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P2 Research and Implementation
for Michigan Metal Finishers (PRIM)

Final Report

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National Center for Manufacturing Sciences
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Ann Arbor, Michigan 48108-3230

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Acronyms and Abbreviations

AESF	███████████ Surface Finishers		P2	Pollution Prevention
			PEL	Permissible Exposure Limit
ATSDR	Agency for Toxic Substances and Disease Registry		PRIM	P2 Research and Implementation for Michigan Metal Finishers
DoD	Department of Defense			
EED™	Emission Elimination Device™		SBEAP	Small Business Environmental Assistance Program
EN	Electroless Nickel		SCR	Silicone Controlled Rectifiers
EPA	Environmental Protection Agency		SGP	Strategic Goals Program
MFASC	Metal Finishing Association of Southern California		SCAQMD	South Coast Air Quality Management District
MTO	Metal Turnovers		STERC	Surface Technology Environmental Resource Center
NASF	National Association for Surface Finishing		TCE	Trichloroethylene
NCMS	National Center for Manufacturing Sciences		U.S.	United States
Ni	Nickel		WWT	Wastewater Treatment
OSHA	Occupational Safety and Health Administration		Zn	Zinc

1. Executive Summary

This project was funded under EPA's Source Reduction Assistance Grant Program. This program funds Pollution Prevention (P2) assistance projects that provide technical assistance and/or training to businesses/facilities to help them adopt source reduction approaches.

The grant was awarded for FY 2017 and 2018. Funding was received in incremental amounts totaling $204,600.

The goal of this project, **P**2 **R**esearch and **I**mplementation for **M**ichigan Metal Finishers or **PRIM**, was to reduce information barriers that prevent widespread implementation of pollution prevention (P2) technologies and approaches by the metal finishing industry with a focus on innovative P2 methods. This was accomplished through these major project tasks:

- Project Organization
- Industry Survey
- P2 Research and Analysis
- P2 Technology Demonstrations
- Output Development
- Information Transfer

1.1 Background

The metal finishing sector is a significant consumer of water, toxic materials and energy and from its manufacturing processes generates wastewater discharges, air emissions and hazardous wastes. This sector is regulated by federal, state and local regulations. Most facilities meet environmental standards by employing end-of-pipe technologies and off-site disposal methods, such as landfills. Source reduction methods and technologies are available, including new innovative approaches that can reduce water consumption, toxic chemical use, air emissions, hazardous waste and greenhouse gas emissions. A significant barrier to P2 implementation is a lack of information concerning the cost effectiveness of this approach. This project reduced this barrier by identifying and demonstrating P2 technologies. Results of the project are being widely distributed through the Surface Technology Environmental Resource Center (STERC), an EPA supported resource operated by the National Center for Manufacturing Sciences (NCMS), and our project partner, the National Association for Surface Finishing (NASF).

2. Project Organization

Overall project management was conducted by NCMS. The original NCMS project manager, Bill Chenevert, who initiated the project, retired during the course of the project and was replaced by Lisa Stobierski, who managed the project through completion. Bill Chenevert and Lisa Stobierski were also responsible for communicating with the EPA Region 5 Project Manager, Donna Twickler. Much of the project technical work was performed by NCMS contractor, CAI Resources. CAI's key project personnel included George Cushnie and Paul Chalmer.

The National Association for Surface Finishing (NASF is the major U.S. metal finishing trade association); and American Electroplaters and Surface Finishers (AESF) Foundation (the major U.S. metal finishing educational society) were primary partners during the project. Throughout the project, these two organizations coordinated communications with the metal finishing industry and encouraged the participation of both P2 technology providers and metal finishing facilities. The primary NASF/AESF Foundation representative was Jeff Hannapel.

The core project team therefore consisted of Bill Chenevert/Lisa Stobierski of NCMS, George Cushnie and Paul Chalmer of CAI Resources and Jeff Hannapel of NASF/AESF Foundation. Bi-monthly telephone meetings were conducted with this group and other individuals were invited to participate as needed, depending on current project activities.

A task tracking matrix (Appendix A) with performance measures was prepared and updated versions were submitted to EPA Region 5 with semi-annual reports.

NCMS planned and conducted a project kick-off meeting on November 29, 2016 at their offices in Ann Arbor, MI. There were 25 meeting participants that include representatives of EPA Region 5, NASF, AESF Foundation, Michigan Chapter NASF, Michigan Department of Environmental Quality, EPA contractors, POTWs, metal finishing consultants and suppliers, private metal finishing industry, and NCMS. A list of attendees is found in Appendix B. Output of the kick-off meeting included development of plans for P2 research and an industry survey.

3. Industry Survey

A survey was conducted to compare current metal finishing shops' environmental performance with established environmental benchmarks for water use, energy use, toxic releases and environmental costs. Both hardcopy and on-line versions of the survey were prepared. The two versions were developed for the convenience of potential respondents with the objective of increasing the rate of participation. The Phase I survey collected basic environmental and production data for all metal finishing shops. The Phase II survey collected detailed information, cost data and process-specific P2 practices.

The Phase I survey was mailed to Michigan metal finishing shops and to NASF member shops U.S.-wide (a total of 600 shops). The mailed package included a cover letter, instructions, the Phase I survey and a postage-paid return envelope. In the cover letter, as an incentive to participate, NCMS offered to give each Phase I survey respondent a copy of the NCMS-published book: *Pollution Prevention and Control Technologies for Plating Operations*. Companies were asked to return Phase I surveys within two weeks.

Copies of the Phase I and Phase II surveys can be found in Appendix E. A total 83 Phase I surveys were received. Of that total, 35 surveys were considered complete. Most of the incomplete surveys were the on-line version.

Due to the relatively low response, it was not possible to update the benchmarking work that was performed by NCMS in 2000. However, an analysis was performed that compares shops in the current study to the respondents from the 2000 survey. The results indicate that a significant percentage of shops performed better from an environmental standpoint in 2016 than in 2000. A statistical analysis of the data is presented in Appendix F.

A question on the Phase I survey dealt with organic air emissions. Organic emissions from metal finishing facilities are mostly related to solvent cleaning with Trichloroethylene (TCE) and to a lesser extent with Methylene Chloride (Dichloromethane). Several respondents indicated that they had organic air emissions in 2016. Since solvent use by metal finishing shops is of interest to EPA Region 5, some additional investigation of this issue was pursued. Specifically, using the EPA TRI on-line database, NCMS searched for TCE emissions by electroplating companies (SIC 3471). This information and other related technical findings are contained in this final report.

4. P2 Research and Analysis

This work included a literature search that focused on journal articles and conference papers mainly from the past 10 years. Also, through our partner, NASF, NCMS contacted technology and chemical suppliers as well as industry experts associated with innovative P2 approaches. Follow-up communications were accomplished primarily through email and telephone interviews. A comprehensive list of P2 practices was developed based on this research (Appendix C).

Using the results of the research, the project team identified six innovative P2 technologies that were further investigated. For each innovative technology, a Technology Summary Sheet was prepared. These are presented in Appendix D. The sheets provide at a glance, technology background information, applications, P2 potential benefits, and information regarding possible demonstrations.

4.1 P2 Technology Demonstrations

Six technology demonstrations were planned, however, three of the planned demonstrations were not conducted. In one case █████, the technology was not installed in time for a demonstration. In the second and third cases (eductor agitation study and switch mode rectifier study), the host facility decided not to participate following extensive investigative work. Each of the six demonstrations, including the three that did not materialize are discussed in this section.

Two of the technology demonstrations were conducted at facilities operating zinc/nickel (Zn/Ni) electroplating processes. Zn/Ni is a relatively new coating and therefore has received less attention than other coatings from a P2 standpoint. This process is associated with high rinse water use and wastewater treatment sludge generation and it presents challenging bath maintenance issues.

Use of Zn/Ni plating has increased significantly in popularity over the past 10 years due mainly to the auto manufacturing sector demands for longer-lasting corrosion resistance coatings. Zn/Ni coatings provide significant performance improvements over common Zn plating. Aerospace Zn/Ni plating applications are fewer than automotive, however, it is also gaining popularity in this sector, including use as a substitute for cadmium plating.

4.1.1 Demonstration of Coventya Zn/Ni 3S Technology

The Coventya 3S technology is applicable to Zn/Ni electroplating baths. The technology uses a porous barrier to divide the bath into an anode and cathode compartment. Electrolyte is recirculated through the anode compartment, which is maintained at a head slightly above that of the cathode compartment, allowing a slow continuous flow of electrolyte. In this configuration, possibly assisted by ion-selective permeability of the barrier, the migration of organic components present in the cathode compartment into the anode compartment is impeded. In ordinary Zn/Ni baths, these compounds are oxidized when they reach the anode, forming cyanide and undesirable carbonates. The 3S technology avoids production of these contaminants. In addition, preventing unwanted side reactions should increase current efficiency, and recirculating anode electrolyte should draw heat away from the bath, reducing power requirements of plating and cooling.

A facility was selected for the demonstration based on the manufacturer's recommendation. The facility had recently installed a Zn/Ni plating line and the 3S technology. At the start of the project, the plating line was undergoing auto industry approvals. This work was delayed for months and a

decision was made to move the demonstration to a different facility. The second facility, located in Chicago, had the 3S technology installed and was fully operational.

Data provided by the Chicago facility indicates that the 3S technology was effective in limiting the production of cyanide. In addition, the power consumed per amount of product plated showed about a 10% improvement in the 3S process compared to a standard Zn/Ni line running at the same facility. An indication of higher water consumption per product plated measured for the 3S process remains unexplained. A capsule report covering this work can be found in Appendix G.

4.1.2 Development of Rinsing Manual and Implementation of Rinse System Improvements

Results from the PRIM survey and observations during facility visits suggested that a systematic method of evaluating rinsing and developing plans for improved water use is needed by the surface finishing industry. A number of articles, reports and guidance manuals provide relatively good, but less than complete information. As a result, under this project, NCMS developed a comprehensive guide (*Rinsing Manual*) for evaluating and improving rinsing practices based on actual results. The guide contains instructions for conducting a rinse survey and detailed descriptions of good rinsing practices. Data, pictures, video and examples from the PRIM survey and facility visits were incorporated into the manual. The manual is available for public use at no charge as an on-line STERC tool at http://www.sterc.org/subs/rinseman.php.

To test the use of the *Rinsing Manual*, a project was conducted on a Zn/Ni electroplating line at a Michigan metal finishing facility. As discussed above, one of the key reasons for selecting a Zn/Ni line was the relative absence of P2 information for this process.

Following the *Rinsing Manual* procedures, surveys of the Zn/Ni line were performed on multiple dates and recommended improvements were developed and presented to facility management. The facility decided to implement five of those suggestions. After that work was completed, the project team returned to measure the impacts of the improvements. A capsule report covering this work can be found in Appendix H.

4.1.3 Demonstration of Coventya Low Nickel EN Bath Chemistry

Electroless nickel (EN) plating is an autocatalytic process used to deposit nickel-phosphorus alloy onto metal or plastic substrates to impart corrosion and/or wear resistance. Performed without the use of an electric current, this process gained commercial popularity in the 1950s and has grown into an immensely popular surface coating technology. Two significant pollution issues associated with EN plating are rinsing and bath disposal. Rinse water from this process contains chelated nickel that presents problems with wastewater treatment; the nickel is more difficult to precipitate than the nickel from common electrolytic processes. Periodic EN bath disposal is necessary because by-products of the process buildup and the solution becomes unusable. The spent bath is difficult to treat on-site and expensive to ship off-site for disposal.

Most EN baths are formulated with 6 g/l nickel. Coventya has developed a low nickel solution that operates at 3 g/l nickel. A demonstration of the technology was performed to determine the P2 benefits of the lower nickel bath chemistry, with a focus on rinsing and bath disposal. The project was performed at a Michigan metal finishing facility.

During the P2 demonstration, Coventya replaced an existing 6 g/l mid-phosphorus EN bath with a 3 g/l nickel mid-phosphorus bath. The new bath contains approximately 50% less nickel (3g/l). Testing included sampling of rinse tanks for both the existing and new EN processes. A capsule report covering this work can be found in Appendix I.

4.1.4 Hardwood Line TriRinse System at ███████████████

The planned demonstration at █████████████████████ was to determine the effectiveness of the Hardwood Line TriRinse System. The TriRinse System provides an equivalent three-stage rinse using only one tank and it combines the benefits of immersion and spray rinsing. It works with either rack or barrel plating. A TriRinse System consists of a rinse tank with spray nozzles, holding tank, PLC, pump and valves. The major benefits of the TriRinse System include a significant reduction in water use, less plating line length and number of tanks as well as the associated cost savings due to reduced water/sewer costs and treatment costs.

The TriRinse System was to be installed on a renovated nickel barrel line at ████████████ ████████████ The installation was scheduled to take place during the 2nd quarter of CY2018. Once installed, the line could be operated in the old mode (drag-out and 2-stage counterflow) to collect baseline data and in the new mode with the TriRinse System. Unfortunately, multiple delays occurred for the plating line renovation and the installation work was not completed during the course of the grant.

A description of the TriRinse System can be found in Appendix D. Although the technology was not demonstrated during the grant, information about the technology, including an animated video, is included in the *Rinsing Manual* posted on STERC.

4.1.5 Demonstration of Eductor Technology as a Replacement for Air Blower at Grand Rapids, MI Facility

Like many metal finishing shops, this facility uses an air blower for solution agitation in plating processes. This method of solution agitation may be less effective for mixing, which can decrease plating efficiency and increase energy use. Also, air agitation contributes to air emissions and can deplete elements of bath chemistry, such as brighteners. In alkaline plating baths, air agitation may also cause carbonate buildup.

An eductor demonstration at this facility was planned to be performed on an acid copper plating tank. The existing air agitation on this tank creates noticeable acidic fumes and adds electrical resistance to the tank's "plating circuit."

The planned demonstration was to investigate the benefits of replacing air agitation with a solution pump and eductor system. Although a single plating tank was selected for the demonstration, the results of the study were to be extrapolated to all applicable process tanks to estimate shop-wide benefits.

A demonstration plan (Appendix J) was developed cooperatively with facility representatives and an eductor technology manufacturer, including an installation design. Unfortunately, just prior to the demonstration, the company cancelled the study, based on concerns raised by their chemical supplier. Since a significant amount of work had been performed on use of eductors, NCMS sought another location to evaluate this technology. NASF was contacted to assist in this effort and they

recommended that the project contact Serfilco, another eductor supplier. However, Serfilco did not have any suggestions for demonstrations. No further work was performed.

