Pollution Prevention in the Commercial Sector

Waste Stream Assessment

in the

Metal Finishing Industry

by

Mohamed F. Dahab,
Principal Investigator

and

David Montag
Research Assistant

Department of Civil Engineering
University of Nebraska-Lincoln
Lincoln, NE 68588-0531

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ABSTRACT

The concept of pollution prevention has recently received much attention in the media. Minimizing harm to the environment by reducing the generation of pollution at its source is a logical approach to pollution problems. The University of Nebraska Lincoln (UNL) is encouraging Nebraska businesses to adopt pollution prevention.

One part of this effort has been a research project focused on industrial pollution prevention. During 1992 and 1993, a pollution prevention project was conducted at a large metal finishing company in Nebraska. The manufacturing processes studied were electroplating, galvanizing, painting, and tubing fabrication.

By examining the available literature and interviewing experts in the metal finishing industry, UNL researchers were able to identify several promising pollution prevention options. Tubing manufacture used a water based metalworking fluid that was susceptible to decomposition by anaerobic bacteria. The bacterial growth was encouraged by oil contamination from leaking gearboxes. This problem was minimized by replacing grease seals on the gearboxes and by installing an improved oil removal system to purify the coolant.

The paint used by the company contained volatile solvents, which evaporate as the paint dries and eventually contribute to smog (ozone pollution). Volatile organic compound emissions can be avoided by using coating materials other than traditional solvent based paint. Alternative materials studied were water based paint, autophoretic coatings, and powder coating. At the time of this writing, the company was seriously considering installing a powder coating line.

The galvanizing process produced large volumes of rinse water which was contaminated with sulfuric acid, and zinc, and which required expensive treatment prior to disposal. A test was conducted that successfully demonstrated that a counter current continuous flow rinse could reduce water use. Tests were also conducted to prove the feasibility of using a
continuous flow rinse to remove flux chemicals from the surface of freshly galvanized parts. These tests were unsuccessful. Testing was also conducted to change the process chemistry to avoid depositing a flux chemical film on the finished work. In this way, the need to rinse could be avoided. Unfortunately the chemistry changes resulted in unacceptable product quality, and the proposed rinsing system was not considered feasible. A rinse water flow reduction of about 21 percent was achieved, however, by installing new spray nozzles in the existing spray booths.
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LIST OF SYMBOLS AND ABBREVIATIONS

EPA - United States Environmental Protection Agency

fpm - feet per minute

gm/ml - grams per milliliter

KCl - potassium chloride

HWSA - 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act

mg/L - milligrams per liter

NH₄Cl - ammonium chloride, a flux chemical

pH - negative logarithm of the hydronium ion concentration

TCLP - Toxicity Characteristic Leaching Procedure

TQM - Total Quality Management

VOC - Volatile Organic Compound

WM - Waste Minimization


ZnCl₂ - zinc chloride, a flux chemical

ZnCl₂/NH₄Cl - weight ratio of zinc chloride to ammonium chloride in a flux solution

°Be - degrees Baume, a scale used to measure the density of liquids. Related to milligrams per liter by the equation:

\[ 145 - \frac{145}{\rho_{(mg/L)}} = °Be \]

Where Rho is the solution density in milligrams per liter.

°C - degrees Centigrade

°F - degrees Fahrenheit
CHAPTER 1: INTRODUCTION

We depend on metals for many materials which add to our quality of life. Metal fabricating and finishing is, therefore, an essential industry. Unfortunately, metal finishing can pollute our land, water, and air. The adverse environmental effects of this industry must be kept to an absolute minimum.

Pollution prevention is becoming widely accepted as the proper approach to minimizing environmental problems caused by manufacturing. This is because pollution prevention focuses on reducing the generation of pollution at its source in the manufacturing process.

Traditional government policies have concentrated on pollution control measures such as waste treatment. The Clean Water Act and the Clean Air Act tended to foster an "end of pipe" mentality by limiting the concentrations of effluents from industrial facilities (Johnson, 1992). An "end of pipe" approach is common in industry and in regulatory agencies, and it is proving to be a hindrance to acceptance of the pollution prevention concept.

The Pollution Prevention Act of 1990 is not the first law to encourage source reduction. In 1984, the Hazardous and Solid Waste Amendments were added to the Resource Conservation and Recovery Act (RCRA). These amendments stated that the policy of the United States is to reduce or
eliminate hazardous waste generation wherever feasible. The 1984 RCRA amendments also required hazardous waste generators to submit biennial reports describing their efforts to reduce their generation of hazardous wastes (U.S. Congress, 1984).

The 1990 act signalled a shift in priority away from controlling pollution and toward preventing the generation of pollution. So far, the only mandatory requirements are for increased reporting concerning quantities of pollution generated and waste minimization techniques. The Pollution Prevention Act of 1990 establishes source reduction as the top priority in the national pollution management hierarchy, but the central focus of the act is still on voluntary pollution prevention (Johnson, 1992).

This report focuses on pollution prevention in the metal finishing industry, specifically in the areas of metalworking fluid use, painting, and galvanizing. The University of Nebraska-Lincoln has spearheaded a pollution prevention pilot project to be implemented at a large metal finishing company in Nebraska, and the experience gained from this project is presented as a case study. It is hoped that the success of this project will serve as an example to encourage businesses throughout the state region and nation to adopt pollution prevention.
OBJECTIVES

The main goal of the pollution prevention pilot project has been to successfully demonstrate the benefits of pollution prevention in order to encourage others to follow this approach. Several objectives were stated in the beginning of this undertaking which have directed later efforts. These objectives are as follows:

1. To perform a detailed assessment of current metalworking, painting and galvanizing practices.
2. To identify and describe all pollution prevention opportunities, including process changes and operating practice changes. Process changes reduce the quantity or toxicity of pollutants generated. Operating practice changes can reduce waste volume and toxicity, encourage in-house recycling, and segregate toxic waste from other wastes.
4. Presentation of recommendations, followed by voluntary implementation of any recommendations which the company considers to be practical.
5. A review of results of any changes that have been implemented.
LITERATURE REVIEW

There is a wide body of information available on pollution prevention in manufacturing. Writings on the subject discuss general approaches to pollution, list regulatory requirements, and sometimes have an industry-specific outlook. Additionally, many publications which are not strictly concerned with pollution prevention give helpful information. The next few pages contain a review of the current literature on pollution prevention, especially as it relates to the metal finishing processes of tubing production, spray painting, and galvanizing.

General Pollution Prevention

As mentioned in the introduction, the 1984 Hazardous and Solid Waste Amendments (HSWA) to RCRA declared pollution prevention and waste minimization to be national policy. At first there was disagreement about the proper meaning of the terms pollution prevention and waste minimization. According to John Hunter and David Benforado of 3M Corporation (Hunter and Benforado, 1987, 1990), there has been a tendency for organizations to equate waste minimization with source reduction, and to neglect recycling. The authors quote the 1984 HSWA to prove that recycling was intended to be a component of waste minimization. The benefits of recycling both on-site and off-site are discussed (Hunter and Benforado, 1987, 1990).
In 1988, the Waste Minimization Opportunity Assessment Manual (WMOAM) was published to aid manufacturing plants and corporations in implementing waste minimization (U.S. EPA, 1988). The WMOAM defined important terms concerned with waste minimization (WM), described how to set up WM programs, gave directions for conducting assessments and generating WM options, and told how to determine the technical or economic feasibility of each option. Implementation of WM options was discussed, including funding and followup evaluation. Worksheets were provided to assist in each WM phase.

The WMOAM discussed the waste management hierarchy, which is the EPA's preferred order of priority for managing pollution problems. The hierarchy has four parts: 1) Source Reduction, 2) Recycling, 3) Treatment, and 4) Disposal. It is important to recognize waste minimization or pollution prevention are terms that apply only to parts of the hierarchy, and that the rest of the hierarchy is also important.

In 1992, the Facility Pollution Prevention Guide was published as a replacement for the WMOAM. The new guide differed from the WMOAM by stressing "multimedia pollution prevention" rather than focusing entirely on RCRA wastes. The Facility Pollution Prevention Guide used the term "pollution prevention" in much the same way as the term "waste minimization" was used in the WMOAM, defining
pollution prevention as "the maximum feasible reduction of all wastes generated at production sites". Pollution prevention and waste minimization both include source reduction and on-site recycling, but unlike waste minimization, pollution prevention does not include off-site recycling (U.S. EPA, 1992). The Facility Pollution Prevention Guide enlarged on many themes from the WMOAM. More guidance was given on obtaining corporate commitment to pollution prevention, measuring results after implementation, and economic analysis. A new section on maintaining pollution prevention programs was also included.

