# Factors Which Affect the Success of Metal/Chemical Recovery Installations in Metal Finishing Industry

Project #71 Report to:

American Electroplaters' Society
Canadian Branch
and
Ontario Waste Management Corporation

ONTARIO RESEARCH
FOUNDATION

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Project No. 71 Report
For: AES and OWMC

EXECUTIVE SUMMARY

Presented in this report are the results of an investigative study into the experiences of the metal finishing industry (MFI) in southern Ontario with chemical/metal recovery technology. Data were solicited through a limited and selective industry survey which consisted primarily of site interviews. The study focusses on the experiences and lessons gained from successful recovery technology system installations, although comments provided by industry on unsuccessful applications are also noted. The principal recovery technologies surveyed were evaporation (vacuum and atmospheric), ion exchange and electrolytic. Ion transfer and electrodialysis are also reviewed, but in less detail. The technologies chosen were determined by the composition of the survey data base.

Due to confidentiality of information requirements, names of recovery system users and manufacturers/suppliers are not revealed.

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## 1. INTRODUCTION

The metal finishing industry (MFI) in Ontario is under intense pressure to reduce both the volume and toxicity of its liquid and solid wastes. Unlike its counterpart in the United States, where strict regulations have been in place since 1976, this situation has been a relatively recent occurrence. A resolute Ontario Ministry of the Environment (MOE) is enforcing new, more stringent regulations to control the discharge and disposal of liquid and solid industrial waste in the province. Regulation 309 required the registration of all hazardous and liquid industrial wastes by September 17, 1986. Until the Ontario Waste Management Corporation (OWMC) begins operating its special waste management facility, which is not scheduled for start-up until 1991-2, industry has only one licensed facility within the province to which it can send these wastes. The situation has caused a rapid escalation in industrial waste disposal costs. In June, 1986, the MOE released a White Paper outlining its Municipal-Industrial Strategy for Abatement (MISA) program to regulate the amount of known toxic substances (the number of target compounds are in excess of EPA priority pollutants) entering the environment, and to prevent the practice of dilution to achieve regulatory compliance. The inclusion of municipal wastewater treatment plants as a primary target sector for MISA will encourage the municipalities to enforce their sewer discharge by-laws much more diligently than in the past. The impact of such action will be severe for small industries such as metal finishing facilities who do not have adequate pre-treatment facilities in place. Indeed, the industry has already experienced a number of plant closure orders in the past year due to increased vigilance by the regulatory authorities.

For the MFI to achieve compliance and, at the same time, remain competitive, it will need an effective approach to waste management. Fortunately, the situation which has existed in the United States for the past 10-15 years has fostered the development of many improved waste management techniques and technologies. A group of commercially available technologies, often referred to collectively as 'Recovery Technologies' and of significant relevance to the MFI, emerged during this period. Based on a variety of scientific and engineering principles, they offer a means of waste reduction through chemical recovery. Although recovery systems have been in place in some Ontario metal finishing plants for many years, they have recently been the focus of increased interest by the industry.

The objective of this study was to learn, through the experiences of the MFI in Ontario, some of the reasons behind the successful implementation of 'Recovery Technologies' and generate guidelines that would enable the industry as a whole to respond more effectively to the regulatory demands being placed on it.

# 2. SURVEY DESIGN

## 2.1 Company Participation

The primary source of information for this study was a limited survey of the metal finishing industry in southern Ontario. The process of identifying potential survey participants was selective, using the following methods:

- Recovery system manufacturers' data
- Trade journal articles
- Personal contacts
- Industry references

Twenty-nine companies with at least one metal/chemical recovery system in operation were identified. Technologies represented were evaporation (vacuum and atmospheric), ion exchange, electrolysis and electrodialysis. A reverse osmosis unit operating commercially on metal finishing wastewater was not located. In addition to examples of operating recovery systems, the views and comments of owners/plant managers concerning recovery systems which had been installed at their facilities, but not currently operational, were also noted.

## 2.2 Questionnaire

In order to provide a co-ordinated approach to the collection and subsequent analysis of information, a comprehensive 5-page survey questionnaire was designed (See Appendix A). It was divided into six main categories through which specific details on topics such as technology, operation, performance and economics were collected.

## 2.3 Confidentiality

Due to the sensitive nature of much of the information being solicited in the survey, it was decided that a personal interview with the designated company representative would be the most appropriate technique to employ. It was recognized that all information provided to us would have to be treated in confidence and specific data which might identify either system user or manufacturer would not be reported.