4.1.6   Demonstration of Switch Mode Rectifiers at Grand Rapids, MI Facility

Various types of rectifiers are employed at electroplating facilities and these units are a major use of electricity (http://www.mntap.umn.edu/industries/facility/metalfinish/energy/), typically accounting for 25% or more of electrical use. In 2016, this facility was using the common silicone controlled rectifiers (SCR), however, they planned to replace these with switch mode rectifiers in 2017-2018. SCR rectifiers are reliable units, however, they are known to be less energy efficient than switch mode rectifiers. Although switch mode rectifiers have been available for over 20 years, they have generally been used for small applications, such as printed circuit board manufacturing, due to previous electrical output restrictions (20kW). However, advances in power semiconductor technology allows the fabrication of switch mode units with power capabilities of up to 400kW, making them competitive with SCR rectifiers for many applications.

A demonstration was planned at this facility to document potential energy savings. Overall, the facility planned to replace 30 SCR rectifiers. The new switch mode rectifiers were supplied by a major rectifier manufacturer. Some testing had already been performed prior to the P2 study and more was planned. Test results were to be shared with Consumer Power, the local utility for the purpose of a credit.

The facility installed rectifier data logging equipment to be used to measure power into the rectifiers (P_i) and the power from the rectifiers (P_o). This ratio (P_i/ P_o) is known as the rectifier efficiency. The facility indicated that preliminary results showed an increased energy efficiency of 51.4% for switch mode rectifiers, although this was not substantiated by the project team. Unfortunately, the facility decided not to participate further in a P2 study with NCMS and the demonstration was abandoned. NCMS did attempt to communicate with the rectifier manufacturer to find out more about the switch mode rectifiers, however, they did not respond.

4.2   Other Demonstrations Considered During Grant

In addition to the P2 technologies discussed above, several additional ideas were investigated during the grant, but not pursued. These include:

4.2.1   Installation of Tank Covers to Reduce Energy Use

A significant portion of energy expended at plating shops is used to maintain elevated temperatures of solutions contained in heated process and rinse tanks. Solutions are mostly heated using steam or immersion electrical heaters. Generally, tanks are open at the top at all times. The tanks lose heat to the plating room and therefore require almost constant heating. In addition to heat loss, the fumes emitted from heated tanks are vented and usually treated using a scrubber. When tank exhaust systems are inadequate, the fumes enter the workplace and may present health issues. One option for reducing heat loss and tank emissions is to install tank covers.

A Michigan metal finishing facility initially expressed interest in pursuing a demonstration project involving installation of tank covers. The purpose of this demonstration was to measure the energy savings from use of this approach.

During the research phase of the project, KCH Services was identified as a source of tank covers and they were contacted to determine if their technology was applicable to the selected facility. The KCH technology is a system designed to provide an efficient removal of air contaminants from the workplace at a level that minimizes the overall power consumption and exhaust volume to the air pollution control device. All vented tanks are fitted with covers that open and close as the hoist moves over the tank to load or unload parts for cleaning and plating.

The dimensions of the plating line at the Michigan facility were provided to KCH for an evaluation. KCH determined that there was insufficient head room between the tops of the tanks and the hoist system for their technology to operate. As a result, a demonstration of KCH technology was not pursued.

4.2.2 Use of Low Temperature Cleaners to Reduce Energy Use

Alkaline cleaning baths are present on virtually all plating lines to remove oils and soils prior to coating. Depending on the formulation of the bath, cleaning mechanisms include emulsification, dispersion, saponification and combinations of these mechanisms. Generally, cleaning baths are operated at temperatures of 160-200 F and therefore require significant amounts of energy to operate. Low temperature cleaners would obviously reduce energy requirements. The applicability of the low temperature cleaners is likely dependent on the types and amounts of oil/soils to be removed. Another consideration is the treatability of any cleaner. Due to their chemical makeup (e.g., chelators), cleaners may cause regulated metals to remain in solution following precipitation.

Despite telephone interviews with several chemical suppliers, no specific commercial product low temperature cleaner was identified during this project. However, one of the chemical suppliers interviewed during the P2 research stage of this project indicated that they exist.

The idea of demonstrating low temperature cleaners was discussed with two of the metal finishing facilities that were interested in being demonstration sites. Both facilities preferred to pursue other P2 demonstrations and therefore, this technology was not further pursued during the project.

4.2.3 Reduction of Cleaner and Acid Dumps through Improved Monitoring and Changes to Disposal Practices

Alkaline cleaners and acid etch baths are used on nearly all plating lines to pretreat parts prior to plating. The cleaners and acids have a limited lifespan due to contamination from oils coming off parts and consumption or neutralization of bath constituents. These baths are periodically discharged to treatment or hauled off-site for disposal, usually based on a disposal schedule and/or by employing chemical analysis to determine their condition.

The purpose of this demonstration was to measure any improvements in use and disposal of cleaners and acid etch baths through close monitoring and changes to disposal practices (e.g., decanting a portion of the bath rather than complete disposal).

The idea of developing a program for reducing cleaner and acid dumps was discussed with two of the metal finishing facilities that were interested in being demonstration sites. Both facilities preferred to pursue other P2 demonstrations and therefore, this idea was not further pursued during the project.

4.2.4 Reduction of Halogenated Solvent Use in the Metal Finishing Industry

At the request of EPA Region 5, NCMS conducted some research into use of halogenated solvents by metal finishing companies. Also, a question on the Phase 1 survey, asked facilities about their solvent use.

Prior to 1995, halogenated solvents were widely used by the metal finishing sector for removing oils and other contaminants from work pieces prior to plating. But, due to regulations (1994 Solvent NESHAP) and the phase-out of a popular solvent (trichloroethane phased-out by the Montreal Protocol), most finishers eliminated solvent use. Also, education by EPA and NASF's predecessor (American Electroplaters and Surface Finishers Society) contributed greatly to a decline in solvent cleaning. By 2005, solvent use by metal finishers had been reduced by 90% of 1994 levels[1]. In most cases, solvent cleaning was replaced by aqueous based cleaners, including new formulations of alkaline cleaners. Further, many residual solvent cleaning operations were upgraded from open tanks to highly efficient closed systems.

In general, NCMS found that only a small fraction of the metal finishing industry is currently using halogenated solvents. The Phase I survey results indicate that five of the 34 facilities that submitted complete data use halogenated solvents for cleaning. Of these five, three facilities do not actually perform electroplating, but rather are primarily involved in painting (many painting operations use solvent as a paint carrier rather than a cleaner). Of the two remaining facilities, one plates mainly electronics and the other is in the aerospace sector. These results are consistent with information found in the literature[2]. Electronics manufacturers often continue to use solvent for cleaning, however, solvent is used in small amounts in closed-loop systems, where very small releases occur. The aerospace industry is the one significant metal finishing sector where solvent use is still prevalent. This is due to critical cleaning requirements and in some cases, military and aerospace specifications. However, even within this sector, new solvent cleaning technology helps to reduce solvent use and releases.

In addition to the above work, NCMS encouraged our project partner, NASF to work directly with EPA Region 5 to pursue a voluntary air toxic reduction effort in the states of Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin. A NASF/EPA partnership was launched in 2018. Information concerning the partnership, is posted on the STERC website and in NASF News.

4.2.5 Emission Elimination Device™ (EED™) Tank Cover for Hard Chrome Plating

Hard chrome plating, also referred to as functional chrome plating, is used to deposit relatively thick chromium coatings on metal parts such as aircraft landing gear, machinery components, and other metal parts that require a hard, smooth surface. Nearly all hard chrome plating is done using a chromic acid bath operated at an elevated temperature. This process generates carcinogenic chromic acid aerosols that must be captured before entering the workplace and treated using air pollution control equipment, such as a scrubber. Strict regulations for the process include rules for both air emissions to the atmosphere (EPA) and workplace (OSHA).

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[1] Cushnie, George, *Pollution Prevention and Control Technology for Plating Operation* (2nd edition), National Center for Manufacturing Sciences, 2009.

[2] Ibid.

EED is an alternative to traditional scrubbing of the fumes generated by hard chrome plating. The EED encapsulates the plating tank, prevents fugitive emissions to the workplace and eliminates the need for fume scrubbers.

As a stand-alone, self-contained system requiring no exhaust fans, scrubbers or mesh pad mist eliminators, fume suppressants, or exhaust ducts and vents to the outside environment, the EED system has by definition, zero emissions to the outside environment.

The EED encloses the hard chrome plating tank using a water seal between the tank cover and the tank. The tank cover is constructed with integrated membranes that are sized to allow hydrogen and oxygen to pass through and trap water vapor and chrome mist inside the tank cover. The membranes are sized based on the tank dimensions, the maximum rectifier amperage and the plating cycle time. A technology description for the EED system was prepared (Appendix D).

Although this technology has been successfully used for 20 years, it is underutilized. The manufacturer of the technology was contacted during the project to determine if a potential demonstration site (current or future installation) is present in EPA Region 5. Unfortunately, none were available.

5. Other Development

The following outputs were developed during the project.

5.1 Survey Report

A report was prepared covering the results of the metal finishing shop survey conducted during the P2 project (Appendix F). This report has been posted on the STERC website http://www.sterc.org/subs/rinseman.php.

5.2 Technical Reports

Technical reports were prepared for three demonstrated technologies:

1. Demonstration of the Coventya Zn/Ni 3S Technology (Appendix G).
   This report has been posted on the STERC website.

2. Application of *Rinsing Manual* Approach to Automated Z/Ni Rack Plating Line (Appendix H). This report has been posted on the STERC website.

3. Demonstration of the Coventya low nickel EN bath chemistry (Appendix I).
   This report has been posted on the STERC website.

5.3 Rinsing Manual

The *Rinsing Manual* is a publicly available on-line tool on the STERC website. The purpose of this manual is to help metal finishing facilities improve their rinsing processes. Better rinsing is crucial for high quality production. At the same time, a well-chosen rinse system can actually save water and minimize sludge generation, leading to reduced pollution and lower operating costs.

In this manual, users will find:

- Description of the three key elements of effective and efficient rinsing.

- Step-by-step procedures to help you evaluate your existing rinse configuration.

- Tools and information to help you evaluate potential improvements, and estimate potential savings.

- Extensive graphics and video that convey key aspects of rinsing P2 options.

6. Information Transfer to Metal Finishing Industry and Assistance Providers

6.1 Surface Technology Environmental Resource Center (STERC)

STERC (formally NMFRC) was established by NCMS and several metal finishing trade organization partners under an EPA grant in 1995. From 1995 to the present STERC has been continuously operated through EPA funding, NASF funding and sales of compliance assistance-related tools. Except for certain products such as books and on-line resources, STERC is open to the public and free of charge. The most recent web statistics for STERC indicate that the number of annual visitors exceeds 110,000.

To maximize the exposure of PRIM project results, a menu item has been added to STERC under Training and Education, which provides users with general information about the PRIM project and provides access to deliverables. Additionally, individual PRIM deliverables are posted in several locations on STERC, including the STERC Library and under Tools and Calculators. The number of users for each PRIM will be tracked and reported under the STERC program.

6.2 National Association for Surface Finishing (NASF)

NASF, our primary industry partner, has provided instrumental communications throughout the project with metal finishing facilities and P2 technology providers. Further, at the completion of the project, NASF is promoting the project deliverables on their website.

During the course of the project, NASF provided several opportunities to engage the metal finishing industry including:

- During the industry survey phase of the project, NASF mailed surveys to their metal finishing member-companies.

- During the technology research phase of the project, NASF sent an email to every supplier, member-company to encourage participation in the PRIM project by submitting P2 product information to NCMS.

- Bill Chenevert presented status of the PRIM project at the annual Midwest Regional NASF Chapter Conference in MI on August 11, 2017 including handing out paper copies of the survey and requesting they be completed and submitted to NCMS.

- George Cushnie presented status of the PRIM project at the Chicago Midwest NASF Chapter Sustainability Summit on October 14, 2017. This was an opportunity to publicize the PRIM project further and seek additional industry participation in the survey and P2 research.

- On February 20, 2018, Lisa Stobierski and George Cushnie presented an overview of the project and preliminary results from the rinsing study at ▮▮▮▮▮▮ to the National SBEAP Technical Committee.

- Lisa Stobierski, George Cushnie and Paul Chalmer presented an overview of the project and preliminary results at NASF's SUR/FIN 2018 Conference in Cleveland OH.

6.3 National Small Business Environmental Assistance Program (SBEAP)

NCMS has a working relationship with SBEAP, including cross-linking of key environmental compliance assistance resources. During the course of the PRIM project NCMS provided a PRIM presentation at a quarterly meeting (Feb. 6, 2018) of SBEAP's technical group. A second presentation, covering final PRIM results and deliverables is scheduled for the July 2019 SBEAP technical meeting.

6.4 EPA Region 5 Webinar

NCMS has offered to participate in a Region 5 webinar that demonstrates the use of the *Rinsing Manual*. This work may be scheduled after the completion of the project.

Appendix A – Task Tracking Matrix

The following is a list of PRIM tasks as identified in the Statement of Work. Time schedule and completion of all tasks is dependent on timing of funding and funding level. This matrix may be adjusted depending on funding timing and level.

