90 gph.
    - PS 125 indicated that their unit has a capacity of 100 gph.
    - PS 196 indicated that both the supplier stated capacities and actual capacities of their units (3) were 90, 75 and 50 gph.
    - PS 213 indicated that both the supplier stated capacity and actual capacity of their unit was 75 gph.
    - PS 298 indicated that their "unit does not meet levels stated in promotional" and that the "quality of distilled water is poor." The supplier stated capacity of their unit is 100 gph and the actual capacity is 70 to 80 gph.
- PS 132 indicated that their evaporator "never performed as sold." No details of their problems were provided.
- PS 034 expressed their feelings about their unit as follows: "Poor design, good technology."

3.3.7 Operational and Maintenance Experience

The following summarizes the respondent's O&M experiences and provides operating labor information relative to vacuum evaporators.

- The average number of annual man-hours spent for operating and maintaining a vacuum evaporation unit were: 657 hrs/yr. The skill requirement commonly needed for operating this technology is trained technician or a wastewater treatment plant operator. The following is a breakdown of the responses for skill requirements:

Environmental Engineer:	1
Process/Chemical Engineer:	1
Chemist:	1
Consultant:	1
Plumber/Pipe Fitter:	4
Electrician:	4
Vendor:	1
Senior-Level Plater:	4
Junior Level Plater:	1
Wastewater Treatment Plant Operator:	8
Trained Technician:	9
Common Labor:	1
Other:	0

- The most frequent and significant operational and maintenance problems identified with vacuum evaporation include: (1) mechanical problems with pumps; (2) damage to components by aggressive plating chemicals; and (3) contamination build-up in the plating bath.
- Approximately 26% of the total number of vacuum evaporation units reported in the survey forms are no longer in use. On the average, these units were purchased 16 years ago. Of those units still in use, the average age is 6 years. The oldest working unit was 14 years old.
- PS 034 indicated that they have weekly problems with their pump and vacuum system.

They attribute the pump problems to improper design. PS 039 also indicated that they problems with the vacuum pump. On a second unit, PS 039 had problems with the eductors. They have abandoned use of both of these units.

- Although they have installed both ion exchange and electrolytic purification, PS 082 indicated that they have trouble keeping their chromium bath free of contaminants because of the closed-loop recovery process. PS 102 used their unit for 4 years and then abandoned its use because of plating bath (copper, cyanide) contamination. PS 125 is experiencing a build-up of sodium and chloride in their nickel bath.
- PS 088 reported that their cooling water was too warm in the summer to effectively condense the vapors and operate their system.
- PS 088, which employs a four stage counterflow rinse prior to evaporation, indicated that users of this technology should concentrate on reducing rinse water flow and the resultant feed to the evaporator.
- PS 124 indicated that they need to clean the condenser of their unit approximately twice per year.
- PS 124 indicated that the maximum feed concentration to their unit is 1 oz/gal CrO_3 (presumably because higher concentrations will etch the glass of their Corning evaporation unit.) PS 196 reported some etching of their glass unit. PS 280, which operates a Corning unit with a fluoride bath, indicated that this application results in a shorter than average equipment life-span and higher maintenance costs. Their unit is three years old.
- PS 125 indicated that they must operate one of their units at <150°F because of nickel brightener considerations (nickel plating) and the other unit at ≤140°F due to fluoride considerations (decorative chromium plating).
- PS 196 indicated that they must operate their unit at >150°F to boil the chromium solution.
- PS 298 indicated that their distillate is sometimes contaminated beyond the limit for good rinsing. When this occurs, they recycle the distillate to the first rinse rather than the final rinse of their 3 stage counterflow rinse system. This results in a need to blow down rinse water to the treatment system.

3.3.8 Residuals Generation

Vacuum evaporators used for the recovery of plating chemicals create three streams: (1) the concentrate, which is reused in the plating bath; (2) the distillate, which is reused in the rinse system; and (3) cooling water, which is recycled using a cooling tower, reused as rinse water or discharged to the sewer. Cooling water requirements were previously described in Exhibit 3-145and 3-17.

Only two respondents indicated that they generate any residual wastes other than the three streams mentioned. PS 143 indicated that they generate approximately 30 gal/mth of sludge, which they mix with their other F006 sludge and sent to off-site recycle. This sludge is generated from the treatment of the distillate.(cyanide oxidation, precipitation, filter press and sludge dryer), which they do not send to the rinse tanks. PS 298 reported that carbonates collect at the bottom of the evaporation chamber forcing periodic removal. They remove approximately 100 lbs/mth of this material and treat it on-site.