Encouraging manufacturers to prevent pollution rather than treating pollution after it has been generated is the main purpose of the 1990 Pollution Prevention Act. In an article entitled "From Reaction to Proaction: The 1990 Pollution Prevention Act", Stephen Johnson devoted 20 pages to describing ways in which the Act could be improved, largely by adding more mandatory requirements (Johnson, 1992). Although the Pollution Prevention Act relies on voluntary efforts by industry, it still represents a dramatic shift from the "pollution control" methods employed in past environmental legislation.

The multimedia approach of the Pollution Prevention Act avoids a serious drawback of previous environmental laws. These laws often concentrated on a single medium, such as water or air, and thus encouraged the use of technologies
which could transfer pollution from one medium to another without actually reducing total quantities of hazardous substances or pollutants released to the environment (Johnson, 1992).

Waste minimization was initially greeted with much enthusiasm. In 1988, Harry Freeman of the EPA's WM research program felt confident in predicting that, thanks to WM, the world's hazardous waste problems would someday be far less serious than they were then (Freeman, 1988). Unfortunately, industry may have become wary of pollution prevention. Some manufacturers fear that the increased reporting requirements of the 1990 Act will be used as a basis for enacting costly future programs (Grayson, 1992).

Barriers to Pollution Prevention

Current regulations interfere with waste minimization in a number of ways. For example, there is still much disagreement on how recycling and reuse fit into pollution prevention. The definition of hazardous waste is too restrictive in that it applies to hazardous material resulting from one process which is then used as raw material in another process. Stricter controls are placed on materials if they are byproducts of a manufacturing process than if they are of natural origin. This favors manufacturing with naturally occurring ingredients instead of reclaimed materials, thus increasing the total quantity
of hazardous substances requiring disposal (Byers, 1991).

Another regulatory barrier is obtaining permits. Byers (1991) believed that permitting requirements for plants engaged in recycling should be no more restrictive than for plants processing similar raw materials. Manufacturers currently obtain separate permits for air, water, and solid waste emissions. Multimedia pollution prevention would be enhanced by issuing just one permit covering all types of emissions (Byers, 1991).

Further regulatory hindrance to pollution prevention is caused by a lack of uniformity between state policies. State pollution prevention programs vary widely, complicating the efforts of companies operating in more than one state. A cost-efficient uniform approach and common waste reduction goals are needed at the state level (Scagnelli, 1991).

Metal Finishing Pollution Prevention

Metal finishing encompasses a wide variety of operations. A major portion of the industry concerns the surface treatment of metal by electroplating, conversion coating, painting, and galvanizing. Another area of metal finishing is the fabrication of parts by welding, grinding, shearing, or impact deformation. Many of these processes result in the production of pollutants which must be disposed of in some manner. Direction on how to reduce
metal finishing pollution can be obtained from several sources.

One way to understand pollution prevention is to consider it an extension of the Total Quality Management (TQM) principles used by business to improve product quality. By including environmental concerns among the product quality characteristics evaluated by manufacturers, reduction of pollution can be engineered into products (Isbell, 1991). The TQM approach clarifies how information originally intended for quality control purposes can also be applied to pollution prevention.

The U.S. EPA has published Guides to Pollution Prevention containing information pertaining to a variety of industries. The guide for the fabricated metal products industry covers several topics of interest in this study (U.S. EPA, 1990). These areas include: metalworking fluid use reduction, minimizing rinse water use through dragout reduction, and reducing paint waste by using alternate materials. Source reduction methodologies applicable to all production processes are housekeeping and inventory control. Chemical spoilage must be minimized through proper storage and through preventing the contamination of raw chemicals. Rotation of stock will prevent chemicals from expiring (U.S. EPA, 1990). Process-specific waste reduction methodologies are discussed with their respective production processes.
Metalworking Fluid Pollution Prevention

Metalworking as discussed throughout this study means the cold-forming of metal to produce metal products that are completely different from the raw material used. Processes which change the shape of metal without adding heat include cold rolling, drilling, and grinding. Fluids are used in these operations for lubrication and cooling purposes. Spent metalworking fluids can be pollutants, so minimizing the quantity of metalworking fluid which requires disposal is a goal of pollution prevention in metal finishing.

The following metalworking fluid management options should be considered: changing operating practices and materials to discourage bacterial growth, recycling fluids, and technology changes (Pojasek, 1992).

An example of metalworking fluid recycling is the use of chip removal equipment, which separates metal particles from the liquid. The importance of chip removal is that chips harbor the growth of anaerobic bacteria which can cause fluid breakdown. Two types of chip removal systems available are magnetic separators and hydrocyclones (Porter, 1988).

Another cause of growth of anaerobic bacteria and fungi is tramp oil contamination. Tramp oil comes from leaking machines in the work area which allow lubricating oil or hydraulic oil to enter the metalworking fluid. Another source of oil contamination is that sometimes the metal
being formed is covered with an oil film to discourage corrosion during storage. Anaerobic bacteria cause coolant breakdown, requiring the fluid to be replaced. The best solution to the tramp oil problem is to improve preventative maintenance practices to prevent oil from leaking into coolant (U.S. EPA, 1990; Hunt, 1988).

Several types of skimmers are available to recover and recycle metalworking fluids by removing tramp oil from coolant sumps. Disk skimmers and belt skimmers are two common types that were studied by Washington Scientific Industries, Inc. (Pallansh, 1988). Tramp oil floats on the surface of the coolant, and adheres to a rotating disc or belt which is partially submerged in the coolant sump. A small blade scrapes the oil off of the disc or belt, and the oil then drops into a collection trough. The oil is conducted by the trough to a container for storage and eventual disposal.

Skimmers cost as little as $100 to install, and both types were found to be cost effective. The belt skimmers have the advantage of being able to be mounted high enough to drain to a large container (e.g. a 55-gallon drum). A small container would require more frequent emptying, increasing the likelihood of spills. Another advantage of belt skimmers is that they remove less coolant with the oil. Oil removal by centrifuging was also tested, but the high capital investment cost of such systems might not be
Paint Application Pollution Prevention

Volatile solvents are the main ingredient of traditional solvent-based paints. These solvents are volatile organic compounds (VOC's), which evaporate when paint is applied, and are often exhausted to the outside air. Sunlight acts on VOC's causing them to react with nitrogen oxides to create ozone (Sterling, 1991). Ozone is the primary ingredient in smog, and is a health and environmental concern (U.S. EPA, 1992). VOC emissions will be strictly controlled by the 1990 Clean Air Act.

Facilities that emit more than 10 tons per year of any one of the VOC's defined as hazardous by the 1990 Clean Air Act will be required to install emission control devices conforming to the Maximum Achievable Control Technology (MACT) standards, which will be determined by future EPA regulations. Available literature on paint booth emission controls describes a variety of methods to decrease the volume of air requiring treatment and thus to reduce the cost of treating the exhaust air stream. Air recirculation is one common method of concentrating VOC's (Ayer and Wolbach, 1989; Kenson and Jackson, 1989). Another method of concentrating VOC's is carbon adsorption (Kenson and Jackson, 1989; Larsen and Pilat, 1991). Treatment of VOC's usually consists of incineration at high temperatures (about...
1,500°F) or catalytic incineration at lower temperatures (about 600°F) (Griffin, 1991). All of the systems for removing VOC’s from paint booth exhaust are complicated and expensive to install, and would add continuing operating expenses to painting operations.

Mr. Douglas Johnson of Industrial Finishing Systems, Inc. describes the task of reducing VOC emissions from painting by stating that "the only way to significantly reduce VOC’s is to paint with different materials" (Johnson, 1992). High solids, low VOC polyester paints used in a study of high solids paint additives typically contained about 2 pounds of VOC per gallon, which was approximately one fourth of the total volume (Berndlmaier et al., 1990). The 2 lb/gal VOC content of low-VOC paint compares to about 6 lb/gal VOC found in a conventional lacquer (Whitesell, 1989). Although high-solids paints are a clear improvement over low-solids paints, it is also clear that more dramatic VOC reductions would be obtained with a paint having little or no VOC content. Since application of high-solids paints will still involve significant VOC emissions, switching to high solids paint is not as attractive as switching to alternate materials. Alternate paint materials considered in this research project are: water-based coatings, autophoretic coating, and powder coating.

Water based coatings are mostly water, containing only a small fraction of the solvent present in traditional paint
(U.S. EPA, 1990), and only about half the solvent of high solids paint (Albers, 1984). Electrostatically applied water based coatings typically emit 40 percent less VOC than electrostatically applied high-solids coatings (Drum, 1985). With a few modifications, water based paint can be applied with solvent-based manual electrostatic spray painting equipment (U.S. EPA, 1990; Drum, 1985; Clancy, 1990).