A letter of introduction was sent to each company requesting its participation in the survey (See Appendix A). This letter also outlined the project objectives and addressed the issue of confidentiality. The letter was accompanied by a copy of the questionnaire for information purposes only. It was indicated that each candidate company would be contacted by telephone to get their response to the request and, hopefully, set up an on-site interview date. The position within the company of those individuals interviewed was generally owner, plant manager or engineer, depending on company size.

## 2.4 Response

All companies to which the letter and questionnaire were sent in early January were contacted by telephone and seventeen site visits were completed by mid-March. Only one of the twenty-nine companies approached refused to take part. However, difficulty in finding a mutually acceptable time to meet eventually prevented the inclusion of another three facilities. Six companies participated by returning the completed sample questionnaire by mail.

The final participation rate was 86 percent of those approached. However, the information provided by three of the companies visited was not incorporated in the survey results, but discussed generally throughout the report. This was because their recovery systems were no longer in operation.

## 2.5 Quality of Data

While a lot of good, reliable information was collected in the survey, the overall quality of the data collected was somewhat inconsistent. This is typical of any survey of this nature. Firstly, not all participants replied to all questions. Some did not wish to provide certain information which, despite our promise of confidentiality, they felt might compromise their competitive position. Others just did not know all of the answers. This was particularly evident in situations where the recovery unit had been installed prior to the interviewee joining the company, or assuming his present position.

The quality of information was variable because some interviewees were recalling from memory or providing 'guestimates', while others had in-house reports to which they could refer. Some interviewees had a better understanding of the process, operating and cost details than others, which, in turn, reflected on the quality of the data reported. Some level of consistency was applied by the author to comparative type information. While follow-up telephone conversations were made subsequent to some site interviews to clarify specific points, verification of the data in general was not possible.

# 3. RECOVERY TECHNOLOGY SURVEY RESULTS

To facilitate a better understanding of the various recovery systems surveyed, basic theory and design data are presented for each technology, prior to the survey results and discussion. The principle recovery technologies surveyed and discussed in this report are evaporation, ion exchange and electrolytic processes. Electrodialysis and ion transfer membrane processes are also discussed, but in less detail.

## 3.1 Evaporative Recovery Processes

### 3.1.1 Theory and Design

Evaporation is a separation technique whereby chemical recovery can be achieved by distilling wastewater to a concentration which will permit its reuse as process solution. This concentration technique is widely used in the metal finishing industry, from simple open evaporation tanks to sophisticated multi-effect evaporators. Evaporation rate is determined by the following parameters (Yates, 1986):

- Solution surface area exposed to the air
- Air movement across the surface
- Air and solution temperatures
- Relative humidity

In an electroplating bath, air movement is the only factor which is not fixed. An ordinary hot plating bath will lose by evaporation between 3 and 6 percent of its total volume per day. By blowing air across the surface of the plating bath, it is possible to double and even triple this evaporation rate (Kushner and Kushner, 1981). Sometimes this surface evaporation rate is sufficient to allow topping up of the plating tank from the first rinse or drag-out tank to be practised. However, a forced evaporation system is normally required to provide adequate water removal.

Evaporative recovery is used for the concentration, recovery and reuse of many metal finishing process solutions, including chromium, nickel, copper, cadmium, brass, zinc, silver, gold, alkalis and acids.

Forced evaporators can be classified as either atmospheric or vacuum systems.

Vacuum Evaporation

In vacuum evaporation, advantage is taken of the reduction in boiling point of the liquid which occurs under low pressure conditions. The use of a lower operating temperature not only reduces the energy requirements, but also the possibility of decomposition of the recovered chemicals.

Three types of low pressure evaporator systems are available commercially. They are the climbing film, flash and submerged tube types (Canning Handbook, 1982).

- Climbing Film

The major components of a climbing film evaporator are vacuum pump, boiler, separator, mesh mist eliminator, condenser/cooler and concentration sensor/controller (Corning, 1984).

Rinsewater is drawn by vacuum into the steam heated tubes of the boiler. Water vapour, along with unevaporated water containing plating chemicals, passes through the separator chamber where the water (containing the chemicals) is drawn by gravity to the base of the separator chamber, while the vapour travels through the mist eliminator into the condenser. Concentrated chemicals are recycled back to the boiler and mixed with incoming feed. Chemicals are retained in this boiler-to-separator-to-boiler loop until the fluid reaches the required concentration.

Climbing film evaporators operate under pressures of 1.3 to 7.5 psi (Cushnie, 1985).