Task	Description	Time Schedule Months from Start (Nov. 2016)	Performance Measures	Status
Organization	-Establish outputs and outcomes. -Organize project team. -Plan and conduct kick-off meeting.	Month 1-2	-Number of and diversity of project participants engaged. -Establishment of outputs and outcomes.	-Kick-off meeting held Nov. 28, 2016. Total of 26 participants representing a wide range of govt. and private industry stakeholders (see list attached to Q1 2017 report). -Outputs and outcomes developed and presented at kick-off meeting. **(Task Complete)**
Research	-Generate comprehensive list of P2 options utilizing our extensive internal resources as well as external resources -Special focus on innovative P2 methods -Categorize P2 options by topic, outcome impact, and metal finishing process -Review options list with wide range of industry experts and project participants and obtain feedback -Revise list and add additional P2 options when identified (ongoing) -Flesh out details of each option*	Months 2-6	-Total number of P2 methods, technologies and approaches identified, categorized and detailed. -Number of innovative P2 methods, technologies and approaches identified, categorized and detailed.	-Identified resources. -Sent supplier letter to request information. -Contacted suppliers and industry experts via email. -Conducted telephone interviews with selected suppliers and industry experts. -Created comprehensive list of innovative P2 technologies. -Identified six innovative P2 technologies **(Task Complete)**

Survey	-Region 5 metal finishing facilities (600) -Use SGP/Benchmarking approach with two step process (Short general survey sent to all 600 facilities, Request greater detail from all step 1 respondents) -Organize survey responses into database -Re-contact facilities as needed for clarification and greater detail -Analyze data, find best performing facilities and potential demonstration sites	Months 2 – 6	-Number of Region 5 metal finishing companies engaged in project -Total number of survey respondents	-Prepared draft survey form, which was circulated to NASF and industry contacts. -Evaluated optional on-line survey approach that would supplement hard copy survey form. -Mailed hard copy (and link to alternative on-line surveys) to 600 shops. Received responses. -Prepared Phase 2 survey to collect detailed P2 and cost information. Sent Phase 2 survey to Phase 1 respondents. -Developed and implemented plan with NASF to follow up on non-respondents. -Solicited further survey participation at the Midwest Regional NASF Conference in MI. Further participated will be sought at the MW NASF Sustainability Summit in October in WI. **(Task Complete)**
Data Analysis	-To facilitate comparisons, use same analytic framework as SGP Benchmarking study -Group responding shops by process type if statistically significant -Divide responding shops into performance tiers -Determine potential savings and avoided impacts if average performance improves to a specified percentile	Months 4 – 7	-Number of metal finishing processes for which statistically valid benchmarks are generated. -Generation of data analysis report (includes performance tiers, potential savings from P2 implementation)	-Performed data analysis and prepared preliminary report. Waiting for complete data set before finalizing. - Further analysis will be performed as additional survey responses come in. **(Task Complete)**

Audits/P2 Plans	-Determine facility environmental data requirements needed to evaluate the applicability of P2 options -Develop P2 audit tools and audit procedures -Select facilities (6 – 10) for audit (Detroit-area preference) -Conduct pre-audit workshop -Conduct 6 – 10 audits -Evaluate audit information -Develop P2 plans for facilities with partiality for innovative approaches (Identify applicable P2 options, Estimate environmental improvements, Estimate cost/savings) -Review P2 plans with project team experts -Send P2 plans to facilities	Months 6 – 10	-Production of audit tools. -Number of metal finishing facilities and suppliers engaged in project (includes attendance at workshop) -Number of audits conducted. -Number of P2 plans developed for facilities.	-Completed work on identifying facilities for audits and demonstrations. This was accomplished by contacting shops in Region 5 and through recommendations of suppliers of innovative P2 technologies. -Conducted visits with five metal finishing facilities. -Completed work on demonstration plans. **(Task Complete)**
P2 Implementation	-Workshop for participating facilities -P2 options implemented by metal finishing facilities -Project team provides technical support during planning, implementation and monitoring -Progress will be monitored using customized data collection forms (or on-line alternative) -Data evaluation conducted by NCMS on-going basis and feedback	Months 11 – 16	-Number of facilities participating in workshop. -Number of facilities participating in P2 implementation. -Number of facilities providing P2 monitoring data.	Conducted surveys and P2 implementation at ██████████ ██████████████ ██████. Worked with shops and technology suppliers to collect operating and cost data. **(Task Complete)**
Output Development	-Organize and analyze P2 implementation data -Develop case studies -Publish P2 reference book -STERC on-line tools -Incorporate results into AESF Foundation train the trainer process and courses	Months 11 – 18	-Number of output methods employed to reach industry audience. -Number of metal finishing facilities reached.	Prepared capsule reports for three demonstrations: Innovative rinsing, Coventya 3S Technology and Coventya Low Ni EN process. Developed *Rinsing Manual*, an on-line tool. **(Task Complete)**

| Information Transfer | -Michigan workshops (2) covering project results and available resources
-NASF SUR/FIN Conference workshop
-Promote project outputs via STERC and NASF websites
-NASF newsletters, etc.
-Promote via P2RX, state agencies, SBEAP, applicable NGOs, etc. | Months 18 – 23 | -Number of metal finishing facilities reached through information transfer efforts. | Presented PRIM project information at the annual Midwest Regional NASF Chapter Conference in MI and at the Chicago Midwest NASF Chapter Sustainability Summit Presented project information to National SBEAP Technical Committee via webinar.
Presented two papers at the June 2018 SUR/FIN Conference in Cleveland, OH.
Posted *Rinsing Manual* (on-line tool) Capsule Reports and Survey results on STERC website for public access.
(Task Complete) |
| Reporting | -Quarterly reports (Outputs: survey results, research results, workshops, published materials, promotion activities)
-Final report (Project summary, Outcomes) | Months 3 – 23 | -Number of semi-annual reports submitted.
-Preparation and submission of final report. | Prepared semi-annual reports and final report.
(Task Complete) |

Appendix B – Kick-Off Meeting Attendees November 29, 2016

First Name	Last Name	Representing	Email	Phone	Address	At Mtg	On-line
Christine	Anderson	EPA Region 5	anderson.christinea@epa.gov	312-886-9749	77 W. Jackson Blvd, Chicago IL 60604		
Kurt	Anderson	Grand Rapids MI Environmental Services	kanderso@grand-rapids.mi.us	616-262-5504	1300 Market, S.W., Grand Rapids MI 49503	X	
Kimberly	Bartell	ERG	kimberly.bartell@erp.com	877-515-1721		X	
Joe	Baweja	Knape & Vogt	Joe.Baweja@kv.com	616-258-5363	7374 4-Mile Road, N.E., Ada MI 49301	X	
Luther	Blackburn	Ypsilanti Community Utilities Authority	lblackburn@ycua.org	734-544-7121	2777 State Road, Ypsilanti MI 48198	X	
Bob	Burger	KC Plating	bob.burger@kcjplating.com		2845 E 10 Mile Rd, Warren MI		
Paul	Chalmer	Chalmer Consulting	paulchalmer@earthlink.net	734-475-0450		X	
Bill	Chenevert	NCMS	billc@ncms.org	734-323-2770	3025 Boardwalk, Ann Arbor MI 48108	X	
George	Cushnie	CAI Resources	george@caiweb.com	434-286-7781		X	
Jenifer	Dixon	MI Department Environmental Quality	dixonj2@michigan.gov	517-284-6872	525 West Allegan St., P.O. Box 30457, Lansing MI 48909	X	
Bradley	Grams	EPA Region 5	grams.bradley@epa.gov		77 W. Jackson Blvd, Chicago IL 60604		X
Janet	Haff	EPA Region 5	haff.janet@epa.gov		77 W. Jackson Blvd, Chicago IL 60604		X
Jeff	Hannapel	NASF	jhannapel@thepolicygroup.com	202-257-3756	631 Blossom Dr., Rockville MD 20850	X	
Brian	Harrick	KC Plating	brian.harrick@kcjplating.com		2845 E 10 Mile Rd, Warren MI	X	
Lori	Hartung	NCMS	lorih@nsms.org	734-995-7061	3025 Boardwalk, Ann Arbor MI 48108		

Bernie	Haviland	Haviland Products	ebhaviland@havilandusa.com	616-361-6691	421 Ann St., Grand Rapids MI 49504		
Paul	Chalmer	Chalmer Consulting	paulchalmer@earthlink.net	734-475-0450		X	
Bill	Chenevert	NCMS	billc@ncms.org	734-323-2770	3025 Boardwalk, Ann Arbor MI 48108	X	
George	Cushnie	CAI Resources	george@caiweb.com	434-286-7781		X	
Jenifer	Dixon	MI Department of Environ-mental Quality	dixonj2@michigan.gov	517-284-6872	525 West Allegan St., P.O. Box 30457, Lansing MI 48909	X	
Bradley	Grams	EPA Region 5	grams.bradley@epa.gov		77 W. Jackson Blvd, Chicago IL 60604		X
Janet	Haff	EPA Region 5	haff.janet@epa.gov		77 W. Jackson Blvd, Chicago IL 60604		X
Jeff	Hannapel	NASF	jhannapel@thepolicygroup.com	202-257-3756	631 Blossom Dr., Rockville MD 20850	X	
Brian	Harrick	KC Plating	brian.harrick@kcjplating.com		2845 E 10 Mile Rd, Warren MI	X	
Lori	Hartung	NCMS	lorih@nsms.org	734-995-7061	3025 Boardwalk, Ann Arbor MI 48108		
Bernie	Haviland	Haviland Products	ebhaviland@havilandusa.com	616-361-6691	421 Ann St., Grand Rapids MI 49504		
Christian	Richter	NASF	crichter@thepolicygroup.com	202-257-0250	700 12th St, NW, Suite 700, Washington DC 20005	X	
Jon	Riley	NCMS	jonr@ncms.org	734-995-0556	3025 Boardwalk, Ann Arbor MI 48108	X	
Ahmar	Siddiqui	EPA	Siddiqui.Ahmar@epa.gov				X
Mark	Siegrist	Haviland Products	marks@havilandusa.com	616-862-1865	421 Ann St., Grand Rapids MI 49504		
Jeff	Spencer	MI Department Environmental Quality	spencerj3@michigan.gov	517-284-6879	525 West Allegan St., P.O. Box 30457, Lansing MI 48909	X	

Lisa	Stobierski	NCMS	lisas@ncms.org	734-995-5636	3025 Boardwalk, Ann Arbor MI 48108	X	
Stuart	Surmann	Knape & Vogt	stuart.surmann@kv.com	616-862-1865	421 Ann St., Grand Rapids MI 49504	X	
Donna	Twickler	EPA Region 5	twickler.donna@epa.gov	312-886-6184	77 W. Jackson Blvd, Chicago IL 60604	X	
Amelia	Valberg	EPA Region 5	valberg.amelia@epa.gov		78 W. Jackson Blvd, Chicago IL 60604		
Totals						21	4

Appendix C – P2 Options List Organized by Topic

General Pollution Prevention Practices

Establish P2 program

- Establish organizational framework – involve all employees
- Set P2 company policy
- Develop P2 plan
- P2 assessment
- Implement P2 program
- Maintain employee awareness and continue education

Data collection, recordkeeping and analysis

- Chemical use
- Water use (rotameters)
- Energy use
- Waste generation
- Production

Housekeeping

- Proper chemical storage
- Preventative equipment maintenance
- Leak/spill prevention and control
- Spill (emergency response) plan

Dragout Reduction, Improved Rinsing and Emissions Reduction

Dragout reduction

- Minimize dragout formation
- Minimize chemical solution concentration
- Design and maintenance of racks/barrels to permit good drainage
- Position parts on racks for optimal drainage
- Slow down work piece withdraw speed from solution
- Allow maximum drainage over process tanks
- Utilize drip/ragout tanks and return solution to process tank
- Utilize dragin/dragout tank
- Drip pans

Rinsing

- Optimize rinse tank design to avoid short circuiting
- Control flow rate of water
  - Flow restrictors
  - Conductivity controls
  - Timer rinse controls
  - Solenoid valves on automatic machines

- Air agitation
  - Compressed air
  - Air blower
  - Eductors
- Alternative rinsing configurations
  - Multiple rinse tanks (counterflow, dragout, etc.)
  - Spray rinsing
  - Multiple stage rinsing in single tank (e.g., Hardwood TriRinse System)
  - Cascade, reactive and dual purpose rinsing
  - Chemical rinsing

Emissions reduction

- Fume suppressants/foam blankets (e.g., Havachrome Mist Eliminator III)
- Tank covers, including automated systems (e.g., KCH)
- Encapsulating tank covers (e.g., Palm Technologies EED)

Chemical Recovery

Process chemical recovery

- Atmospheric evaporators
- Vacuum evaporators
- Ion exchange
- Electrowinning
- Electrodialysis
- Reverse osmosis

Other

- Meshpad mist eliminators

Chemical Solution Maintenance

Preventative and corrective bath maintenance

- Filtration
- Carbon treatment
- Electrolysis
- Carbonate freezing
- Precipitation

Technologies

- Microfiltration (e.g., alkaline cleaners)
- Ion exchange (e.g., hard chromium solution)
- Acid sorption
- Ion transfer
- Membrane electrolysis
- Diffusion dialysis

Green Chemistry

Trivalent decorative chromium plating (e.g., Columbia Chemical)

Non-chromium conversion coatings

Low concentration chemistries (e.g., Coventya Enova RI Electroless nickel plating chemistry)

Zinc nickel (cadmium substitute)

Non-cyanide solutions (e.g., copper, zinc)

Chlorinated solvent elimination (e.g., aqueous cleaning)

Dry processes (e.g., vacuum plating)

Improved cleaners (e.g., non-phosphate, low chelate cleaners, low temperature, etc.) (e.g., Hydrite Chemical Co. Walchem 600)

Energy Use Reduction/Green House Gas Reduction

Tank covers, including automated systems (e.g., KCH)

Tank insulation

Low temperature chemical solutions (e.g., alkaline cleaners)

Push-pull tank exhaust systems

Compressed air improvements (MnTAP's Greening Your Business Compressed Air page for tips for increasing compressed air system's efficiency and decreasing costs.)

Power supply improvements (http://mntap.umn.edu/metalfinish/energy.html)

Ventilation improvements (http://mntap.umn.edu/metalfinish/energy.html)

Lighting improvements (http://mntap.umn.edu/metalfinish/energy.html)

Fan efficiencies

HVAC improvements

Wastewater treatment improvements (e.g., sludge dewatering, sludge dryer)

Appendix D – Technology Summary Sheets

TriRinse System

Company Name: Hardwood Line Manufacturing Company

Company Contact Information: Tony Lazaro; tonyl@hardwoodline.com, 773-463-2600

Technology Name: TriRinse System

Background Information: High quality metal finishing requires good rinsing after each process step (cleaning, etching, electroplating, etc.) to remove the film of chemical solution (dragout) on the parts and racks (or barrels). Rinsing prevents the carryover of chemicals from one bath to the next, which would cause cross contamination of solutions and lead to their premature disposal. After processing is complete, a final rinse is needed to prevent staining and/or corrosion of the parts.

Rinse water easily accounts for the largest volume of wastewater generated at plating shops. Most rinse waters must be treated prior to discharge to remove regulated heavy metals and for pH adjustment. The required hydraulic capacity of a wastewater treatment (WWT) system and the quantity of treatment chemicals used are both dependent on the volume of rinse water to be treated. Combined with water and sewer costs, rinse water treatment represents a very significant operating cost at most metal finishing shops.

Rinsing is conducted in tanks and there are various configurations used. Single overflow immersion rinse tanks (once through flow of water) can provide good rinsing, but they consume very large volumes of water because it takes copious amounts of water to dilute dragout. Multiple stage rinse tanks (e.g., two or more tanks in a counter flow arrangement) can exponentially reduce the volume of water needed for good rinsing; however, multiple tanks take up valuable shop floor space, which in some cases is not available. Spray rinsing is a viable alternative to immersion rinsing, but by itself has limitations (e.g., less effective with hidden surfaces) and generally needs to be combined with immersion rinsing to be fully effective.