Water based paint can also be applied by flow coating. In flow coating, a large quantity of paint is sprayed onto parts, and the excess is allowed to drip off. The thickness and smoothness of the paint coating is determined by the viscosity of the paint (Powell, 1992). Ideally, flow coating transfer efficiency should be very high because the paint that drips off parts falls back into a sump for reuse (Powell, 1992). The feasibility of flow coating with water-based paint is well demonstrated (Industrial Finishing, 1991).

Another way to reduce emissions of VOC's, such as xylene, is to switch to an autophoretic painting process marketed by Parker Amchem. The process involves dipping metal to be painted into tanks filled with paint. The coating is deposited by a chemical reaction between the paint and the metal. The autophoretic process resembles electrocoating, except that the driving force for coating deposition is chemical rather than electrical. Metal painted by this process reportedly has withstood salt spray
tests of up to 3,000 hours without coating failure, and the paint also exhibits a high degree of hardness (Jones, 1991). Autodeposition does not require phosphating in order for the coating to adhere to steel, and zinc can be coated without being etched (Roberto et al., 1991). The autophoretic process would eliminate emissions of xylene and other VOC's.

Powder coating is the third alternative painting material considered in this study. In powder coating, fine plastic particles are applied electrostatically to a metal surface and then baked. This causes the particles to melt and flow together, forming a smooth protective coating. Powder coatings do not contain solvents, so VOC emissions are very low (Gribble and Bowden, 1985; Kinzig, 1985). Some of the reasons for using powder coatings include: low VOC emissions, very little solid waste produced, low energy and labor costs, and good quality coating film produced (Gribble and Bowden, 1985). The drawbacks of powder coating are the difficulty of changing colors (Kinzig, 1985), and high installation cost (Brewer, 1984).

Galvanizing Pollution Prevention

Galvanizing pollution prevention is a new field. Even the American Galvanizers Association, which claims about 70% of all U.S. galvanizers as members, is only just beginning to become involved in pollution prevention (Vaithinathan, 1993). There is no body of literature specifically devoted
to galvanizing pollution prevention, but there is a great deal of literature concerning proper equipment, materials, and procedures for efficient high quality galvanizing.

In order to discuss galvanizing pollution prevention, a brief description of the process and associated terms is needed. The case study will give a detailed description of the galvanizing practices of the company where the research was conducted.

Hot-dip galvanizing is a process by which a thin coating of zinc is applied to steel parts for the purpose of improving their resistance to corrosion. The seven steps involved in a typical galvanizing process are as follows: removing oil, rinsing, pickling, rinsing, prefluxing, galvanizing, and cooling. Oil is removed from steel parts by dipping them in caustic solution. The caustic solution is then rinsed off with water. The next step, pickling, is the removal of scale (rust) by dipping in acid. The pickling acid is then rinsed off. The prefluxing step involves the deposition of a layer of flux chemicals on the part. Flux removes oxides from the steel surface during galvanizing, which helps the zinc to adhere tightly. After prefluxing comes galvanizing, the step in which parts are dipped in a tank of molten zinc (the "kettle") and then withdrawn, leaving a thin coating of zinc over the steel base metal. After galvanizing, the parts are usually cooled by rinsing.
Sources of pollution in the galvanizing process are: rinse water contaminated with cleaning chemicals or flux chemicals, vapors rising from cleaning tanks or the kettle (kettle smoke), and spent acids and bases contaminated with metals. This study concentrated on investigating methods of minimizing pollution from rinse water.


Cook is a strong proponent of the "dry kettle" galvanizing method (Cook, 1986). In dry kettle galvanizing, flux chemicals are applied in a separate tank preceding the galvanizing kettle. In wet kettle galvanizing, a layer of flux chemicals floats on the top of the zinc in the kettle.

Since the flux used in wet kettle galvanizing forms a layer covering the kettle, some of the flux is dragged out each time parts are withdrawn from the zinc. The flux contains zinc chloride, which enters the water used for cooling. Removal of flux residue requires the use of greater quantities of rinse water than would be needed for cooling (Dugan, 1993). There is no layer of flux on the
kettle in dry kettle galvanizing, so no zinc chloride enters the rinse water, and less water is required. Therefore, from a pollution prevention standpoint, dry kettle galvanizing is preferable to wet kettle galvanizing.

To obtain good fluxing in dry kettle galvanizing, careful management of preflux chemistry is needed. The preflux tank holds a solution of zinc chloride (ZnCl₂) and ammonium chloride (NH₄Cl). Proper concentrations of ZnCl₂ and NH₄Cl must be maintained, and concentrations of iron and sulfate from the sulfuric acid in the pickling step must be minimized. Frequent sampling is required for good chemistry control (Cook, 1986).

The most common preflux chemistry problem indicated by Cook is a deficiency in NH₄Cl concentration. This condition causes poor fluxing, resulting in thick and uneven zinc coatings. To successfully employ the dry kettle method, adequate NH₄Cl must be present (Cook, 1979).

Rinsing is required following the caustic and acid cleaning steps in order to remove any chemicals which are dragged out on the steel. Otherwise, these chemicals would contaminate tanks of chemicals used for later process steps. Rinsing can also be used for cooling after galvanizing. Effective rinsing is important in order to prevent drag out from contaminating subsequent process tanks. One way to improve rinsing efficiency is to dip parts twice in the same flowing rinse tank. This reduces contamination of the next
tank to less than one fifth of the level obtained with only one dip (Cook, 1987). Proper selection and use of a wetting agent reduces drag out by improving drainage of solution from parts. Improving rinsing efficiency in these ways will allow lower rinse flow rates, reducing the volume of waste generated.

As the discussion of Cook’s work illustrates, two promising areas for galvanizing pollution prevention are the preflux chemistry controls necessary to assure successful dry kettle galvanizing, and minimizing rinse water use. Alternatives for disposal of spent caustic and acid solutions were not addressed here. This is because the manufacturer involved does not perform caustic cleaning, and was already doing a good job of recycling acids for reuse. Although galvanizing does cause some air pollution in the form of "kettle smoke" and acid vapors, air pollution from galvanizing was considered to be of less concern than water use at this time. For this reason, ways to minimize galvanizing air emissions were not considered.

**Waste Minimization Assessment Methods**

The waste minimization assessment procedure outlined in the WMOAM and the Facility Pollution Prevention Guide has been very successful when put into practice (Curran and Stone, 1990). The procedure is lengthy, requiring collection of detailed information on material balances and
production processes. This approach to assessments has been labeled the "prescriptive" approach, because it originated with checklists originally developed for environmental compliance auditing (Pojasek and Cali, 1991). Some shortcomings of the prescriptive approach are that the forms often are not very applicable to a particular industrial process, and the interrelation of various bits of data is often unclear. In the summer issue of *Pollution Prevention Review*, Pojasek and Cali (1991) suggested using a "descriptive" approach, which focuses on the manufacturing process and all associated losses of materials. Development of process flow diagrams is a basic component of this approach. A process flow diagram helps to direct information gathering efforts and serves as a summary of the auditing team's understanding of the process. Identifying sources of losses is the main advantage of the descriptive approach, but it also has the disadvantage of requiring a greater level of technical expertise. Descriptive audits might not be practical for smaller companies lacking the resources to fund an in-depth study of their production processes. Pojasek and Cali (1991) indicated that companies that can afford to take a descriptive approach might achieve fundamental waste reductions. The assessment method followed in the case study presented here was very detailed, and so it more closely resembled the descriptive approach than the prescriptive approach.
Life-cycle assessments can be more thorough than assessments conducted according to either the prescriptive or descriptive approach. A life-cycle assessment seeks to consider all emissions released to the environment during the entire life cycle of a product. The impact of these releases is analyzed, and ways to reduce the environmental harm caused by the product are also evaluated (Fava and Page, 1992). This method of analysis is intended to allow industry to take into account all environmental consequences of a production decision. Life cycle analyses are especially helpful in choosing between production methods or products which are equivalent in other important aspects such as function and production cost (Bailey, 1990). It was not considered possible to conduct a lifecycle assessment for this study due to the complexity of the systems being analyzed and the age of the facility.

Measuring the Success of Pollution Prevention Programs

In the spring issue of Pollution Prevention Review, Pojasek and Cali (1991) stress the importance of loss tracking systems for measuring the success of pollution prevention programs (Pojasek and Cali, 1991). Several methods are presented for normalizing waste production to account for variations in production from one year to the next. These methods all rely on detailed data about production and waste generation.
Another measure discussed is an "economic" measure of waste reduction. In this method, all possible waste reduction methods are identified, and savings in terms of reduced waste treatment costs are calculated for each. Any waste reductions actually made are then compared to the theoretical total possible, and in this way a company's waste reduction percentage can be calculated. The economic measurement method is good at encouraging cost-effective pollution prevention efforts, but the amount of calculation required is very high (Pojasek and Cali, 1991).