- **Flash Evaporators**

In a flash evaporator, wastewater is heated up under atmospheric pressure after which it is fed into a reduced pressure system. The reduction in pressure causes the water to boil. Water vapour leaves the top of the unit and a concentrated solution falls to the bottom to be removed. The recovered solution can be refed into the system until required concentration is achieved. Flash evaporators work using a fairly high vacuum [1.3 psi] (Canning Handbook, 1982).

- **Submerged Tube Evaporators**

In submerged tube evaporators, the wastewater is heated under vacuum using steam coils submerged in the liquid. This type of evaporator also uses a relatively high vacuum [1.3 psi] (Canning Handbook, 1982).

## Atmospheric Evaporation

The atmospheric evaporator operates in a mode very similar to a fume scrubber, in that the liquid being evaporated is passed countercurrent to the air stream. Generally, the solution is sprayed on a large area sometimes called "mass pack" or "packing material" (Yates, 1986). The air stream is forced to pass over the wet surface where it picks up moisture. It then continues through the mist eliminator assembly which removes the airborne droplets. Water is usually not recovered and the humidified air is exhausted to atmosphere.

The degree of solution concentration achievable depends on the solution temperature and on the relative humidity of the forced air draught (Canning Handbook, 1982). Relative humidity has a direct effect on the evaporation rate of room temperature baths, but less effect on hotter solutions. This is due to the air being heated when it comes in contact with hot solution, allowing greater moisture holding capacity.

Solutions that are susceptible to foaming, such as high cyanide and still nickel baths, may not be suitable for atmospheric recovery.

## Single and Multi-Effect Evaporators

Single effect vacuum evaporators operate with one reboiler or evaporator section (Cherry, 1982). The water vapour is either condensed or exhausted to atmosphere. Approximately 0.5 kg (1.1 lbs) of steam is consumed in the evaporation of 0.454 kg (1 lb) of water from the plating solution.

A technique often used to reduce steam demand for evaporation is the double effect evaporator. In this system, approximately 50% of the wastewater is concentrated in the first effect using steam. The vapour from the separator of the first effect enters the second effect reboiler and condenses to provide additional thermal energy for the final concentration step. Indeed, each effect could be used to concentrate a different solution. A lower boiling point occurs in the second effect because of the higher vacuum.

### 3.1.2 Survey Results

#### Industrial and Process Application

Fourteen installations employing evaporative recovery technologies were surveyed in industries that included computer parts, automotive parts (trim, grills, dashes, etc.), plating on plastics, zinc diecastings, as well as job shop production applications. Details of each installation are presented in Appendix B.

Some of the process solutions being recovered include chromic acid etch, chromium, nickel, zinc and copper plating and rinse solutions, a neutralizer rinse, and a tin palladium catalyst rinse.

Three of the fourteen systems were atmospheric evaporators, two of which were on nickel plating and one on chromium plating solutions.

#### System Installation

All of the units were installed between 1971 and 1987. The last vacuum system was installed in 1985 and the first atmospheric unit in 1986. Over fifty percent of the vacuum units and all of the atmospheric units were installed by in-house labour.

### Process Configuration

Six of the eleven vacuum evaporators were applied to process rinse water in a closed loop configuration as shown in Figure 6.1.1. Purification units are generally used to remove impurities from the system. These are anion and/or cation ion exchange columns. In one instance (chromic acid etch), the evaporator was put directly onto the process solution in a similar configuration to Figure 3.1.3.

A further four vacuum evaporators were employed solely for the purpose of concentrating the wastewater prior to treatment, while, in some cases, recycling the recovered water (see Figure 3.1.2). This reduces the size of the waste treatment plant required.

In two of the atmospheric evaporator installations, a conventional countercurrent running rinse overflowed into the plating tank to make up for the water being evaporated.

In the third installation, a countercurrent spray rinse system is employed which has greatly increased the rinsing efficiency of the line, resulting in a reduction in water use (See Figure 3.1.3-A). Process solution make up is provided by a spray rinse over the plating tank supplied by water from the first rinse tank.

### Maintenance and Downtime

Downtime for both types of evaporation systems was found to be low. Sixty four percent (seven) of the vacuum units were