Technology Description: The TriRinse System provides an equivalent three-stage rinse using only one tank and it combines the benefits of immersion and spray rinsing. It works equally as well with either rack or barrel plating. The attached brochure explains how the system works for barrels. A TriRinse System consists of a rinse tank with spray nozzles, holding tank, PLC, pump and valves.

Although variable, here is an example of when 10 gal. of water is used per rinse.

The barrel is initially lowered into a partially filled rinse tank and rotated to improve drag-out removal (1st rinse). An amount of water is then pumped out of the rinse tank, of which 10 gal. are sent to WWT and the balance going to the holding tank. The water level in the rinse tank is now below the bottom of the barrel. The barrel, now out of solution, is rotated to improve drainage of rinse water.

The first of two fresh water sprays sends 5 gal. of fresh water into and over the barrel (2nd rinse). After the spray, the barrel is again rotated to improve drainage.

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The second of two fresh water sprays then sends 5 gal. of fresh water into and over the barrel (3rd rinse). Thus, the 10 gal. of rinse water that were previously sent to WWT has been made up with two 5 gal. fresh water sprays. The barrel is again rotated.

The barrel is removed from the tank and the level of water in the rinse tank is raised to the correct height by sending water back from the holding tank. The system is ready for another cycle.

With this example, only 10 gal. of fresh water were used. If the rinse was operated as a single stage immersion rinse, more than 10 times as much wastewater would have been generated to attain the same level of cleaning.

Pollution Prevention Benefits: The major benefits of the TriRinse System offer a significant reduction in water use, less line length and number of tanks as well as the associated cost savings due to reduced water/sewer costs and treatment costs.

Status of Technology: The TriRinse System is fully designed and is now being fabricated for use at an approved beta testing site.

Potential Demonstration Sites: ███████████████████████████████ is considering a beta test of the TriRinse System in 2018.

Required Actions: With permission of Hardwood Line, contact ██████████████████████ to discuss a potential demonstration. If the beta TriRinse System is going to be installed on an existing plating line, it may be possible to collect baseline data (prior to beta installation), including water use and production volume. Following beta installation, similar measurements would be taken to determine the water savings. WWT cost savings could be estimated using their WWT chemical purchasing records and historical water use data ($/K gal.).

More information: ███████████████████████████████

Emission Elimination Device™ (EED™)

Company Name: Palm Technology Inc.

Company Contact Information:
Chris Finley
Sales Engineer
Palm Technology, Inc.
1717 JP Hennessy Drive
La Vergne, TN 37086
Ph: 615-967-1855

Technology Name: Emission Elimination Device

Technology Description: The EED is applicable to hard chrome plating. It is an alternative to traditional scrubbing of the fumes generated at a hard chrome plating tank. The EED encapsulates the tank and eliminates the need for fume scrubbers and fume suppressants.

As a stand-alone, self-contained system requiring no exhaust fans, scrubbers or mesh pad mist eliminators, fume suppressants, or exhaust ducts and vents to the outside environment, the EED system has by definition, zero emissions to the outside environment.

The EED encloses the hard chrome plating tank using a water seal between the tank cover and the tank. The tank cover is constructed with integrated membranes that are sized to allow hydrogen and oxygen to pass through and trap water vapor and chrome mist in the cover. The membranes are sized based on the tank dimensions, the maximum rectifier amperage and the plating cycle time.

The cover in the EED system is set in a water trough built into the lip of the chrome plating tank. It contains the water vapor and chrome mist. As the water vapor rises beneath the EED, a cloud forms that blankets the plating solution. Any chrome mist that comes in contact with the cloud is "washed" by the water vapor, creating heavy chrome droplets that fall back into the plating tank. As the water vapor continues to rise it comes in contact with the cover, condenses, forms water droplets and falls back into the plating tank and water seal trough. The hydrogen and oxygen gasses rise to the highest point beneath the cover where the patented membrane allows free passage of the two gases to the atmosphere.

On completion of the plating cycle, residual hydrogen and oxygen gasses, water vapor, and chrome mist must be evacuated from beneath the cover before the cover is removed. Once the rectifier has been turned off, it takes approximately 3-5 minutes to complete the evacuation cycle. The cycle varies based on the volume contained by the cover.

The evacuation system consists of a regenerative blower, moisture separator, pre-filter and final HEPA filter. The operation is as follows:

- The blower turns on and the air flow passes through the moisture separator where residual moisture is collected.

- The air stream passes through the inline filter and through the blower.

- In the final step the air is passed through HEPA filter and into the room.

The evacuation cycle can be controlled automatically with a controller and interlocks to prevent premature opening of the tank.

See full description of technology: http://www.dtic.mil/dtic/tr/fulltext/u2/a460123.pdf.
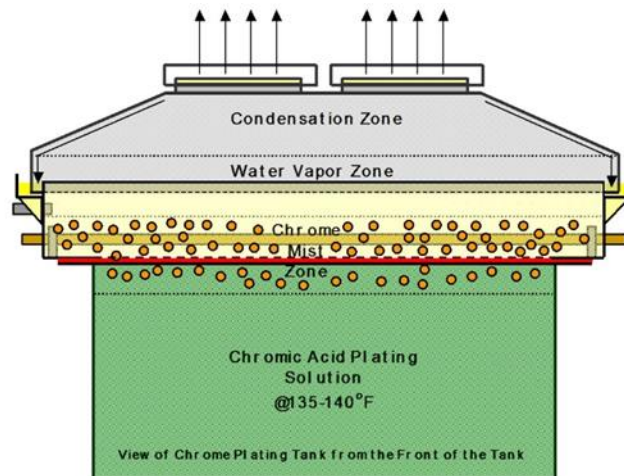
Background Information: Hard chrome plating is regulated by the Chromium NESHAP, which limits the amount of Cr^{+6} that can be discharged to the environment. The common method of compliance is to install a tank exhaust system, ductwork and a mist elimination system or wet scrubber. These systems are expensive to operate due mainly to energy costs (exhaust fan and cost of make-up air, which may be heated or cooled).

Status of Technology: The technology has been commercially available since the 1990s. There are approximately 30 installations, of which eight have been during the past year.

Pollution Prevention Benefits:

- The need for exhaust hoods, ductwork and fume scrubbers/fans is eliminated, resulting in a major reduction of energy use.

- With a properly installed and operated EED system, emissions are eliminated.

- Because no exhaust stacks are required, chrome fumes cannot escape into the atmosphere as they could if the scrubber system fails.

- No wastewater discharge as there is with a scrubber system.

Potential Demonstration Sites: No demonstration sites have been identified. No existing installations are present in Region 5.

TriCOL Trivalent Decorative Chrome Plating

Company Name: Columbia Chemical

Company Contact Information:
Brett Larick
President
330-819-1216 (cell)
1000 Western Dr
Brunswick, OH 44212

Technology Name: TriCOL Décor

Technology Description: Trivalent chromium plating, also known as tri-chrome, Cr^{+3}, and chrome (III) plating, uses chromium sulfate or chromium chloride as the main ingredient. Trivalent chromium plating is an alternative to hexavalent chromium in most decorative applications.

A trivalent chromium plating process is similar to the hexavalent chromium plating process, except for the bath chemistry (mostly sulfate-based) and anode composition.

Columbia Chemical's TriCOL Décor process is chloride-based, which reportedly provides a faster plating speed as compared to trivalent chromium processes operating in full sulfate electrolytes. This minimizes cost in plating line modifications for existing hexavalent chromium plating line conversions that would need to accommodate the slower plating speed of a sulfate-based trivalent chromium process.

Background Information: Decorative chromium plating is one of the most common plating process in the U.S. Most decorative chrome plating is performed using hexavalent chromium chemistry. Approximately 40 years ago, commercial trichrome decorative chemistry became commercialized and made its way into the U.S. market. However, acceptance of the trivalent chrome process has been very slow, mainly due to early concerns over esthetics and corrosion protection. Trivalent-based electrolytes are now available which overcome the quality and cosmetic issues of older systems. However, industry and customer acceptance has not caught on. One issue is the cost of converting from a hexavalent to trivalent process.

Status of Technology: Fully commercialized. Used for approximately 15% of decorative chrome plating in the U.S. Much higher use abroad, especially EU.

Pollution Prevention Benefits: Trivalent decorative chrome plating is not a new technology, but industry experts believe it remains underutilized. The purpose of re-looking at this technology would be to closely examine the operating costs and P2 potential with the premise that such detailed information may help increase acceptance of the technology among the industry and its customers.

Converting from hexavalent to trivalent chromium plating eliminates use of hexavalent chromium, which results in several benefits:

- Eliminates Cr^{+6} in air emissions, which are regulated under an EPA NESHAP.

- Eliminates Cr^{+6} wastewater, which is regulated by EPA effluent guidelines.

- Wastewater treatment is simplified because the chromium reduction step (Cr^{+6} must be converted to Cr^{+3} prior to precipitation) is not necessary.

- Eliminates worker exposure to Cr^{+6}, which is regulated by OSHA PEL.

In addition to the above P2 benefits, the trivalent chromium bath contains less than 20% of the metal content of the hexavalent bath. This results in a proportional decrease in hazardous sludge (F006) generated during wastewater treatment.

Inert anodes that last indefinitely are used with trivalent plating as opposed to the lead anodes used with hexavalent plating and deteriorate over time. Using inert anodes eliminates the lead sludge that is present in hexavalent baths, which must be filtered out or periodically removed and disposed of as hazardous waste.

Further, the trivalent chromium process uses less energy compared to hexavalent plating due to operational advantages, such as improved throwing power.

Potential Demonstration Sites: No demonstration sites have been identified.

3S Membrane Technology

Company Name: Coventya, Inc.

Company Contact Information:
Mike Kelly
Vice President
Tel: 216-351-1500 x305
Cell: 216-469-6918

Ambrose Schaffer, CEF
R&D Manager
315-768-6635 x224

COVENTYA Inc.
4639 Van Epps Road
Brooklyn Heights, OH 44131 USA
www.coventya.com
m.kelly@coventya.com

Technology Name: Patented 3S Membrane Technology for PERFORMA Alkaline Zn/Ni Baths

Technology Description: Zn/Ni is a high performance coating that provides exceptional corrosion protection in harsh environments. It is a replacement for cadmium plating, which has various environments issues.

Traditional high alloy (12-16%) alkaline Zn/Ni baths utilizing standard Ni or Fe anodes typically:

- Form CN
- Offer low plating efficiency
- Require higher energy consumption
- Tax in-house waste treatment equipment capabilities due to "bleed and feed" techniques.

The ion selective membrane prevents the passing of organic molecules (i.e., complexants) and thusly eliminates the formation of CN and greatly reduces the oxidation and creation of break-down products at the anode.

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Background Information: Coventya 3S (selective separation system) membrane anodes:

- Prevent the formation of cyanide.
- Increase plating efficiency by 30-40%.
- Reduce energy consumption by 50%.
- Eliminate the need for "bleed and feed" which dramatically reduces the amount of plating bath (Zn, Ni, CN) that needs to be treated.

Status of Technology: Coventya currently has 50+ global installations utilizing the 3S membrane technology (1 fully installed and 5 projects pending in the USA).

Pollution Prevention Benefits:

- The formation of CN is reduced 100%.
- Energy consumption is reduced by 50%.
- Ni consumption is reduced by 25%.
- Total Zn/Ni proprietary chemical costs are reduced by 20-25%.
- Throughput is increased by 40-150%.
- Waste treatment costs are greatly reduced.

Potential Demonstration Sites: Coventya recently installed the 3S Membrane technology at a large applicator in the Detroit, MI area. We have introduced the P2 opportunity and the applicator is interested in discussing further.

ENOVA RI Electroless Nickel

Company Name: Coventya, Inc.

Company Contact Information:
Mike Kelly
Vice President
Tel: 216-351-1500 x305
Cell: 216-469-6918

Ambrose Schaffer, CEF
R&D Manager
315-768-6635 x224

COVENTYA Inc.
4639 Van Epps Road
Brooklyn Heights, OH 44131 USA
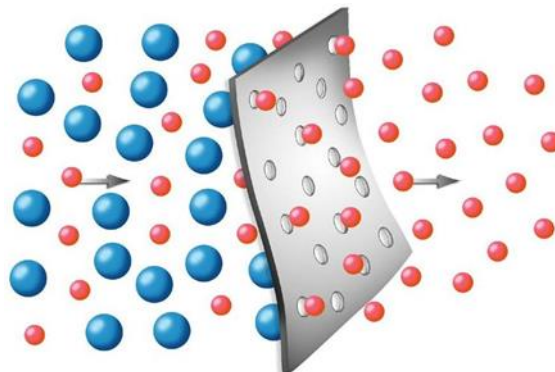www.coventya.com
m.kelly@coventya.com

Technology Name: ENOVA RI Electroless Nickel

Technology Description: The <u>ENOVA</u> <u>R</u>educed <u>I</u>on electroless nickel technology offers an advanced generation of electroless nickel development which incorporates innovative "additive" chemistry into a low ionic strength formulation. This technology is offered in high, mid and low phosphorus platforms. The RI systems operate at 1/2 the nickel metal concentration which offers the plater both environmental and operational benefits.

Background Information: The surface finishing industry has lost the battle with hexavalent hard chrome where imminent sunset dates will push the technology into extinction. Soluble nickel metal has caught the eye of regulatory agencies in both Europe and the U.S. In 2005 Agency for Toxic Substances and Disease Registry (ATSDR) issued a public health statement regarding nickel. Maine attempted to list metallic nickel in its top 49 toxic metal list. In France there are tank placard requirements for nickel containing solutions that exceed a specific level. EPA/OSHA continues to look at nickel and have approached suppliers in the past about technology to mitigate nickel air emissions.

The question regarding restrictions on nickel should not center on if, but rather when. ENOVA RI technology directly addresses these concerns for electroless nickel plating.

- Reduces the working concentration of soluble nickel in the electroless bath from the conventional 6,000 ppm to 3,000 ppm eliminating the need for potential hazard placards on the electroless nickel tank.

- Reduces the amount of soluble nickel dragged out of the working bath thus cutting the nickel concentration in post-plating rinse tanks by 1/2.

- Cuts in 1/2 the amount of nickel emissions that applicators are exposed to during operation.

- Extends solution life thus reducing waste.