There is more than one way to judge the success of pollution prevention programs. Rather than measuring pollution prevention progress strictly according to reductions in pollutant emissions, the importance of the new cooperative relationship between government and industry should also be recognized (Grayson, 1992). It is hoped that industry will begin to look upon government more as a partner and less as an adversary.
CHAPTER 2: CASE STUDY

A pilot project was established in Nebraska with the intention of promoting industrial pollution prevention and minimization. The project sought to demonstrate that with proper management and operating practices, an industrial operation could reduce pollution significantly. The program focused on finding cost-effective solutions to pollution problems. The study was conducted at a manufacturing facility in Nebraska engaged in fabricating metal products for farm and industrial uses. In the past, waste disposal at this facility has resulted in potential problems to both surface and ground water resources in the area. In this case study, the findings of the industrial pollution prevention pilot project are presented.

The facility performs many metal finishing operations including electroplating, conversion coating, cleaning, machining, grinding, impact deformation, shearing, welding, sand blasting, hot-dip galvanizing, painting, electroplating, assembly and testing. Many of these processes result in the production of a variety of pollutants (gaseous, solid, and liquid) that must be disposed of in some fashion. For example, the hot-dip galvanizing process results in the production of rinse water which must be treated to remove zinc and iron prior to discharge. The painting processes result in the production of used industrial cleaners, acids, solvents, and chemicals
used in the cleaning and de-greasing of metal components.

The initial phase of this study began in early 1992 with a detailed waste stream assessment of all operations. The painting, tubing manufacture, and galvanizing processes were evaluated. Other processes that were evaluated were one manual electroplating line and one automatic electroplating line. Evaluations of these processes are detailed elsewhere (Dahab, Montag, and Parr, 1993). Recommendations were made about how to prevent pollution from each process, and the company implemented some of the recommendations. The entire project, including impacts of any changes, is summarized here.
CHAPTER 3: TUBING MANUFACTURE

The process of tubing manufacture was studied by videotaping the tube mill in operation, interviewing workers, and obtaining records about materials used. It soon became clear that the major concern in this area was the use of metalworking coolant, and that reducing coolant use was the best pollution prevention opportunity presented by the tube mill. A brief description of the tubing manufacturing process follows.

The tube mill is used to form pipes from coils of sheet steel. The pipes, which are about 1.5 inches in diameter, are used to make livestock handling equipment, and are also sold to other companies. Major tube mill components are the coil unwinder, the feeder, the initial cold rollers, the welder, the final cold rollers, the meter and cutter, and the coolant distribution and collection system.

The first component of the tube mill is the coil unwinder. The coil unwinder holds two coils, and pivots to allow the operators to load new coils. It unwinds at 500-700 feet per minute (fpm), compared with the 100 fpm speed of the rest of the mill. The unwinder automatically starts when the feeder calls for more metal.

From the unwinder the metal goes to the feeder. The feeder stores metal strip, and feeds it at a constant rate of 100 fpm. The feeder automatically stops when a coil is finished. An operator then loads a new coil on the unwinder.
and butt-welds it to the end of the coil in the feeder. In this way, the mill can continue to operate without stopping to load new coils.

The metal strip is fed to the initial cold rolling section. The strip starts out flat, and goes through inner rolls and then outer rolls to make a tube. In addition to shaping the metal, the rollers provide the driving force to move the metal strip through the mill. The rollers are driven by gear boxes which are joined together by shafts which are driven by an electric motor. A small tube supports the impeder, a part of the welding system, which enters the gap before it is closed by the rolls.

Welding follows the initial cold rolling. Welding is performed by inducing a current in the edges of the metal tube, which heats them. A high frequency current of about 400,000 cycles per second is induced in the open seam of the tube by an induction coil just ahead of the weld point. The coil acts as the primary windings of a transformer, and the tube acts as the secondary winding. The path of the induced current is around the outside of the tube, concentrating along the edge of the open seam and especially at the weld point. The high current heats the areas where it is most concentrated, melting the steel. The tube then passes through a set of rollers, which compress the tube, pushing the hot edges together and welding them. After welding, a scraper removes excess metal from the outside of the weld.
When galvanized metal is formed into tubes, the zinc coating is lost from the area of the welded seam. To reduce corrosion of the seam, a thin layer of aluminum is applied over the outside of the weld.

When tubes exit the welder they are oval in cross-section. Further cold forming makes them round. After final forming, the tubing is measured and cut to the desired length.

Coolant is used for a variety of lubrication and cooling purposes. The tube mill uses "Metkool 711" (Metalworking Lubricants Co., Pontiac, MI.), a water based coolant. One hundred and ninety-five gallons of this fluid are consumed per month at a cost of about $800. Metcool 711 is sprayed on the rollers for lubrication, and is pumped through the welding area equipment for cooling. Freshly welded tubing is also immersed in coolant to remove heat. The coolant is pumped through the impeder into the inside of the tubing at the weld area, and stays inside the tube until it is cut. When the tubes are cut, the coolant drips out and falls into a trench in the floor, which leads to a sump. The coolant is pumped from the sump back into the system.

The coolant flows from its application points into sumps below the components, and the sumps drain by gravity to a large collection tank. A heat removal system draws coolant from the collection tank, passes it through a heat exchanger, and discharges it back to the collection tank.
The collection tank is also where the coolant distribution pump suction is attached.

At the beginning of this study, the collection tank contained an oil removal system consisting of a tygon tube that was being pulled through the liquid coolant. Floating oil would stick to the rubber tube, and then be removed by a scraper. The oil removal system was not able to remove oil fast enough.

A tube mill area supervisor said that the oil present in the coolant was from grease leaking out of the gearboxes. This explanation seemed reasonable since the metal coils being welded have no apparent oil on them.

Oil and grease covered the tube mill and the surrounding area. Gearbox grease and metal filings (chips) from the scraper made a black substance that filled the bottom of the sumps in about a month. The mill was occasionally shut down while operators scooped out all the grease. Most of the coolant was lost each time the sumps were cleaned.

**Recommended Tube Mill Changes**

The recommendations for pollution prevention in the tube mill were mostly concerned with minimizing grease contamination of the coolant. These recommendations included:
1. Replacing the old oil removal system with a new one that is more efficient.
2. Finding ways to reduce leakage of grease from gearboxes, or directing leakage away from sumps.
3. Reducing the quantity of chips falling into the sump below the scraper, so they don’t combine with the grease.
4. Shutting down the system and cleaning the entire area including all equipment, the floor grates, and the return trough.

The first suggested change which has been put into practice is the installation of a new oil removal system. The new system is a belt type oil skimmer mounted in the main coolant sump. The new skimmer appears to remove more oil than the old one, and the maintenance department agrees that the skimmer works better. No data are yet available about the exact impact that the system will have on coolant consumption.

Another recent development may help reduce coolant use. Periodic maintenance has recently been performed on the tube mill gearboxes, and leaky grease seals have been replaced. As mentioned earlier, keeping grease out of the coolant is an important part of increasing coolant life.
CHAPTER 4: PAINTING

The metal finishing company in this case study paints a wide variety of metal parts for agricultural and building purposes. The parts to be painted are hung from a conveyor near the ceiling of the building, and travel through a series of booths in which they are washed, etched, oven dried, painted, and oven cured. As with the tube mill, the paint line's operation was recorded on videotape, operators were interviewed, and records were examined. Figure 1 below and the following description will help illustrate how this process functions.

Figure 1. Paint Line Layout
Washing

The first booth is the soap wash booth, which removes oil from the parts being cleaned. A row of nozzles on either side of the washer sprays "Ridolene 3000" (Parker Amchem, Madison Heights, MI.), a sodium hydroxide soap solution, onto the parts as they pass through the booth. The solution is kept at 160°F, and is stored in a 5,400 gallon tank beneath the booth. The tank is dumped to the waste treatment system every 4 or 5 weeks, whenever the solution stops removing oil effectively. According to purchasing records, an average of 2,840 pounds of "Ridolene 3000" are used each month. Parts proceed from the wash booth to a rinse booth.

Rinsing

After washing, the parts are rinsed using the municipal water supply. The water is heated to 130°F, and is stored in a 4,320 gallon tank beneath the booth. The water becomes contaminated with chromic acid from acid etching, so it must be treated before it can be released to the waste treatment plant. Treatment of the rinse water is the same as the treatment of etching chemicals, which will be discussed in the next section. After the parts are rinsed, the conveyor takes them to be etched.
Etching

Etching is considered a necessary step prior to painting galvanized metal. Etching removes oxides and roughens surfaces, which helps the paint stick. As in washing, etching requires a solution to be sprayed on by nozzles at the side of the booth. The etching solution is stored in a 2,000 gallon tank, and is changed every 4 to 6 months. The solution is composed of chromic acid and nitric acid, and contains hexavalent chromium. Etching chemicals are: "Granodine 68" (Parker Amchem, Madison Heights, MI.) "Granodine 108B" (Madison Heights, MI.), and "Toner 308" (Madison Heights, MI.). "Granodine 68" contains nitric acid, sodium dichromate, and a small amount of hydrofluoric acid. About 1,450 pounds of "Granodine 68" are used per month. "Granodine 108B" contains nitric acid and chromic acid, and about 1,400 pounds are used per month. "Toner 308" contains hydrofluoric acid and nitric acid, and about 200 pounds are used per month.