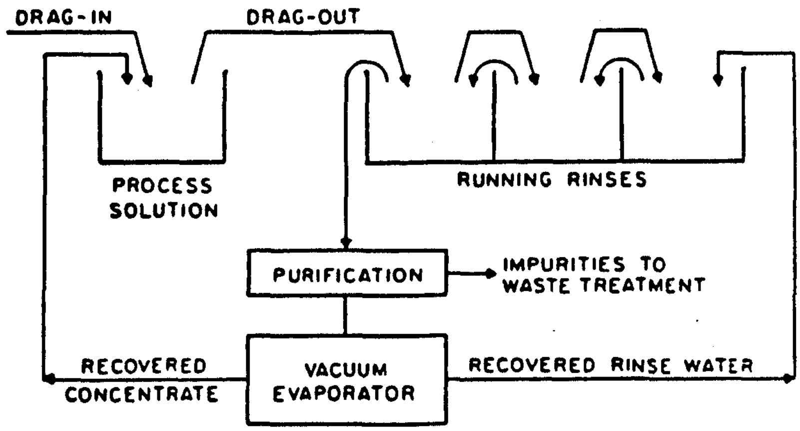


Figure 3.1.1 CLOSED LOOP EVAPORATIVE RECOVERY.

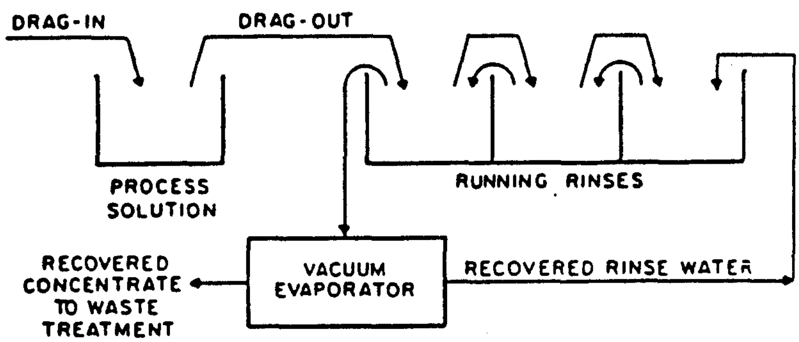


Figure 3.1.2 RINSEWATER CONCENTRATION BY EVAPORATION

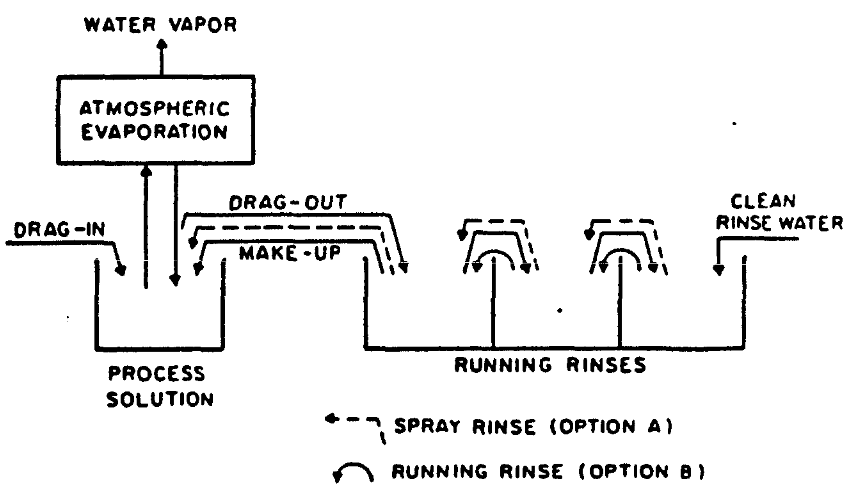


Figure 3.1.3 ATMOSPHERIC EVAPORATIVE RECOVERY (A and B)

reported as having negligible downtime, as were all the atmospheric systems. Of the four remaining vacuum systems, an average 0.75 days every two months applied.

Only one of the fourteen evaporators (a vacuum unit installed in 1978) is serviced by the manufacturer.

## Operators

One designated operator each was used on six of the vacuum systems. Four more employed any of three men working on the line during a shift, basically because the units operated without need for much attention. The level of education of the operators ranged from Grade 10 through 12 to technician/technologist. All training was provided to the operators by their supervisors.

Operators were described as having a good appreciation of the process chemistry/physics in six (or 43%) out of the fourteen cases of vacuum evaporation. This compares with a 93% "good" rating for their knowledge of the process equipment.

## Capital and Operating Costs

Capital cost estimates were provided for seven individual vacuum evaporators. The remainder were installed at a single plant as part of a large recovery and waste treatment package. Converted to 1987 dollars, costs of new vacuum evaporators ranged between $46,000 and $235,000, with the average cost at $161,000. In addition to this, one unit was bought on the used equipment market for about $5,000.

The capital costs for the three atmospheric units were considerably lower, ranging between $9,000 and $16,000 installed.