This information, as disclosed to the EPA, shall be protected as the proprietary and confidential information of NCMS and its members named herein in accordance with this agreement and applicable laws and regulations.

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Status of Technology: ENOVA RI electroless nickel technology was commercialized in 2012 and there are numerous production tanks in Europe, most notable in France and Germany. There are roughly five installations currently operating in North America and Coventya is currently expanding the product line further while installing more systems in both current and new customers.

Coventya has delivered a number of presentations on the subject of ENOVA RI and has actively promoted in trade magazines.

Pollution Prevention Benefits:

- Cut nickel metal in air and rinse waters by 50%.

- Reduced nickel allows platers to reduce water flow rates in rinse tanks, maintain rinse quality and meet discharge limits.

Potential Demonstration Sites: Coventya has approached a number of large, technically competent electroless nickel platers in Region 5. We have identified and approached three demonstration sites in Minnesota, one in Illinois and two in Michigan. We have not received commitments as of yet.

Havachrome: Mist Eliminator III

Company Name: Haviland Enterprises, Inc.

Company Contact Information:
Rich Held (richh@havilandusa.com)
R&D Manager
1835 Turner Ave. N.W.
Grand Rapids, MI 49504
616-510-6824 (cell)
616-365-6567

Technology Name: Havachrome: Mist Eliminator III

Background Information: This technology is a mist wetting agent/fume suppressant that is applicable to hard chrome plating. Like similar products it reduces the surface tension of the bath and therefore reduces the production of chrome aerosols.

Technology Description: Haviland Products Surface Finishing Division has developed a new wetting agent/fume suppressant which contains no fluorine and is bio-degradable. Havachrome Mist Eliminator III produces a very tight, stable foam blanket in medium to high temperature hexavalent chrome plating solutions. With usage shown as low as one gallon per 80,000 ampere hours to keep the surface tension below the EPA limits, the molecule shows great stability. Havachrome Mist Eliminator III is also compatible with products from other producers, allowing for rapid slide conversion. See 2/28/17 email for a little more information.

Pollution Prevention Benefits: Mist Eliminator III does not contain Perfluorooctanesulfonic Acid (PFOS, pronounced P-Fos) or Fluorine and it is bio-degradable. It produces a very tight, stable foam blanket in medium to high temperature plating solutions. With usage shown as low as one gallon per 80,000 ampere hours it is able to keep the surface tension below the EPA limits.

Status of Technology: This is a new commercial product. There are no existing installations.

Potential Demonstration Sites: A demonstration was started in Grand Rapids, however it was discontinued. The manufacturer indicated that the problem was due to incorrect dosage and not the product itself.

Required Actions: Look for a new demonstration site, preferably in Michigan. The facility must have a hard chrome plating process.

Appendix E – Phase I and II Survey Forms

Metal Finishing Industry Pollution Prevention and Benchmarking Survey

Endorsed by: National Association for Surface Finishing (NASF)
                      AESF Foundation
                      Michigan Chapter of NASF

Instructions

1. The National Center for Manufacturing Sciences (NCMS) is conducting this benchmarking survey and is responsible for all aspects of data collection and management. All information and data contained in this survey form will be kept confidential. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form. If you have any questions or concerns with respect to confidentiality, contact Bill Chenevert of NCMS at 734-995-7989 (email: BChenevert@ncms.org).

2. Companies responding to this survey will receive a **free copy** of *Pollution Prevention and Control Technologies for Plating Operations*, second edition. Thousands of copies of this book have been sold world-wide and it is generally considered the most comprehensive text for this subject. A book will be mailed to you within two weeks of receiving your completed survey form.

3. Please complete all applicable sections of the survey form. Some questions request specific data, such as costs or quantities of waste. If exact data are not available, use estimates based on your knowledge of the process.

4. If your responses do not fit into the spaces provided on the survey form, please use ordinary paper and clearly indicate which question the response applies to. Please print clearly or type.

5. If you have any questions, please contact George Cushnie at 434-286-7781 (email: geoc@caiweb.com).

All information and data contained in this survey form are confidential. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form.

Return the completed form to:

   Surface Finishing Environmental Resource Center
   Technical Offices
   5199 W River Rd.
   Scottsville, VA 24590
   Phone: 434-286-7781

Metal Finishing Industry Pollution Prevention and Benchmarking Survey

1. Background information

This information will be used to contact you for clarification, if necessary, and at the completion of the project to provide you with a summary of the results.

Your Name: _____ Title: _____

Facility Name: _____

Phone: _____ E-mail: _____

Street Address: _____

City/State/Zip: _____

2. Water purchased/wastewater discharged

This information will be used along with other data to evaluate differences in water use among metal finishing companies.

Volume of water purchased during 2016: _____ gal/year

Volume of metal finishing wastewater discharged during 2016: _____ gal/year

3. Which wastewater regulations applied to your facility during 2016 for metals and cyanide?

This information will be used to evaluate and compare different discharge conditions and restrictions.

☐ Electroplating (40 CFR 413)
☐ Metal Finishing (40 CFR 433)
☐ Combination of 413 and 433 standards
☐ Local standards that are more stringent (for at least one parameter) than the Electroplating and Metal Finishing standards [**Please attach a copy of the standards or write them out on an attached sheet**]
☐ Other: _____
☐ Not sure

4. Wastewater treatment sludge data

The data collected by this question will be compared to other data in the survey to evaluate <u>differences</u> in sludge production among metal finishing processes and the extent to which sludge is being recycled.

Total amount of wastewater treatment sludge generated during 2016: _____ lbs/year

Amount of hazardous wastewater treatment sludge generated during 2016 that is shipped off-site for land disposal*: _____ lbs/year

Average <u>water</u> content of wastewater treatment sludge: _____ % by weight

Indicate sludge dewatering technology used:

☐ Filter Press ☐ Sludge Dryer ☐ Other (indicate):_____

*If your wastewater treatment sludge was delisted or it was sent off-site for metals recovery rather than disposal, enter zero.

5. Organic chemical emissions to air and water (2016)

Record any organic chemicals found on the TRI list that are used at your facility and indicate the quantity of these chemicals that are released to the air and water. Common TRI organic chemicals used by metal finishing companies include: trichloroethylene (TCE), toluene, methyl ethyl ketone (MEK), formaldehyde, methanol, isopropyl alcohol, n-butyl alcohol, thiourea, glycol ether, and xylene.*

              Chemical name   Quantity of chemical released to air + water (lbs/year)

1. _____   _____

2. _____   _____

3. _____   _____

If more space is needed, attach additional pages.
*This is not an exhaustive list of TRI organic chemicals. A complete list can be found at: https://www.epa.gov/toxics-release-inventory-tri-program/tri-listed-chemicals.

6. Wastewater treatment processes

Check the boxes for the systems that best describe your treatment methods during 2016 for metals and cyanide.

Cyanide Destruction

☐ None

☐ Alkaline chlorination: (☐ Batch ☐ Continuous)

☐ Other:_____

Chromium Reduction

☐ None

☐ Chromium reduction using sulfur dioxide, sodium bisulfite, or sodium metabisulfite:
(☐ Batch ☐ Continuous)

☐ Other:_____

Pretreatment of Spent Cleaners or Other Concentrated Solutions (prior to combining with main flow)

☐ Yes (please specify: _____)

☐ No

Metals Removal

☐ None

☐ Conventional hydroxide precipitation using a clarifier for solids removal: (☐ Batch ☐ Continuous)

☐ Conventional hydroxide precipitation using a membrane filtration for solids removal:
(☐ Batch ☐ Continuous)

☐ Conventional hydroxide precipitation, plus end-of-pipe ion exchange polishing: (☐ Batch ☐ Continuous)

☐ Conventional hydroxide precipitation, plus granular bed filtration polishing: (☐ Batch ☐ Continuous)

☐ Sulfide precipitation using a clarifier for solids removal: (☐ Batch ☐ Continuous)

☐ Sulfide precipitation/hydroxide precipitation combination using a clarifier for solids removal:
(☐ Batch ☐ Continuous)

☐ Ion exchange

☐ Other:_____

7. Energy data use (2016)

Many metal finishing companies can reduce operating costs by lowering energy use. The data collected by this question will help establish a benchmark for different segments of this industry so that companies can evaluate their own usage rates and possibly lower their operating costs in the future.

Electricity consumed: _____ kWh/year Natural gas consumed: _____ therms/year*

Fuel oil/other (specify type, units): _____

*Report whatever units are convenient (e.g., therms, ccf, BTUs)

8. Production data

The data collected by this question will be used to "normalize" your data so that it can be meaningfully compared with data from other facilities.

Please provide value(s) for 2016:

Metal finishing sales: $_____

Total number of labor hours for all people working in the metal finishing shop: _____

9. What percentage of your 2016 metal finishing sales was derived from the following business areas (responses should total 100%)?

The data collected by this question will be used along with other survey data to identify differences in water use and other factors among metal finishing business areas.

_____% Motor Vehicles	_____% Aerospace/Aircraft	_____% Railroad
_____% Building/Construction	_____% Wire Goods and Pipes	_____% Plumbing Fixtures
_____% Sporting Goods/Toys	_____% Military/Govt.	_____% Printed Wiring Boards
_____% Other Electronics	_____% Jewelry/Watches	_____% Medical
_____% Furniture	_____% Machinery/Industrial	_____% Boats/Ships
_____% Household Appliances	_____% Other Household Items	_____% Hardware/Tools
_____% Fasteners	_____% Telecommunications	_____% Other (indicate: _____)

10. The level of automation at metal finishing shops varies widely and can effect water use, sludge generation, etc. Also, some metal finishing shops process different types of parts every day and must account for this by frequently making changes to their production methods. Other shops process nearly identical parts day after day, even though the workload may come from different clients, and don't need to change their processing methods.

What percentage of your 2016 metal finishing sales were performed on automatic plating machines?

_____% of metal finishing sales performed on automatic plating machines

What percentage of your 2016 metal finishing sales was from repetitive work and what percentage was from non-repeating work (the total of these two responses should equal 100%):

_____% of metal finishing sales was from repetitive work

_____% of metal finishing sales was from non-repeating work

11. Metal Finishing (MF) process data for 2016

This question is a key element of the survey. The data collected by this question will be used with data from most other sections of the survey to identify differences in water use, sludge generations, energy use, etc. between various processes employed by the metal finishing industry.

Process	In the two columns below indicate the approximate percentages contributed by each process. Each column should add up to 100%.		Percentages of work performed with each process that is transported using racks, barrels, or other. See instructions below.		
	Percentage of MF sales, %	Percentage of MF shop labor, labor hours, %	% Rack	% Barrel	% Other
Total	**100%**	**100%**	**--**	**--**	**--**

List general processes only. For example, if you operate a decorative Cu-Ni-Cr line, do not list cleaning, Cu plating, Ni plating, etc. Simply list decorative chromium. The following list is intended to help select process names.

Electroplating	Silver	Bright dipping	Painting
Brass	Tin	Chem milling	Passivation
Bronze	Tin-lead	Chromating	Phosphating
Chromium, decorative	Zinc	Electroforming	Powder coating
Chromium, hard	**Other Surface Finishing**	Electropolish	Printed circuit boards
Copper	Anodizing, chromic acid	Mass finishing	
Gold	Anodizing, sulfuric	Mechanical plating	
Nickel	Black oxide	Nickel, electroless plating	

End of Survey. Thank you for your time.

Metal Finishing Industry Pollution Prevention and Benchmarking Survey
Phase II

Endorsed by:
National Association for Surface Finishing (NASF)
AESF Foundation
Michigan Chapter of NASF

All information and data contained in this survey form are confidential. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form.

Return the completed form to:

Surface Technology Environmental Resource Center
Technical Offices
5199 W River Rd.
Scottsville, VA 24590
Phone: 434-286-7781
Email: george@caiweb.com

This information, as disclosed to the EPA, shall be protected as the proprietary and confidential information of NCMS and its members named herein in accordance with this agreement and applicable laws and regulations.

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Instructions

1. The National Center for Manufacturing Sciences (NCMS) which operates the Surface Technology Environmental Resource Center (STERC), is conducting this pollution prevention (P2) and benchmarking survey and is responsible for all aspects of data collection and management. All information and data contained in this survey form will be kept confidential. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form. If you have any questions or concerns with respect to confidentiality, contact Bill Chenevert of NCMS at 734-995-7989 (email: bchenevert@ncms.org).

2. This survey is the second phase of a two-phase P2/Benchmarking project. Only companies which responded to Phase I have received this form. For consistency, it is most desirable that the same person who completed Phase I also complete this Phase II survey. However, it is not absolutely necessary.

3. Please complete all applicable sections of the survey form. Some questions request specific data, such as costs or quantities of waste. If exact data are not available, use estimates based on your knowledge of the process.

4. If your responses do not fit into the space provided on the survey form, please use ordinary paper and clearly indicate which question the response applies to. Please print clearly or type.

5 If you have any questions, please contact George Cushnie at 434-286-7781 (email: george@caiweb.org).

Benchmarking Survey Form – Phase II

The purpose of this survey form is to collect detailed information that will be used to expand implementation of pollution prevention practices and establish a metal finishing pollution control benchmark.
The benchmark will help determine how the best performing facilities achieve environmental protection.
The information you provide will be correlated with your Phase I responses.

1. Company/Point-of-Contact *(please change any incorrect information)*

Facility Name: _____

Point-of-Contact: _____

2. Staff Size and Training
This information will be used to evaluate the effects of training on environmental success.

How many metal finishing shop supervisors did you have as of the end of 2016?
(Do NOT include pure office workers.): _____

How many hourly metal finishing shop floor employees did you have as of the end of 2016?: _____

Indicate below how many of those metal finishing shop supervisors and hourly employees (the ones you counted above) have received formal training through AESF Foundation courses.

	Number of Managers	Number of Hourly Shop Workers
Completed one or more AESF Foundation courses, but have not attained a level of certification		
Attained level of Certified Electroplater Finisher (CEF)		
Attained level of Certified Aerospace Finisher (CAF)		
Attained level of Master Surface Finisher (MSF)		

3. Pollution Control and Energy Cost Information
This information will be used to estimate the costs associated with environmental compliance and the potential costs savings associated with implementing pollution prevention.

Please provide the following cost information for 2016. For water, sewer and electricity, please provide the average unit price. For the remaining items, provide your total annual costs paid for 2016.