Since the wastewater treatment plant on site can only precipitate trivalent chromium, the contents of the etching booth are treated with sodium bisulfite to reduce the chromium VI in solution to chromium III. Before dumping the rinse tank contents, about 100 pounds of sodium bisulfite and 30 gallons of 66°Be sulfuric acid are added.

Prior to releasing the storage tank’s contents, the solution is tested to ensure that no Chromium VI remains. A
Hach (Hach Chemical Company, Loveland, CO.) test kit indicates absence of Chromium VI by turning a test solution blue. Treating the etching tank and the two rinse tanks consumes 420 pounds of sodium metabisulfite and 2,045 pounds of 66 °Be sulfuric acid per month.

Rinsing

After etching, the metal is rinsed in a fresh water rinse booth. Unheated municipal water is used. The water is stored in a 3,240 gallon tank, which is emptied every two or three days. This water also is treated to reduce chromium VI to chromium III.

Drying

Following the rinsing step, the metal must be dried. An oven is used to dry the pieces in preparation for painting. Normally, work pieces are dried as they travel from one end to the other through the oven.

Painting

Four identical paint stations are used at this facility. Each station is equipped with a 14 foot wide water wall booth, which exhausts air from the work area outdoors using overhead exhaust systems. Overspray in the exhausted air is removed by being drawn through the booth water, and then skimmed off. "Booth Compound 702" (Calgon
Vestal Laboratories, Saint Louis, MO.) is a chemical that is added to the booth water to aid in separating the paint by making it float. The booth compound also helps solidify the paint, which reduces the amount of water mixed with the waste. "Booth Compound 702" contains sodium hydroxide, sodium metasilicate, and Stoddard solvent. About 413 pounds of this compound are used each month.

Water from one of the four rinse booths is discharged to the waste treatment system once a month on a rotating basis. Paint skimmed from the booths is collected in 55 gallon drums. The first third of each drum is filled with absorbent material, the middle third of the drum is filled with paint skimmings, and the last third is filled with additional absorbent material. Each month, the company landfills about 20 drums filled with this waste. The EPA allows landfilling of up to twenty-two 55 gallon drums of the mixture per month because this paint waste passed a Toxicity Characteristic Leaching Procedure (TCLP) test.

All of the paints used at the facility are traditional solvent based paints. In 1991, 34,567 gallons of the 47,312 gallons of paint used by the automatic paint line went to painting gates. In addition to paint, large quantities of solvent are used. "Vanblend 99" (Van Waters & Rogers, Inc., Kirkland, WA.) is a mixture of several aromatic solvents, which is used with the paint applied to gates. About 570 gallons of "Vanblend 99" are consumed each month. "Barsol
D-150" (Union Oil Company of California, Schaumburg, IL.) is the solvent for building panel paint, and 620 gallons per month are used. "Vanblend 99" and "Barsol D-150" have many ingredients, but they are mostly composed of xylene and toluene in addition to the paint pigment material. A distillation unit purchased shortly before the beginning of this study reclaims solvents used to clean lines when switching colors. This change has decreased the quantity of waste solvent by about 86 percent. Eleven 55 gallon drums of still bottoms were produced in the first 7 months after the distillation unit was purchased. The still bottoms are considered to be hazardous wastes, and are hauled away to a disposal facility by US Pollution Control, Inc., of Wichita, KS, a subsidiary of Union Pacific Corporation.

The equipment used to apply the paint is almost as important as the materials being used. The paint guns used for gates and general work are of the air assisted airless electrostatic spray type, and are manufactured by Ransberg-Gema, Inc., of Indianapolis, IN. The paint is heated as it enters the gun, and a positive charge of 80,000 volts is applied. According to the paint line foreman, the system gives a high a transfer efficiency when used for painting flat metal sheets, but only about 45% efficiency is achieved on gates. According to the spray equipment supplier, the low transfer efficiency for gates is because the gates are made of cylindrical tubes with a lot of open space between
these tubes. In addition, the cylindrical shape is
difficult to cover with paint (Johnson, 1992). The guns
used for painting building sheets are of the rotary bell
type and reciprocate vertically to paint the sheets
uniformly.

After painting, parts are conveyed to ovens, which
assist drying and curing. Building panels are painted with
silicon polyester paint that is thermally set by heating in
an oven at 230°F for 6 minutes.

Flow Coating

The paint line also contains a flow coater which
provides an alternative method of paint application. The
flow coater sprays paint onto the parts. It is located
between the first two paint booths and the last two booths.
The flow coater is rarely used at this facility. This is
because in flow coating tests conducted several years ago,
poor runoff of excess paint resulted in thick and uneven
coatings.

Oven Curing

Ovens are used to assist in curing the silicone
polyester paints. The oven is heated to 230°F. Other
paints do not require thermal curing, but heating speeds the
drying process. Emissions from the ovens go directly
outdoors through overhead exhaust fans. After curing, the
parts pass through an air cooling tunnel, and are then unloaded.

PAINTING CHANGES

The painting system described in the preceding paragraphs has maximized transfer efficiency, so it produces about as little VOC pollution as possible with a traditional solvent based painting system. However, there are other ways to further prevent painting pollution. Water based painting, autophoretic coating, and powder coating are examples that are discussed in detail below.

WATER BASED PAINT

As stated in the literature review, the only practical way to reduce VOC emissions is to change to paint materials that contain little or no VOC’s. One choice is to use water based paint for gates, which account for over 70% of the company’s paint use. The paint line foreman has indicated that he would not want to use water based paints, since it would be difficult to apply them electrostatically, and the high transfer efficiency obtained with electrostatic application is important.

Fortunately, there is an alternative to electrostatic application of water based paint which avoids the reduced transfer efficiency problem. The alternative is to use water based paint in the flow coater. Excess paint drips
off the parts into the flow coater's collection sump. Since the paint in the sump can be reused directly, the excess paint sprayed onto parts is not wasted.

In flow coating with water based paint, the coating thickness and smoothness is controlled by controlling the viscosity of the paint, so a high quality finish is possible.

The principal advantage of this method is that no new equipment would be needed to start using water based paint in the flow coater. Therefore, this alternative would involve less expense than any other materials change. Some water based flow coating paint should be purchased, and experiments should be conducted using it to paint gates. The paint can be obtained from several suppliers including PPG industries, and Glidden.

Mr. Jeff Powell of PPG industries indicated that his company would be happy to send testing equipment and a team of experts to assist in determining the suitability of PPG's paint. PPG would be willing to run such a test for about $2,000 including the cost of the paint (Powell, 1993).

An objection has been raised to flow coating gates. A few years ago, flow coating gates with solvent based paint was attempted. The results were unsatisfactory, due to excess paint being retained in recessed spaces.

The behavior of water based paint might differ enough from the behavior of solvent based paint that drainage will
not be a problem. It may be possible to improve drainage of excess paint by drilling a few drain holes in the products. Testing such modifications should be carried out at the same time as testing of other aspects of flow coating with water based paint is conducted.

Although Electrostatic application of water based paint was ruled out in the early stages of this project, manual electrostatic spray equipment for water based paint is available. Installing such equipment would be another low cost way to reduce VOC emissions. This alternative should be further investigated.

AUTOPHORETIC COATING

Another way to reduce VOC emissions from painting gates, and possibly to eliminate the need for chromic acid etching of galvanized building panels, is to switch to the so-called autophoretic painting process (Parker Amchem, Madison Heights, WI.). This process involves dipping metal into tanks filled with paint. The coating is deposited by a chemical reaction between the paint and the metal. Metal painted by the process reportedly can withstand up to 2,000 hours of salt spray exposure without coating failure. The paint also is reported to exhibit a high degree of hardness (Jones, 1991).

The following discussion of costs and difficulties of installing an autophoretic painting system is based on
conversations with Mr. Norb Intorp, a Parker Amchem salesman. An autophoretic system to coat gates was estimated to cost about $300,000. Parker Amchem has never built an autophoretic coating system large enough to coat building panels, so a detailed analysis would be required to be sure it is possible. Further expected difficulties include color variability and a limited number of available colors. Because gates are painted either red or green, these are the colors of interest in this study. The red and green produced by autophoretic coating vary somewhat in tint. This variation is due to the changing iron content of the solution as chemicals are added. Since each color requires a separate tank and the tanks required for building panels would be very large, the only color which would be practical for building panels is a clear coating. The clear coating could then be used as a base coat for paint. Paint adheres very well to an autophoretic coating, so the paint can be of an inexpensive variety. Companies using this system have reported costs to be about 3 cents per square foot applied (Intorp, 1992). It is recommended that the facility investigate the potential use of this painting method particularly since it's suppliers are willing to assist in this effort.