Labour requirements for vacuum evaporation systems were estimated to range between 0.5 hours per 24-hour day to 2.5 hours per 8 hour day. The average was about 0.75 hours per 24 hour day. Labour and materials costs were estimated between $3,000 and $10,000 per year for five vacuum units, with an average cost of $5,500. Although the cost of energy is significant for evaporation, an estimate was available in only one case, where costs of $10,000 per annum were incurred to boil off at a rate of 150 L/hour.One plant reported higher than expected material replacement costs for a climbing film evaporator.

Operating and energy costs were reported as negligible by the users of atmospheric evaporators.

Recovery Rate

Evaporative recovery functions in either of two ways:

1. It concentrates rinsewater which permits its reuse as process solution. This can be done in either closed or open loop process configurations.

2. It assists process tank surface evaporation to allow for the overflow of rinsewater or drag-out into the process tank as top-up.

In either case metal recovery is in solution form, and is quantified in Table 3.1.1 based on the reduction of raw chemicals consumed in the process. Recovery rates (or avoided losses) range from a low of 13 kg to a high of 275 kg of metal daily. This is converted into cost savings estimated as ranging between $15,000 and $319,440 per annum.

Nine of the vacuum units had associated water savings through the use of a closed or partially closed loop process configuration.

All of those surveyed were satisfied with their evaporative recovery systems and all stated they would purchase the same technology again given the opportunity. Although information was not available on four of the systems, a total of six, or 43% considered other technologies prior to selecting/purchasing an evaporative system.

### 3.1.3 Discussion

Because evaporation as a unit operation is well established, it is not surprising that five of the units surveyed were installed prior to 1980. While the continued operation of these units, some for over 15 years, reflects well on the application of the technology to metal finishing processes, it did cause some difficulty in getting accurate data on items such as capital costs, installation and reasons for technology selection. However, estimates were provided by the current plant personnel when possible. One plant, which installed a number of evaporative recovery systems in 1978, did so along with a variety of other recovery and treatment systems for a single purchase cost, thereby making it virtually impossible to place even reasonable estimates on each individual evaporator.

Only one company reported higher than expected operating costs associated with evaporation. The evaporator, set up in 1978 on a chromium plating line, has high parts and materials (glass and teflon) replacement costs which are incurred more frequently than originally anticipated. Other than that, they expressed total satisfaction with the system.

Responsible for a number of vacuum evaporative recovery units, one plant manager suggested that probably 95% of the maintenance problems which he encounters with these systems are due to vacuum leaks, with the other five percent being electrical. As expected with all concentrative recovery technologies, the build-up of impurities in the process solution is a major concern. Chloride build-up was reported as being the biggest problem for one chrome plater. These could be removed with an anion exchange bed.

It is noteworthy that four vacuum evaporators were being used to concentrate rinsewater prior to waste treatment. In three of these cases, quality control ruled out reuse of recovered solutions in-house. Recovery for sale value was not considered to be economically viable, although this situation is likely to change in the near future.

All users of atmospheric evaporators reported encouraging performances. However, each of the three systems surveyed has been installed very recently and, therefore, experience is limited.

The normal process configuration for atmospheric evaporators involves the counterflowing of concentrated (low volume/flowrate) rinsewater back to the process tank as solution make-up. A relatively new approach being employed on a nickel plating line involves the use of spray rather than flowing countercurrent rinses. Prior to installing an atmospheric evaporator and spray rinse system, this line was discharging 680 L/hour of rinsewater containing 5 g/L of nickel. The new spray rinsing system has reduced the rinsewater flow to 230 L/hour at 0.9 g/L nickel. The final system bleed-off to treatment is expected to be about 40 L/hour at 0.6 g/L nickel.

Another user of an atmospheric evaporator advised on the importance of incorporating in the design a capability to deal with humidity and temperature variation in the air stream which effects the evaporation rate.

The concentrative nature of evaporative recovery necessitates the provision of a method to prevent the build-up of impurities in a closed loop system. Carbon adsorption is being used to remove the unwanted organics such as brighteners, while small ion exchange scavengers are used to remove unwanted cationic and anionic contaminants.

Past Experiences with Evaporative Recovery

Only one interviewee had any past experiences with evaporative recovery to recount. The company, which is currently considering a number of waste recovery technologies, reported that it did have vacuum evaporators in the past which worked well, but which were not maintained and were eventually allowed to deteriorate to the point where they had to be scrapped. This neglect was due to the lack of a proper maintenance program. This emphasizes the fact that no process equipment, no matter how simple, will operate indefinitely without adequate maintenance.

## 3.2 Ion Exchange Recovery Process

### 3.2.1 Theory and Design

The ion exchange process has been available commercially for many years, but has been used primarily for water deionization or softening (Cushnie, 1985).