Item	2016 Cost ($)
Water/1,000 gal (or give units)	
Sewer/1,000 gal (or give units)	
Electricity/kWh*	
Wastewater treatment chemicals	
Misc. supplies (filter cloths, cartridge filers, etc.)	
Laboratory services	
Compliance/engineering services	
Sludge transportation/disposal/recycle	
Bulk chemical treatment	
Permits/taxes/licenses	
Other	
Other	

*For electricity provide the average unit cost (total dollars spent/total kWh consumed).

4. **Labor (2016)**
   These data will be used to evaluate environmental-related costs for shops.

Estimate the number of labor-hours spent during 2016 for each of the following tasks. Be certain not to "double count" hours that were spent on related tasks such as wastewater treatment operation and maintenance.

Item	2016 Labor Hours
Environmental management	
Wastewater treatment operation	
Monitoring	
Inspection	
Maintenance of pollution control systems	
Analytical testing	
Hazardous waste management	
Waste reduction	
Reporting/recordkeeping	
Training	
Local emergency planning	
Other	
Other	

5. **Process Specific Information**
   This information will be used to identify methods of pollution prevention that are used with specific types of processes.

Listed below are the processes you identified in your Phase I survey form. For each process, please provide a description of any pollution prevention (P2) and recovery methods or equipment that you have implemented/installed. Consider cleaning and post-plating processes that are associated with the listed process. Include P2 methods used for extending the life of process solutions, preventing drag-out, reducing water use, recovering chemicals, reducing energy use, and substituting less toxic materials. Use additional sheets, as needed.

Process Name Pollution	Prevention Strategy

6.   Other P2 Information

This information will be used to identify innovative P2 methods.

Describe below any special elements of your environmental compliance, P2 or energy conservation programs not covered elsewhere in the survey form, especially those that you consider innovative. Include both management/employee elements (e.g., incentive programs, quality control programs) as well as equipment/facility elements (e.g., recycling equipment, energy conservation efforts).

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Appendix F – Survey Results

PRIM Survey Date – Preliminary Summary and Analysis

In this preliminary report, we summarize the data received so far, carry out a comparative analysis, and indicate some possible trends that can be explored further during the next phase of the project.

Background – 2000 Benchmarking Study

The June 2000 report, *Benchmarking Metal Finishing,* provides a statistical analysis of responses from 132 metal finishing facilities, covering over 30 different metal finishing processes, with information on six key environmental variables. The data set contained a wealth of useful information, but extracting the information in useful form presented a challenge. Most metal finishing shops run a mix of processes, each with its own particular set of environmental impacts. Shops generally know their overall water and power usage rates, and the total amount of sludge they generate, but are not typically able to provide a process-by-process breakdown of those totals. That makes it difficult to compare one shop's performance with another's, or the impacts of one process with that of another, using the raw data from the reported totals alone.

Although the shops could not say what portion of environmental impacts were due to each process, they were asked for information that could provide surrogate measures of the relative contribution of each process to the total. The most robust of these measures turned out to be the dollar amount of sales due to each process, as a percent of total annual sales over the survey year (1998, in the case of the 2000 report).

Since we now had both total impact numbers and a measure of process mix from each shop, we could apply the statistical technique of regression analysis to extract a measure of how much of each impact variable is associated with each specific process. (A number of statistical tests were performed to check for the influence of variables such as the customer mix of the shop, and to distinguish apparent trends from random fluctuations. A detailed description is provided in the 2000 report.)

The result of the analysis was a set of regression coefficients, one for each impact variable and each process. After tests for statistical significance were applied, sets of coefficients were provided for six major processes:

- Zinc plating
- Nickel plating
- Decorative chromium plating
- Electroless nickel plating
- Anodizing
- Hard chromium plating

For each of these processes, coefficients were provided for four major impact variables:

- Water usage
- Sludge generated
- Hazardous waste generated
- Electricity use

(The coefficients for the remaining combinations of processes and impacts were not statistically significant at the relatively lenient 10% significance level.)

The coefficients measure the average amount of each impact variable generated for every dollar of sales from a specific process. For example, the study found that, based on the data from the survey, a metal finishing shop running a zinc plating operation in 1998, performing at the industry average, could expect to discharge 4.9 gallons of wastewater for every dollar of sales from the zinc line. For the many shops whose sales were primarily from some mix of those six processes, we could calculate from their total sales dollars what their expected total wastewater generation rate would be if they were an average shop. By comparing that expected number with the actual number they provided, we could tell them how they compared with their peers. We could also look for other characteristics of the top performing shops that might indicate what methods or equipment might be particularly effective. The findings are listed in the 2000 report.

PRIM Survey Data

The goal of the PRIM (**P**2 **R**esearch and **I**mplementation for **M**ichigan Metal Finishers) project is to eliminate the information barriers that currently impede the metal finishing industry's ability to implement innovative pollution prevention (P2) technologies and techniques. As part of this initiative, the project is assessing the current environmental performance level of the industry, compared to the information gathered in the 2000 study. A survey was distributed to 600 shops (including members of the NASF nationwide, as well as metal finishers located in Michigan). Participants were given the option of mailing back a paper form, or replying on-line.

As of September 30, 2017, complete surveys have been received from 31 metal finishing facilities (14 paper and 17 on-line). The data collected so far are sufficient to permit some meaningful comparisons between shops responding today and shops in the 2000 study survey, although it does not represent a large enough sample to duplicate the statistical analysis carried out for the 2000 study report.

One way to compare data from the current survey with the 2000 results is to make use of the regression coefficients calculated during the earlier study. The method can be applied to shops whose process mix is dominated by the six processes identified in the 2000 study that had statistically significant coefficients. In such cases, we can use the regression coefficients together with the 2017 sales data to estimate what impact we would expect from a shop if it were performing like the average shop in the 2000 data. We can then compare that number with the actual reported impact, and see whether the shop in 2017 is doing better than, worse than, or about the same as, the average shop in the 2000 data set running the same mix of processes. For 14 of the shops responding to the 2017 survey, 60-100% of their sales were generated by some combination of the six processes.

In order to approach an apples-to-apples comparison, we need to consider how quantities calculated with data from 1998 might have changed over time, even if the population being sampled stayed the same. The regression coefficient can be thought of as a ratio, expressed as impact per production unit. We want to use the ratio to determine whether there have been changes in impact over time. Because we're specifically interested in tracking changes in the numerator, impact, over time, we need to keep the denominator constant – a unit of production from the 2017 data needs to correspond to the same amount of product as measured by the 1998 data.

The 2000 study identified sales dollars as the best production unit for our purposes. One contributing factor may be that companies can typically provide much more accurate data, broken down by process, on sales than they can on other measures (such as total square feet plated, or number of employee hours spent). We expect this remains the case, and that sales dollars are still the best metric to use. But while neither the square foot nor the hour has changed noticeably over the past several years, the dollar is never what it used to be. This unavoidably complicates a comparison based on reported dollars.

To convert 1998 dollars to 2017, we can use a standard inflation measure, the Gross Domestic Product implicit price deflator, as provided by the St. Louis Federal Reserve Bank (https://fred.stlouisfed.org/series/GDPDEF/). Comparing indices for the fourth quarters of 1998 and 2017 respectively, we find that according to this measure, we should use a factor of 1.417 to relate a 1998 to a 2017 dollar. Of course, this is an imperfect measure, since price trends in some metal finishing markets might not match that of the economy as a whole. In particularly competitive sectors, where prices aren't keeping up with inflation, a somewhat smaller factor might be appropriate. (Few metal finishers would be expected to command prices in excess of the general economy, so we assume that a case where the appropriate factor would be greater than 1.417 is unlikely to arise.)

We also need a way to account for that portion of a shop's production that is not included among the six processes with usable coefficients. We assume that, whatever other processes a shop might run, their contributions are small or diverse enough that the average impact per unit due to all of the processes that aren't one of the six works out to about the same as the average impact per unit of the processes that are among the six. That means that the estimated impact can simply be scaled up. Thus if, for example, if we calculate a shop's expected impact due to the processes among the six, and if this represents 90% of the shops production, we would estimate the shop's total impact for all processes to be 100%/90% = 1.11 times the impact estimated for the six processes.

With those two provisos, we are ready to calculate expected vs. actual values for fourteen of the shops in the 2017 data set. Table F-1 lists the regression coefficients from the 2000 study (covering data from 1998) for the six processes and for four environmental impact variables:

- Wastewater discharge (total annual, in gallons).
- Sludge generation (total annual, in pounds).
- Hazardous waste sent to landfill (total annual, in pounds).
- Electricity used (total annual, in kilowatt-hours).

In each case, the table also provides the values of the coefficients when they are rescaled from 1998 to 2016 dollars, as explained in the previous section. The rescaled coefficients measure the expected impact due to each dollar of sales in 2016 if companies' environmental performance were the same on average as companies' performance in 1998, and the only difference between the two time periods were the value of the dollar. (Note that the rescaled coefficients are smaller. Since the same quantity of plated product commands more dollars in 2016 than in 1998, the impact from producing that quantity is being spread over more dollars, so the impact per dollar of sales is lower.)

A typical example can be used to show how the coefficients are used, along with the data from the current study, to generate an estimate of the total annual impact that would be expected from each shop's process mix if they were performing at the average level of shops in the 1998 data set. We

will work through the expected wastewater generation rate for one representative company from the 2016 data set. The calculations are similar for all of the remaining impact variables and companies.

So for example in the case of facility #16, 95% of sales in 2016 were from processes among the six with coefficients (80% from decorative chrome, 10% from nickel, and 5% from zinc), and 5% from another process not included among the six. Their sales total in 2016 was $2,728,500. To find the facility's "expected" wastewater discharge for 2016, the calculation would proceed as follows:

80% chrome sales in 2016 x $2,728,500 total sales = $2,182,800 from chrome.

From Table 1, each 2016 sales dollar would generate 1.603 gallons of wastewater from shops performing at the 1998 average.

$2,182,800 x 1.603 gallons/2016$ = 3,497,948 gallons expected from chrome sales.

Similarly:

10% nickel sales x $2,728,500 total sales x 1.405 gal/2016$ = 383,310 gallons expected from nickel.

5% zinc sales x $2,728,500 total sales x 3.381 gal/2016$ = 461,321 gallons expected from zinc.

So the total expected flow from processes with coefficients is:

3,497,948 + 383,310 + 461,321 = 4,342,579 gallons

If, as explained above, we assume that the impact per sales dollar due to the remaining process is reasonably close to the average of the other processes, we can scale up the total flow proportionally:

4,342,579 / 0.95 = 4,571,136 gallons

Tables F-2 – F-5 summarize the results of similar calculations for the 14 facilities whose process mix qualifies them for this analysis, applied to wastewater discharge, sludge generation, hazardous waste shipments to landfill, and electricity use.

Table F-1. Regression Coefficients from 2000 Study, Together with CoEfficients Rescaled for 2016 Dollars

	Anodizing, sulf	Cr, decorative	Cr, hard	E'less Ni	Nickel	Zinc	Zinc (barrel)	Zinc (rack)
Average water discharged (gal/1998$)	1.960	2.270	0.200	1.420	1.990	4.790		
Average water discharged (gal/2016$)	1.384	1.603	0.141	1.002	1.405	3.381		
Sludge generation rate (lb/1998$)	-0.015	0.008	0.006	0.005	0.007	→	0.054	0.016
Sludge generation rate (lb/2016$)	-0.011	0.006	0.004	0.003	0.005	→	0.038	0.012
Haz. sludge, land-disposed (lb/1998$)	0.019	0.005	0.002	0.011	0.002	0.025		
Haz. sludge, land-disposed (lb/2016$)	0.013	0.004	0.001	0.008	0.001	0.017		
Electricity use (kWh/1998$)	0.485	0.458	0.536	0.153	0.453	0.514		
Electricity use (kWh/2016$)	0.342	0.323	0.378	0.108	0.320	0.363		

Table F-2. Expected vs. Actual Wastewater Discharged

		WW discharged (gal/yr)		
		expected		actual
		six processes	all processes	all processes
Facility code	5	26,783,076	31,509,501	18,161,271
	8	38,650,520	42,945,022	21,499,016
	10	5,666,156	8,572,097	7,843,215
	11	17,544,909	17,902,968	6,505,652
	13	176,487	176,487	460,000
	14	224,801,270	241,721,795	78,000,000
	15	54,164,677	54,164,677	31,836,146
	16	4,342,580	4,571,137	1,201,450
	17	17,295,761	17,295,761	12,100,000
	18	14,733,882	15,509,349	18,411,421
	19	6,481,251	10,802,085	-
	25	2,090,493	2,986,418	-
	26	18,093,484	30,155,807	25,000,000
	31	2,419,606	3,722,471	1,300,000

Table F-3. Expected vs. Actual Sludge Generated

	Sludge generated (lb/yr)			
	Expected		actual (wet)	actual (dry*)
	six processes	all processes	all processes	all processes
5	123,570	145,377	723,484	289,394
8	437,340	485,933	1,957,600	783,040
10	38,476	58,209	10,640	4,256
11	198,525	202,576	-	-
13	7,513	7,513	6,800	2,720
14	1,189,694	1,279,241	951,401	761,121
15	278,512	278,512	894,900	357,960
16	21,361	22,485	65,800	26,320
17	-193,500	(193,500)	800,000	320,000
18	60,178	63,346	50,682	20,273
19	30,330	50,551	12,000	4,800
25	6,287	8,981	-	-
26	41,034	68,389	106,631	42,652
31	732	1,127	8,000	6,400

Table F-4. Expected vs. Actual Hazardous Waste Shipped to Landfill

	HazWaste landfilled (lb/yr)		
	Expected		actual
	six processes	all processes	all processes
5	127,442	149,932	-
8	197,691	219,656	40,000
10	28,981	43,845	-
11	89,739	91,571	-
13	1,853	1,853	6,800
14	762,979	820,407	82,798
15	126,464	126,464	-
16	10,816	11,385	-
17	164,133	164,133	-
18	97,413	102,540	50,682
19	41,355	68,924	-
25	11,961	17,088	-
26	100,104	166,839	106,631
31	12,348	18,997	-

Table F-5. Expected vs. Actual Electricity Used

	Electricity used (kWh/yr)		
	Expected		actual
	six processes	all processes	all processes
5	3,137,467	3,691,138	3,800,000
8	4,147,467	4,608,297	6,316,929
10	608,018	919,845	483,680
11	1,882,690	1,921,112	1,935,293
13	472,986	472,986	440,000
14	38,267,119	41,147,440	25,400,000
15	10,928,380	10,928,380	5,053
16	842,512	886,855	841,093
17	4,279,818	4,279,818	7,200,000
18	1,584,457	1,667,849	2,240,160
19	868,445	1,447,408	960,000
25	236,581	337,973	380,000
26	3,183,832	5,306,387	3,575,415
31	270,686	416,440	134,000

Preliminary Conclusions and Questions:

To assist in interpreting the results, the information from the tables is presented in graphic form below. In each case, the expected impact from each facility is depicted as a yellow bar. Immediately to the right of each bar, a second bar shows the actual reported impact from that facility. These bars are colored either green or red, depending on whether the actual impact is better or worse, respectively, than expected.