POWDER COATING

As mentioned above, over 70 percent of the items
painted at this facility are gates, which come in only two colors, red and green. Product uniformity makes agricultural gates an ideal candidate for powder coating.

Powder coating is a process in which fine plastic particles are applied electrostatically to a metal surface and then baked to form a coating similar to paint. Because the powder contains no VOC's, powder coating is considered the best available control technology for preventing VOC emissions from painting (U.S. EPA, 1988). Transfer efficiency is not an issue in powder coating because overspray is captured and blended with fresh powder for reuse. Powder coating gates would eliminate VOC's from about 70% of the current production. Mr. Doug Johnson of Industrial Finishing Systems, a long-time painting equipment supplier, estimated that powder coating could be added to the existing paint line for as little as $40,000 (Johnson, 1992). Unfortunately, because the paint line is quite old, a completely new line should be installed for powder coating. When including the cost of a new line, the cost of powder coating is estimated to be over $150,000 (Brewer, 1984). High installation cost is the major drawback of powder coating.

Due to concern over future regulation of VOC's under the 1990 Clean Air Act, the company has become very interested in powder coating. To gather information on powder coating, a group from the company attended
"Finishing'93", the annual surface finishing conference hosted by the Society of Manufacturing Engineers. Although no equipment has been purchased yet, it seems that powder coating is the preferred choice for preventing pollution from this painting operation.
CHAPTER 5: GALVANIZING

At the beginning of the assessment, current galvanizing practices were studied by examining the system layout and by interviewing operators. The galvanizing process at the facility is a five step procedure consisting of pickling, rinsing, prefluxing, galvanizing, and final rinsing. Mechanical cranes carry the fencing from station to station as each production step is carried out. Since a majority of galvanizing production is devoted to wire fencing, the description of the galvanizing process will assume that the items being galvanized are fence panels. Other products are galvanized in much the same way. Figure 2 provides an illustration of the galvanizing line used at this facility.

![Galvanizing Line Layout](image-url)
As shown in Figure 2, the first step is pickling, which prepares fence for galvanizing by removing oxides from the steel surface using a 10% (by weight) sulfuric acid solution at a temperature of 160°F. The fencing is dipped in pickling acid for five to ten minutes, and then taken away to be rinsed.

After pickling, the fencing is rinsed in a rinse booth to remove the pickling acid. The fence panels are sprayed with unheated municipal water in the rinse booth located adjacent to the pickling tank (Figure 2).

After the first rinsing, the fencing is placed in the preflux tank. In this tank, the work is coated with flux chemicals (ZnCl₂ and NH₃Cl) prior to entering the zinc kettle. Fluxing is necessary in order to remove traces of oxides that form on the steel surface after pickling. Proper fluxing helps zinc adhere tightly to the base steel.

The preflux tank is kept at 160°F. Normally, the preflux solution should be allowed to dry thoroughly before proceeding with galvanizing.

Galvanizing is accomplished by immersing the fence in a tank filled with molten zinc for 2 to 3 minutes. For livestock fencing, the wet kettle galvanizing method is used. For all other products, the dry kettle method is used. Wet kettle galvanizing means that a flux layer floats on top of the galvanizing kettle. Fence panels pass through the flux layer as they enter and leave the kettle. For
galvanizing other materials such as building components, the kettle flux layer is skimmed to the side and not used.

The freshly galvanized fencing material is cooled by rinsing it in a second rinse booth located next to the galvanizing kettle. This final rinse is needed to cool the fence panels so operators can unload them, and to remove any flux dragged out with the fencing.

The procedure described above is good for producing galvanized products of acceptable quality, but it generates large quantities of water requiring treatment. Because of dragout of flux materials from the galvanizing step, the rinse water contains a significant concentration of zinc chloride. It would be very desirable to reduce this waste stream in both volume and zinc concentration.

GALVANIZING PROPOSALS

The recommendations for pollution prevention and waste minimization in the galvanizing line concentrated on reducing the volume and metal content of rinse water. For that purpose, chemistry and equipment changes were considered.

As pointed out in the literature review, there is a lack of literature available on galvanizing pollution prevention alternatives. Many articles have been published concerning ways to cut costs and improve product quality. These articles deal with issues related to pollution from
the standpoint of minimizing the cost of raw materials used in production. For example, minimizing dragout from the pickling process reduces makeup acid requirements in addition to reducing the rinsing required to remove acid. Similarly, improving rinsing effectiveness reduces contamination of downstream baths and also minimizes the amount of rinse water required.

Although a number of possibilities were initially considered as potential solutions to the pollution problems of the galvanizing line, these were eventually narrowed down to just a few alternatives that were investigated in detail. The following alternatives were presented in a meeting between project researchers and company management:

1. Use of rinse tanks to replace rinse booths.
2. Switching from the wet kettle process to the dry kettle process for fence panels.
3. Recirculating water from a storage tank through a rinse booth.

Testing was conducted to establish the feasibility of the proposals before making any equipment changes.

RINSE TANK SYSTEM

At the beginning of this assessment, the galvanizer used about 70,000 gallons of rinse water per day. At least
600 gallons were used for each load of fence panels galvanized. During the waste stream assessment period, flow through the rinse booth used for removing pickle acid was measured at 300 gallons per minute. Flow through the rinse booth used for cooling was estimated at approximately 500 gallons per minute.

As an ultimate goal, rinsing in tanks rather than in booths was considered desirable because it would save rinse water. The benefit of such a system is that it allows water to be reused several times before it is discharged as wastewater, in addition to the fact that work pieces are always rinsed using the cleanest water as they leave the process line. A six tank galvanizing system was proposed. The rinse water flow path would be to enter the final cooling tank and then to pass through two counter-current rinse tanks used for pickling acid removal. Expected advantages of such a system included reduced water use, ease of operation, and increased production rates.

The cost of the system was estimated at $95,000 for equipment changes. This included $70,000 for installation of new tanks based on quotes from Huber Construction in Houston, Texas (Wilson, 1993), and Excel Coatings of Schuyler, NE (Modde, 1993). Ventilation system modifications would cost an additional $25,000 based on a quote from R.W. Engineering in Lenexa, Kansas (Walla, 1993). Reduced waste treatment expenses would eventually recoup
these costs. A payback period of 10 months was predicted by using an estimate of treatment cost provided by the company ($7.10 per 1000 gallons treated) and a projected water savings of 45,000 gallons per day.

The proposed system layout is shown in Figure 3. In this figure, production steps are numbered and water flow is indicated by arrows.

![Figure 3. Proposed Galvanizing System](image)

**POST PICKLING RINSE TEST**

To test the accuracy of the savings prediction and to ensure that no unforseen product quality problems would
arise, feasibility testing was performed. The ability of a flowing rinse to adequately remove pickling acid from fence panels was demonstrated by testing conducted on April 1, 1993. The test was performed by temporarily converting a spare galvanizing tank to a continuous flow rinse, and by using this tank instead of the rinse booth which is normally used.

The temporary rinse tank was drained and refilled with clean city water, and a continuous flow rate of 42 gallons per minute was then established. The production steps followed were the same as usual except for the rinsing step. After pickling, the fencing was dipped in the rinse tank instead of being sprayed off in the rinse booth.

Rinse water pH and conductivity and preflux pH were each measured about every thirty minutes during the test. Rinse tank pH and conductivity were used to show how long it took to reach equilibrium conditions in the tank. Preflux pH was used to show whether or not rinse water contamination was harming the preflux.

The first part of the test was to allow rinse water conductivity to reach a constant level. This took about 6 hours of rinsing time in the tank. The second part of the test was to keep rinsing in the same manner for an additional 9 hours while continuing to draw and analyze samples. Throughout the test, preflux pH was monitored closely to see if any change occurred. The rinse test
equipment setup was as illustrated in Figure 4, below.

![Figure 4. Setup for Post-Pickling Rinse Test](image)

Preflux pH was essentially unchanged during this period, so this test was interpreted as having proved that acid was thoroughly rinsed off.

Because the test was performed using only one tank and the proposed system would use two tanks, it was necessary to interpret the test results accordingly. Using rinsing equations from Durney (1984), calculations were performed to compare the rinsing efficiency of one flow-through rinse
tank versus the efficiency of two tanks operated in a counter-current manner. Based on these calculations, a rinse flow rate of 6 gallons per minute would remove pickling acid as well as 42 gallons per minute did in testing. Since six gallons per minute is a very modest flow rate compared to current practices at this facility, counter current rinsing was considered feasible and desirable. The data collected during this test are shown graphically in Figure 5, below.

Figure 5. Post-Pickling Rinse Test Data
INTERIM GALVANIZING SYSTEM

Due to the high cost of the proposed system, phased installation was recommended. The first proposed phase would be to add the final cooling tank, and the second proposed phase would be to add two counter-current rinse tanks. This also necessitated that ventilation system improvements be made to remove pickling acid vapor from the work area. The acid vapor problem would be caused by the fact that the pickling tank would be moved to the far end of the galvanizing line, where no exhaust ventilation was provided. Upon completion of the first stage improvements, pickling acid would be rinsed off in a rinse booth, but the final cooling step would take place in a rinse tank installed where the final rinse booth had originally been.

This change was estimated to cost only $17,000 to implement based on the estimate by Huber Construction of Houston, Texas (1993), and was expected to cut galvanizing water use to about 40,000 gallons per day. Assuming a treatment cost of $7.10 per 1000 gallons, this modification would have a payback period of three months. A layout of the interim system is shown graphically in Figure 6, below.
INITIAL COOLING RINSE TEST

Once the feasibility of counter-current rinsing for removal of pickling acid was established, it remained to be proven that cooling in a tank would yield an acceptable quality product. A concern regarding product quality was raised by the galvanizing line foreman. He believed that wet kettle galvanizing of the fence panels would continue to be necessary. Based on his prior experience, he thought that if all of the kettle flux was not removed, the fencing would corrode quickly. This factor had not been considered...
in the original analysis, and so it was decided to run a test to see if cooling in a rinse tank would work. It is important to remember that both the proposed system and the interim solution included a final rinse tank. Therefore the results of the cooling test affected the feasibility of both proposals. The extra rinse tank was set up in the same way as in the previous rinse test, except that the flow rate selected was 9 gallons per minute. Fencing was dipped in the rinse tank after galvanizing. Figure 7 below shows production steps and water flow setup for the test.

![Figure 7. Cooling Rinse Test Setup](image-url)
The test was performed on June 15th 1993. The conductivity, and temperature of the cooling tank water were measured about every thirty minutes, and the zinc concentration was measured about once an hour in order to determine when equilibrium had been reached. As illustrated in Figure 8, the zinc concentration graph indicated that equilibrium conditions were reached after 15 hours of operation. The other parameters stabilized in the same time period. Conductivity rise is shown in Figure 9, and temperature rise is shown in Figure 10.

Figure 8. Zinc Concentration Rise in Cooling Rinse Test
Figure 9. Conductivity Rise in Cooling Rinse Test

Figure 10. Temperature Rise in Cooling Rinse Test
At about 13 hours into the June 15th rinsing test, operators began to notice a deterioration of product quality. A chalky white film was being left on the fence panels. Some of the fencing material galvanized at the end of this test was set aside in the company's outdoor storage yard and allowed to weather naturally for about 2 months. There was a higher than usual rate of corrosion (white rust) formation compared to the corrosion of fencing rinsed by the normal method. This was judged as unacceptable product quality by the sales department. A better way of removing flux residue had to be found.

DRY KETTLE GALVANIZING

The disappointing results of the June 15th cooling test prompted a change in the project's direction. Because it seemed difficult to rinse kettle flux off of fencing, efforts to eliminate the kettle flux entirely gained considerable importance. A switch to dry kettle galvanizing would have the effect of making the proposed rinsing system feasible, in addition to reducing the amount of zinc in the waste stream.

Fencing was being fluxed twice: once in the preflux tank, and a second time as it entered the kettle. For galvanizing of all other objects than fence panels the kettle flux was skimmed to the side and was not used. The kettle flux was 98% ZnCl₂, and contained a small amount of
KC1. Kettle flux adds significantly to the metal content of galvanizing rinse water, so discontinuing the use of kettle flux would enhance pollution prevention.

Before use of a kettle flux could be discontinued, it was crucial to obtain optimum performance from the preflux. As indicated earlier in the literature review, this required maintaining proper concentrations of ZnCl2 and NH4Cl, and minimizing iron and sulfate contamination.

Two parameters are especially important in preflux chemistry. These parameters are density and zinc chloride to ammonium chloride ratio (ZnCl2/NH4Cl). The density is determined by the ZnCl2 concentration, and the optimum range is from 12 to 15 degrees Baumé (°Be), (1.09 gm/ml to 1.12 gm/ml), measured at 70°F (21.1°C). The other important parameter, ZnCl2/NH4Cl, is the weight of ZnCl2 in a given volume divided by the weight of NH4Cl in the same volume of preflux solution. In U.S. practice, recommended values of ZnCl2/NH4Cl range from 0.85, used by most galvanizers, to 0.56 to 0.71 recommended by Cook (1982). Sjoukes (1990), a galvanizing expert from the Netherlands, recommends a ratio of 0.40 to 0.57.

The initial process assessment had brought to light the fact that, although chemicals were added every three or four days, sampling to determine preflux chemical concentrations was only being performed two or three times a year. Therefore actual ZnCl2 and NH4Cl concentrations were rarely
known. Preflux samples were drawn four times during May and June of 1993 in an attempt to establish whether or not there was any consistent problem with preflux chemistry. The samples were analyzed for density by hydrometer, and for ammonia concentration by a distillation procedure published by Cook (1982). Zinc chloride concentration and ammonium chloride concentration were calculated from the test results by using information provided in the same article. The analyses showed that ZnCl₂ concentration was consistently between 7°Be and 8°Be (1.05 gm/ml to 1.06 gm/ml), and NH₄Cl concentration was consistently about 0.5 pounds per gallon. These values are very low compared to recommended values. For instance, a density of 13°Be (1.10 gm/ml) is typical for preflux, and 0.93 pounds per gallon of NH₄Cl is required for the highest recommended ZnCl₂/NH₄Cl (the lowest recommended ammonium chloride concentration) at a preflux density of 13°Be.

An additional problem with preflux chemistry was identified. Preflux samples drawn on June 9th and June 15th 1993 were analyzed for sulfates by barium chloride turbidity according to Standard Methods (American Public Health Association, 1992), and were found to contain 0.6 percent of this contaminant. The upper limit for sulfates is commonly considered to be 0.5 percent. A sample was sent to the Mineral Research and Development Corporation of Charlotte, North Carolina for confirmation (Mineral Research supplies
Preact, the flux that was in use at the time). Results of the confirmation sample came back with about the same concentrations for ZnCl₂ and NH₄Cl, but with no value listed for sulfate. The Preact sales representative insisted that this meant that there was no sulfate in the preflux. Another sample was drawn, and it was analyzed by UNL Chemistry Department Laboratory personnel using ion chromatography. This sample had 0.6 percent sulfate, and thus agreed with the first analysis. Eventually the Mineral Research Laboratory was contacted, and they explained that their sulfate analysis equipment had been out of operation at the time they analyzed the sample, and that was the reason no result was reported for sulfates. Preact then analyzed some of the same sample and found 0.74 percent sulfate.

**PREFLUX CHEMISTRY ADJUSTMENTS**

To remedy the problems of high sulfate concentration and low preflux strength, it was decided to first empty half the existing preflux to reduce the sulfate concentration, and then to add ZnCl₂ and NH₄Cl to make up a new stronger batch of preflux. Quantities of chemicals required and associated costs are listed in the Appendix. The total cost of the chemicals to be added was about $4,050. About $3,650 of this total was for curing the problems with sulfates and density, and only about $400 of this cost was for raising
the ammonium chloride concentration (lowering the ZnCl₂/NH₄Cl ratio). On August 20th 1993, half the preflux was disposed of by sending it to the waste treatment plant. The recommended quantities of chemicals were then added.

Other adjustments were made to facilitate changing to dry kettle operation. These changes included raising the preflux tank temperature to aid in preflux drying (Cook, 1986), and raising the zinc kettle temperature to improve zinc runoff. Aluminum was added to the kettle to raise the kettle zinc concentration to 0.004 percent, the minimum concentration Cook (1983) recommends for dry kettle operation. After these preparations had been made, dry kettle galvanizing was attempted. Two loads of fencing were galvanized by this method, and the results were inspected. The fence panels were covered with small pointed projections which were probably oxides that had not been removed during skimming of the kettle surface. The fencing was for livestock pens, and the company did not want animals brushing against the fence to cut themselves. Consequently, dry kettle galvanizing was deemed impractical for fencing. Therefore, no further attempts were made to galvanize fencing by the dry kettle method.