As is apparent from the graphs, this comparison indicates that almost all of the facilities did significantly better – in some cases dramatically better – in wastewater discharged per sales dollar than would have been expected from the average performance of shops in 1998. The results for sludge generation and for electricity usage are mixed. (Fewer shops were able to provide information on hazardous waste shipments, so this impact variable was not graphed.)

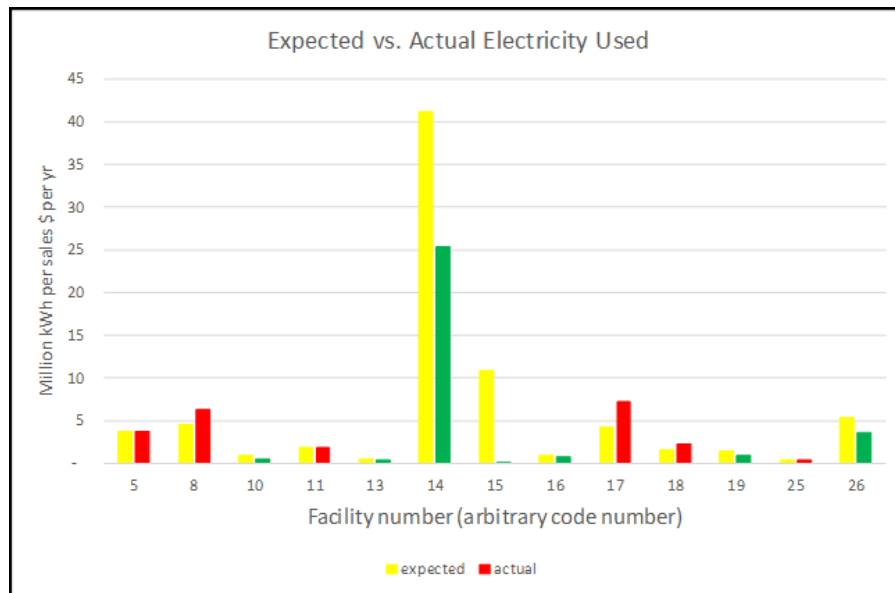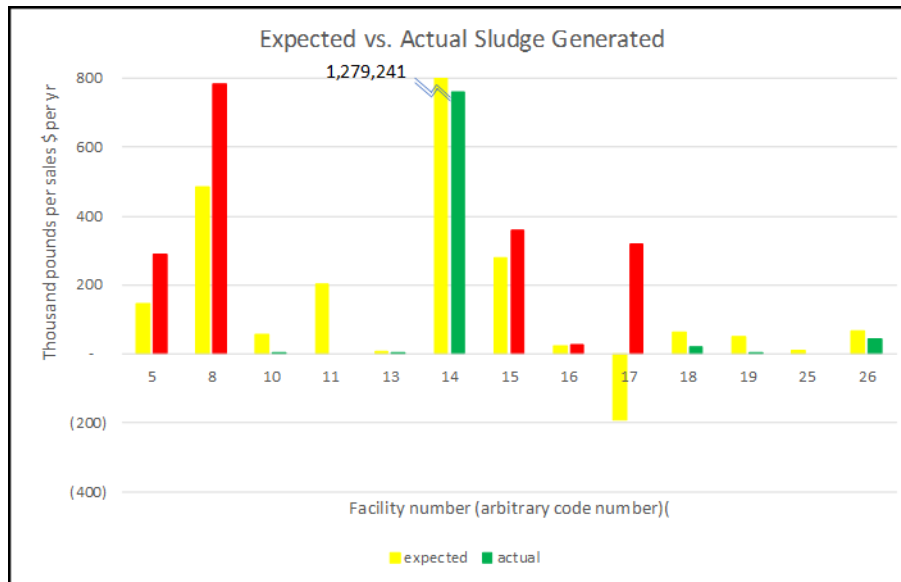As described above, two of the steps in the calculation, the inflation adjustment and the scale-up for processes without coefficients, introduce some unavoidable uncertainty into the analysis. If, for example, all of the impact variables were showing systematic improvement, the apparent trend could be due to an inappropriate choice of inflation factor. The fact that sludge generation and power usage do not follow the same trend suggests that the inflation factor is not introducing a systematic bias. As far as the scale-up is concerned, inspection of Table F-2 indicates that, in many cases, the actual wastewater generation rate is below what would be expected if the processes without coefficients hadn't even been running (i.e., compared to what the expected impact would have been before it was scaled up). The conclusion that shops represented in the 2016 data set have actually improved their wastewater reduction practices, compared to shops in 1998, seems reasonably robust.

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Expected vs. Actual Sludge Generated

Expected vs. Actual Electricity Used
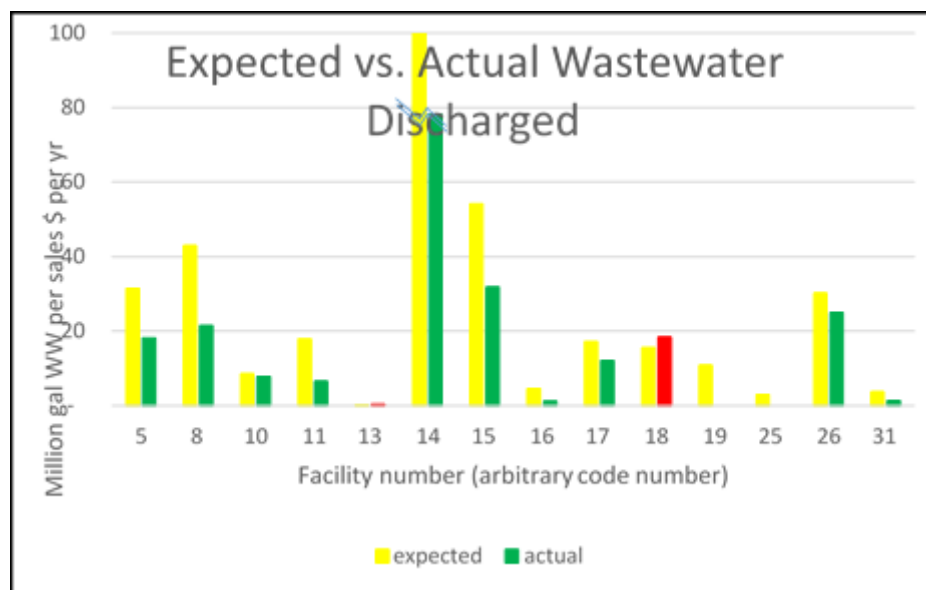
Next Steps

This preliminary analysis suggests several questions that may warrant further investigation during subsequent stages of the project. For example:

- What factors might be associated with the apparent overall improvement in water consumption over the past two decades? Possibilities might include economic factors (such as increasing water and/or sewer rates), or factors associated with regulatory or reporting requirements.

- Why have improvements in water consumptions not been matched by corresponding improvements in electricity use and sludge generation rates? Have electricity rates and sludge disposal costs increased less rapidly than costs associated with water use and wastewater disposal? In the case of sludge generation rates, do metal finishers perceive less regulatory emphasis on minimizing solid waste than on minimizing wastewater disposal?

- Is it possible that improvements in water consumption and discharge rates are associated with factors that mask improvements in the other impact measures? Better sludge removal might be improving the quality of the wastewater, easing the treatment load for the POTW, but at the cost of generating that much more sludge. Better wastewater treatment might also be associated with somewhat higher power consumption.

It may also be worthwhile at this stage of the project to try to understand why the response rate for the 2017 survey fell below that for the 2000 study. Factors might include changes specific to the industry (such as increasing fragmentation as manufacturing moves offshore), as well as a general "survey fatigue" that is not restricted to metal finishing. The fact that the 2000 study was conducted in the context of the Strategic Goals Program (SGP), an EPA initiative that offered regulatory recognition for targeted improvements, might also have given participants in the earlier study additional incentive to cooperate. It may not be possible to recreate under current circumstances the conditions that boosted the response rate two decades ago, but it may be worthwhile to understand the extent to which sector-based voluntary programs like SGP can help promote sector-wide cooperation in pollution prevention efforts.

Appendix G – Capsule Report: Coventya Zn/Ni 3S Technology

Demonstration of the Coventya Zn/Ni 3S Technology

Introduction

This capsule report was prepared under EPA Grant Number 00E02050, funded through the EPA Source Reduction Assistance Grant Program. This program funds Pollution Prevention (P2) assistance projects that provide technical assistance and/or training to businesses/facilities to help them adopt source reduction approaches.

Various tasks have been performed under this EPA grant. The purpose of this particular project was to demonstrate the Coventya 3S Technology, which is a zinc/nickel electroplating bath maintenance system. The project focused on the potential reduction of water use, reduction of discharges to the wastewater treatment system, and reduction of energy use.

Background Information

The technology uses a porous barrier to divide the bath into an anode and cathode compartment. Electrolyte is recirculated through the anode compartment, which is maintained at a head slightly above that of the cathode compartment, allowing a slow continuous flow of electrolyte. In this configuration, possibly assisted by ion-selective permeability of the barrier, the migration of organic components present in the cathode compartment into the anode compartment is impeded. In ordinary zinc/nickel baths, these compounds are oxidized when they reach the anode, forming cyanide and undesirable carbonates. The 3S technology avoids production of these contaminants. In addition, preventing unwanted side reactions should increase current efficiency, and recirculating anode electrolyte should draw heat away from the bath, reducing power requirements of plating and cooling.

A plating facility, located in Chicago, had the 3S technology installed and by 2018 was fully operational. The same facility is still running a conventional zinc/nickel process on a nearby plating line, using a process designated "160" by the facility. Data were obtained concurrently from both processes, enabling a side-by-side comparison on several key performance factors, including generation rate of unwanted by-products, power requirements for plating and cooling, and water consumption.

Data provided by the Chicago facility include comparisons of power consumption, concentrations of selected bath components and contaminants, and water consumption between the 3S and the 160 processes, and the makeup rate for anolyte (sodium hydroxide solution circulating through the anode compartments). The data for each performance factor are presented in summary tables, followed by a brief discussion.

Power Consumption

Two test runs compared power consumption, normalized per pound of product, between the 3S and 160 processes. In both cases, the 3S process was found to have a measurable savings of 10-12% in total electric energy per pound of product required, compared to the conventional process.

Electrical (Amps/Lb.)				Electrical (Amps/Lb.)		
Test Run No. 1				Test Run No. 2		
	3S (315)	160			3S (315)	160
Load Size	221	194	Load Size		251	226
Avg. Voltage used	13	13	Avg. Voltage used		13	13
Plate time (minutes)	117	117	Plate time (minutes)		117	117
Amp/Barrel Used	600	600	Amp/Barrel Used		600	600
Amps/lb. (Barrel)	2.71	3.09	Amps/lb. (Barrel)		2.39	2.65
Amp-Hrs./Barrel Used	1,170	1,170	Amp-Hrs./Barrel Used		1,170	1,170
Amp-Hrs./Lb. Used (1 Barrel)	5.29	6.03	Amp-Hrs./Lb. Used		4.66	5.18
Power saved	12%		Power saved		10%	

Bath Composition

Sample Date	Carbonates (oz/gal)		Zinc (oz/gal)		Nickel (mg/l)		Cyanide (mg/l)	
Lab 1	315-3S	160	315-3S	160	315-3S	160	315-3S	160
7/20/2018	3.36	3.90	0.55	1.20	402	1,620	?	?
7/27/2018	4.20	4.50	0.90	1.01	850	1,880	?	?
8/2/2018	2.66	4.42	0.53	0.63	440	1,510	?	?
8/14/2018	2.83	4.60	0.61	0.91	1,010	1,990	?	?
8/23/2018	1.95	4.60	0.77	1.06	942	1,780	<49.4	148
8/29/2018	2.30	3.36	0.45	1.15	815	1,990	<49.4	98.7
mean	2.88	4.23	0.64	0.99	743	1,795		
std dev	0.80	0.50	0.17	0.21	259	198		

Lab 2	315-3S	160	315-3S	160	315-3S	160	315-3S	160
7/20/2018	8.0	8.1	1.2	1.6	530	1,470		36
7/27/2018	8.5	9.8	1.2	2.1	710	1,760	ND	10
8/2/2018	5.4	10.2	1.3	1.7	702	2,010	ND	51
8/14/2018	8.3	9.5	1.0	1.4	890	2,080	ND	8
8/23/2018	8.4	11.0	1.2	1.9	815	1,990	ND	25
8/29/2018	8.1	10.1	1.3	1.7	980	2,250	ND	
mean	7.78	9.78	1.20	1.73	771	1,927		
std dev	1.18	0.97	0.11	0.24	159	274		

Lab 3	315-3S	160	315-3S	160	315-3S	160	315-3S	160
7/20/2018			1.35	1.38	660	1,890		
7/27/2018			1.52	1.49	900	2,350		
8/2/2018			1.42	1.41	1,140	1,730		
8/14/2018			1.42	1.52	1,120	1,690		
8/23/2018			1.25	1.50	985	1,850		
8/29/2018			1.40	1.45	980	2,250		
mean			1.39	1.46	964	1,960		
std dev			0.09	0.05	175	275		

Both the 3S and the 160 baths were sampled on six occasions between July 20 and August 29, 2018. Samples were analyzed by three different laboratories (a commercial laboratory, Coventya, and the facility's in-house laboratory) for zinc and nickel, and by two of the laboratories for cyanide and carbonates.

Within each laboratory's data set, the data are generally consistent, and exhibit the expected differences between the two baths. Concentrations of all components are lower in the 3S bath. The primary reagents, zinc and nickel, are maintained at a lower concentration by design, and the contaminants, cyanide and carbonates, are being generated at a lower rate (in the case of cyanide, non-detectably) in the 3S bath, as intended.

When data from the laboratories are compared with each other, several questions emerge. If the samples sent to each laboratory were split from the same bath sample, closer quantitative agreement would be expected. The fact that each data set shows the same pattern may indicate, for example, a difference in reported units. More puzzling is the lack of correlation: if one laboratory's result for a particular sample date is particularly low compared to that laboratory's mean for all six samples, each of the other laboratories should also show a low value for that sample compared to its own mean for the six samples. That does not appear to be the case.