SECOND COOLING RINSE TEST

The inability to galvanize fencing by the dry kettle method left wet kettle galvanizing as the only choice.
Therefore, a renewed effort was made to remove flux by rinsing in the cooling tank. A second cooling rinse test was set up in the same way as the first rinse test had been. A flow rate of 15 gallons per minute was chosen for this test. Calculations based on rinse equations contained in Durney (1985) indicated that the equilibrium zinc concentration would be 660 mg/L instead of the 1100 mg/L obtained in the first cooling rinse test; a possible reduction of 40% in zinc concentration. The equilibrium concentration of other contaminants would fall by the same percentage. The significance of this decrease is that contaminant concentrations would be reduced to levels which had been reached by the nine hour point in the first cooling rinse test, long before product quality problems showed up. On September 17th, 1993, the second cooling rinse test was conducted. Flow through the spare rinse tank was set at 15 gallons per minute based on the expected reduction in contaminant concentrations calculated above. The final cooling step of the galvanizing process was carried out by dipping fence panels in the tank. Obvious quality problems arose at the very beginning of the test which did not improve as the test continued, so the effort was discontinued after only ten hours.

The lack of success was an unexpected disappointment, but upon reviewing the circumstances of the test, these results are not surprising. In order to save time, only
half the contents of the rinse tank had been emptied prior to starting this test. The author, who also performed the test, was under the impression that the only purpose the tank had been used for was to cool freshly galvanized parts. This turned out not to have been the case. The rinse tank had been used for post pickling rinsing, and was contaminated with an unknown amount of sulfuric acid. The acid was deemed to be the likely reason that this test had failed. In support of this hypothesis, it should be noted that a zinc test run on a sample drawn at the end of the test showed only 140 mg/L of zinc. Although further testing may be justified, the company had wished to delay further tests due to a large current demand for galvanized fence. The company was having trouble meeting production goals, and could not spare much more time for testing. Reuse of galvanizing rinse water may still be possible under optimum conditions. Perhaps the manufacturer will try another test when time is available.

A modification made during the spring of 1993 has reduced galvanizing water use measurably. Low flow water saving nozzles were installed to replace the orifices which previously controlled the water spray in the cooling rinse booth. Twenty nozzles rated at ten gallons per minute each were installed, reducing the booth flow rate from five hundred gallons per minute to two hundred gallons per minute. Operators claim that the kettle flux is more
thoroughly removed due to an improved spray pattern. The result of the change has been a reduction of water use of about 15,000 gallons per day (21 percent) with no harm to product quality. Savings in terms of reduced waste treatment expenses are about $107 per day. This is not as dramatic a reduction as was hoped for by researchers, but it is significant. Although the implemented change was not among the options studied, it was certainly a product of the heightened awareness of the need to limit water use.
CHAPTER 6: DISCUSSION AND CONCLUSIONS

This research project has yielded several positive results. Tubing manufacture will use less coolant due to improved oil removal, painting process changes are under consideration which would dramatically decrease VOC emissions, and galvanizing water use has been reduced by about 21 percent.

This project has reached many of the objectives stated at its beginning. A synopsis of the each objective and what has been accomplished is as follows:

1. Assessments of the process lines - Each line was examined in detail through first hand observations, operator interviews, and review of records. These assessments were necessary in order to familiarize researchers with the production processes before they attempted to make improvements. The assessments also served to make operators aware of how their actions can create or prevent pollution.

2. Identification of pollution prevention opportunities - Tube mill coolant contamination with grease and chips was addressed. Reducing VOC emissions from painting was studied. Paints were considered that were based on water, or applied chemically, or applied as a powder. Galvanizing rinse system changes and chemistry changes were investigated.
3. Economic evaluation of pollution prevention alternatives - Summarized in the Table 1 below:

Table 1. Economic Summary of Painting Alternatives

<table>
<thead>
<tr>
<th>Tube Mill Oil Removal System</th>
<th>$500 for the system installed</th>
<th>$400 per month likely savings on coolant use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative Painting Methods</td>
<td>$2,000 for water based paint test</td>
<td>Expected savings will be in terms of reduced emission control requirements when the 1990 Clean Air Act takes effect</td>
</tr>
<tr>
<td></td>
<td>$300,000 for Autophoretic System</td>
<td></td>
</tr>
<tr>
<td></td>
<td>At least $150,000 for Powder Coating</td>
<td></td>
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<tr>
<td>Proposed Galvanizing Equipment Changes</td>
<td>$95,000 for a six tank system</td>
<td>10 month payback due to reduced waste treatment</td>
</tr>
<tr>
<td></td>
<td>$17,000 for a cooling tank</td>
<td>3 month payback</td>
</tr>
<tr>
<td>Low flow nozzles</td>
<td>No cost - the nozzles were found in inventory</td>
<td>$107 per day savings</td>
</tr>
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</table>

4. Presentation of recommendations and voluntary implementation - Recommendations have been presented, and some of these recommendations have already been implemented.

5. Review of implemented changes - As described earlier, a tube mill oil removal system was installed, but results are not yet fully available at this time. Initial indications are that the new system removes several times as much oil as the old system did. The improved
oil removal should increase the usable life of the tube mill coolant significantly.

Painting changes have not been made, but powder coating is being considered favorably. Galvanizing rinse water use has been reduced about 21 percent by the installation of low flow nozzles.

Other results of this project are not as easy to quantify. For example, the tube mill evaluation illustrates that simple housekeeping is an important issue in pollution prevention. This company needed to pay better attention to cleaning, and there is still much need for improvement in this aspect of tubing manufacture.

The galvanizing study pointed out the need to switch to dry kettle galvanizing wherever possible. Dry kettle galvanizing prevents pollution by minimizing water use and zinc concentration of rinse water. Dry kettle galvanizing is usually possible with careful quality control (Dugan, 1993), and the lack of success with fence panels is probably due to their unusual shape. Additional tests need to be conducted to demonstrate the potential use of this method.

Valuable experience has been gained by all parties involved in this project. The participants were able to use their varied academic and industrial backgrounds to solve common problems. This type of cooperation is crucial to the success of pollution prevention in Nebraska and nationally.
REFERENCES


Dearborn MI, p 3-29 to 3-39.


the Air Pollution Control Association, 37(10):1206-1210.


Proceedings, Society of Manufacturing Engineers,
Dearborn MI, p 3-22 to 3-28.


Sjoukes, F. (1987). "The role of iron in the hot dip


U.S. Environmental Protection Agency. (1993). A Primer for Financial Analysis of Pollution Prevention Projects,
EPA Report No. EPA/600/R-93/059, April.
APPENDIX

Two Epoxy coated quench tanks - $13,200 each
Truck transport for two tanks from Texas - $3,000
Tank installation - Including brick lining: $12 - $13 per square foot. About $14,000 per tank.


Pickling tank lining with fiberglass and polyester can be performed for $13 per square foot. For a 24' long by 5' wide by 8' deep tank this would come to $7,600. Assuming some preparation work will be required - $9,000 is approximate cost of lining a pickling tank.
From this cost analysis, it can be seen that about $3,650 is required to remedy high sulfates and low density, and about $400 is needed to add more ammonium chloride for running the proposed test.
Calculations to Show Why a Cooling Rinse Test Should Work At a Flow Rate of 15 gallons per minute

\[ C_s = \left( \frac{D}{QM+D} \right) = 1,100 \text{ mg/L Zinc} \]

Assuming D and Q are approximately equal to 10:

\[ 1,100 = \left( \frac{1}{Q_1+1} \right) C_o \]

\[ \frac{1,100}{X} = \left( \frac{1}{Q_1+1} \right) C_o \]

\[ \left( \frac{1}{Q_2+1} \right) C_o = 1,100 \left( \frac{Q_1+1}{Q_2+1} \right) = 1,100 \left( \frac{9+1}{15+1} \right) \]

\[ X = 660 \text{ mg/L of Zinc} \]
Required Rinse Flow for Removing Pickling Acid with 2 Tanks. 
Durney (1985) page 692.

\[ C_r = \left[ \frac{QM - 1}{D} \right] \left[ \frac{QM^3 - 1}{(QM^3 - 1)} \right] C_0 = C_0 \left( \frac{D}{QM + D} \right) C_0 \]

\( Q_1 \) is known to be 42 GPM for one rinse tank. \( M \) is approximately 10 minutes, \( D \) is approximately 10 gallons. \( Q_2 \) is the unknown flow rate:

\[ \frac{Q_2 - 1}{Q_2^3 - 1} = \frac{1}{Q_1 + 1} \]

\[ \frac{Q_2 - 1}{Q_2^3 - 1} = \frac{1}{42 + 1} = \frac{1}{43} \]

\[ 43Q_2 - 43 = Q_2^3 - 1 \]

\[-Q_2^3 + 43Q_2 = 42 \]

\[ Q_2 = 6 \text{ GPM} \]
The purpose of the test was to demonstrate that switching from using booths to dipping the pickled parts into continuous-flow rinse tanks will not harm the preflux. A flow rate of about 42 gpm was maintained throughout the test. Initial conditions were as follows:

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<th>Minutes Elapsed</th>
<th>Hours Elapsed</th>
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<th>Preflux pH</th>
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