Water Consumption

When data from the laboratories are compared with each other, several questions emerge. If the samples sent to each laboratory were split from the same bath sample, closer quantitative agreement would be expected. The fact that each data set shows the same pattern may indicate, for example, a difference in reported units. More puzzling is the lack of correlation: if one laboratory's result for a particular sample date is particularly low compared to that laboratory's mean for all six samples, each of the other laboratories should also show a low value for that sample compared to its own mean for the six samples. That does not appear to be the case.

	315-3S		160		Gallons used per pound produced	
Date	Prod (lb)	gal	Prod (lb)	gal	315-3S	160
6/18/18 - 6/29/18	161,100	3,474,814	92,237	159,440	21.6	1.7
7/1/18 - 8/31/18	630,987	10,427,650	391,592	676,224	16.5	1.7

Potential Savings

Assuming that the production volume during the two-month period 7/1/18 – 8/31/18 in the water consumption table is representative of the annual production rate, yearly production of the 315-3S product would be 5,047,896 pounds. From these totals, it is possible to project annual savings in power consumption and wastewater treatment costs. The comparison will be based on the expected impact of producing 5,000,000 pounds of product using the 3S process with the corresponding impact expected had the same amount of product been produced with the 160 process.

For electric power, using test run #2 above for the more conservative estimate, annual production using 3S would consume 5,000,000 lb * 4.66 amp-hr/lb * 13V = 302,900 kWh, compared to 5,000,000 * 5.18 * 13 = 336,700 kWh, a savings of 33,800 kWh. The total average industrial rate for

electric power in Illinois in 2018 was 6.04 cents per kWh[3], so that the total annual cost savings for power would be $2,042.

For wastewater, the estimate is complicated by the variety of factors that contribute to the cost of treatment and disposal. Different pollutants require different levels of treatment. Cyanide treatment requires an oxidation step, which can presumably be avoided if the wastewater contains no detectable cyanide. Because the 3S bath has half the nickel concentration and substantially lower zinc concentration than the standard bath, the wastewater would be expected to have correspondingly lower concentrations of both metals. The average cost for wastewater treatment and disposal as indicated by a recent survey is found to be $13.85/1000 gallons. Assuming the water consumption figure for the 160 process (1.7 gallon/lb) is representative of what the 3S process will ultimately consume, production of 5,000,000 pounds would require treatment and disposal of 8,500,000 gallons, at an estimated cost of $117,725. If the absence of cyanide and the lower metal ion concentration amounted to as little as 10% cost reduction, the total wastewater treatment and disposal cost savings would be over $10,000/year.

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[3] Data from Edison Electric Institute, Typical Bills and Average Rates Report - Winter 2018, available at https://www.rockymountainpower.net/about/rar/ipc.html

Appendix H – Capsule Report: Innovative Rinsing

Introduction

This capsule report was prepared under EPA Grant 00E02050, funded through the EPA Source Reduction Assistance Grant Program.

Various tasks have been performed under EPA Grant 00E02050. The purpose of this particular project was to implement a methodology for evaluating and improving rinsing practices at electroplating facilities. The methodology was developed was under a separate task of the EPA pollution prevention project and is referred to as the *Rinsing Manual*. It is publicly available on Surface Technology Environmental Resource Center (STERC) at http://www.sterc.org/subs/rinseman.php.

Overall, the *Rinsing Manual* methodology consists of five steps:

1. Establish a baseline through data collection and by evaluating existing rinse systems.
2. Evaluate alternative methods of improving rinsing.
3. Implement changes.
4. Measure results, calculate savings.
5. Institute a program of continuous monitoring and recordkeeping.

To test the methodology, a project was performed at a Michigan electroplating shop. The facility agreed to allow a team to assess their operations and develop recommendations for improvement. The facility had the option of implementing any or all of the recommendations and they were responsible for any costs associated with the implementation.

An automated zinc/nickel (Zn/Ni) electroplating rack line was selected for evaluation. A baseline for the rinse systems was established using both historical data and new measurements. Alternative methods of improvement were evaluated and recommendations for improving rinsing were developed and communicated to shop management. Some of the recommendations were implemented by the facility. Following implementation, the plating line was re-evaluated and savings were estimated. The results are presented in this capsule report.

Facility Description

The *Rinsing Manual* protocols were tested at an electroplating facility in Michigan. This shop has various electroplating processes, including the automated Zn/Ni rack line that was evaluated during the project. The Zn/Ni line consists of 18 tanks including cleaners, electroplating, conversion coatings, sealer, rust inhibitor and rinse tanks. The line is normally operated 7 days a week, 24 hours per day. Various automotive parts are plated on the line, including tubular parts and various sized flat and angled parts. A photograph of the Zn/Ni line is shown in Figure H-1.

Figure H-1. Automated Zinc/Nickel Rack Plating Line

Baseline Evaluation

Using the methodology found in the *Rinsing Manual*, a baseline evaluation of the Zn/Ni line was performed. The information from that evaluation is presented in this section.

Tank layout. A diagram of the plating line is shown in Figure H-2. Unplated parts are racked at Station 101. There are two racks used per load. Different rack configurations are used, depending on the shape and size of the parts being plated. Once the racks are loaded, a hoist raises the two racks from the load station, moves them horizontally to the soak cleaner (Tank 101) and lowers them into that tank. The racks remain in the soak clean for approximately ten minutes. During this time period, the hoist is busy moving other sets of racks through the process. After ten minutes, the hoist returns to Tank 101 and transports the racks to the next tank in sequence (Tank 102: Electrocleaner). From start to finish, the process takes approximately 1.5 hours. Typically, there are eight sets of racks being processed through the line at any given time.

Each tank has one station (a station holds one set of two racks) with the exception of Tank 110, the Zn/Ni plate tank, which has four stations. A larger number of stations are needed in this tank because the racks are retained there for about 45 minutes to allow a sufficient thickness of Zn/Ni electrodeposit to occur.

Rinse systems. Rinsing is performed in two and three-stage counterflow immersion rinse systems. Two spray rinses are located above two of the immersion rinse tanks (111, 118).

The counter flow rinses are well designed. Incoming water lines are located in the second rinse of each system (3rd rinse tank in the case of the 3-stage system). Flow restrictors are present on incoming water lines, limiting the flow to 3 gpm per rinse system. Incoming water is dispersed in the 2nd rinse by air agitation and it overflows a weir to the first rinse. The first rinse is also mixed by air agitation. Water exits the first rinse via a weir and is conveyed by gravity flow to the wastewater treatment system.
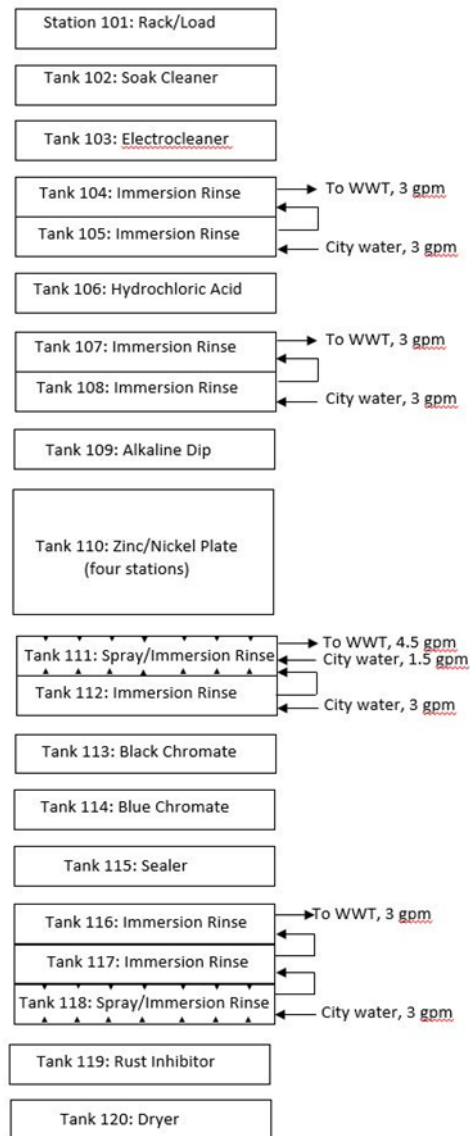
Figure H-2. Zinc/Nickel Electroplating Line

Tank 111, the first rinse following Zn/Ni plating, had an auxiliary incoming water line that did not have a flow restrictor. The flow rate was variable during the study, but averaged 1.5 gpm. This additional water is used to keep the first rinse sufficiently low in conductivity.

Air Agitation. Air agitation is achieved using a blower. Air is conveyed into each rinse tank via PVC piping that is run down the side of each rinse tank and across the bottom of the tank. Small holes are drilled in the bottom PVC pipe that evenly distribute the escaping air and causes mixing as the bubbles float to the surface of the tank. Air flow to each rinse tank is controlled by a hand valve. Although air agitation is available for each rinse tank, it was observed to be inadequate in most tanks. Using an arbitrary 0-5 scale (5 being the best), only one tank received a score of 5 (Tank 118). Scores for the other tanks ranged from 0 to 3. Figure H-3 compares the air agitation of Tank 111 (score of 1) and Tank 112 (score of 4).

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Figure H-3.   Visual Comparison of Tanks with Poor (left) and Good (right) Air Agitation

In part, poor air agitation at this shop was a result of precipitated solids building up on the bottom of the rinse tanks. In some cases, a sludge blanket completely covered the air agitation piping on the bottom of the tank and prevented air from being released.

Dragout. The volume of dragout from the Zn/Ni tank (110) that enters the rinse system (Tanks 111/112) was measured using the procedure outlined in the *Rinsing Manual*. The measurements were conducted for this tank only, because, due to its high metal content, it contributes much more significantly to WWT sludge generation than the dragout from the other tanks on the plating line. Test results indicated that the dragout from Tank 110 is 1.02 gph. On the average, 4.9 rack sets (9.8 racks) are processed per hour. Therefore, the dragout rate per rack set is 0.21 gal.

Dwell time in rinse tank. The programming of the hoist allows for sufficient dwell time in the rinse tanks. A minimum of 3 minutes of dwell time was observed. In most cases, dwell time was longer than 4 minutes.

Rack withdrawal rate. The rack withdrawal rate was the same speed for all process and rinse tanks, 1 ft./sec.

Drain time. The plating hoist is programmed to drain racks over most of the process tanks for 2 seconds after being removed from the tank and before traveling to the next station, which takes an additional one second. The only exception is Tank 110 (Zn/Ni plate), where the drain time is set at 8 seconds (measured from when rack is out of the bath to moving). Travel time is 1-3 seconds for Tank 111, depending on the starting position.

Observations and testing made during the survey indicated that the drain time is too short. This is especially the case for the Zn/Ni tank. The Zn/Ni solution is very viscous, causing the solution to drain off slowly. The racks and parts are still significantly dripping when they are moved to the first rinse (111), as shown in Figure H-4.

Figure H-4. Dragout Still Draining Just Prior to Rinsing

Conductivity of rinse water. The conductivity of rinse water is measured regularly by the facility. Average conductivity values for a five month time period are shown in Table H-1. The measurements are presented in both microsiemens/centimeter (μs/cm) and millisiemens/centimeter (ms/cm). Note that 1,000 μs/cm equals 1 ms/cm.

Rinse efficiency. Rinse efficiency was measured using the method described in the *Rinsing Manual.* The manual defines rinse efficiency as C1/C2, where:

- C1 = the conductivity of the water remaining on the rack or parts after rinsing
- C2 = the conductivity of the rinse tank water

Table H-1. Rinse Tank Conductivity Measurements

Rinse Tank	Average Conductivity (five months) (μs/cm)	Average Conductivity (five months) (ms/cm)
104	1,390	1.390
105	280	0.280
107	9,320	9.320
108	410	0.410
111	3,620	3.620
112	360	0.360
116	850	0.850
117	300	0.300
118	260	0.260

Under ideal conditions, C1/C2 = 1. However, testing performed under this EPA P2 project showed that the ratio of C1/C2 is usually above 2.0, and can be much higher.

C1 was measured by capturing the drips of water coming off of the rack and parts after being removed from a rinse tank. This was accomplished using a four foot section of 3-inch PVC pipe that was cut lengthwise and capped on the ends. When the rack was lifted from the rinse tank, the pipe was held under the rack and it captured the dripping water (Figure H-5). The sample (C1) was then measured for conductivity. A sample of the rinse tank was also taken and measured for conductivity (C2).

Results of the rinse efficiency study are shown in Table H-2, for Tanks 104 and 111. In each case, the test was performed twice, with air agitation set at 0 and 4, using the arbitrary scale described above. In each case, rinse efficiency improved significantly with good air agitation. The range of improvement was 23.5-45.2%.

Figure H-5. Sampling Drainage After Rack Removed From Tank

Table H-2. Measurements of Rinse Efficiency

Rinse Tank	Air Agitation 0-5 scale	C1 ms/cm	C2 ms/cm	C1/C2	Improvement Due to Increased Air Agitation
104	0	2.42	0.78	3.1	-
104	4	1.33	0.77	1.7	45.2%
112	0	0.78	0.23	3.4	-
112	4	0.57	0.22	2.6	23.5%

Spray rinsing. Spray rinses are present on two rinse tanks (111 and 118). They were fabricated in-house using 1-inch PVC pipe and spray nozzles. The spray bars, with seven nozzles per side, are mounted on the lip of the rinse tanks. They are automatically activated for six seconds by a momentary switch when the rack is lifted from the tank. Each nozzle deliveries 0.06 gal of fresh city water per cycle. Therefore, the set of 14 nozzles delivers 0.84 gal per cycle. The spray rinse system is shown in Figure H-6.

A semi-quantitative test was performed at Tank 111 to see if the spray rinses were effective. Immediately following a spray event, the drips from the rack/parts were collected and the conductivity was measured as was the conductivity of the rinse tank. The conductivity of the rinse tank was 0.57 ms/cm. However, the conductivity of the drips was 4.53 ms/cm, indicating that the sprays were very effective in removing dragout from the racks/parts that the immersion rinse left behind.

Figure H-6.   Spray Rinse on Tank 111

Drip/drain boards. No drip boards were present on the plating line. This was especially apparent between Tank 110 (Zn/Ni plate) and Tank 111 (rinse tank), where a buildup of chemicals occurred on a PVC pipe covering tank busing and on the tank lip (Figure H-7). Some of the dragout falling in that zone flowed into the rinse tank, which increases the need for rinse water. As mentioned previously, a separate incoming water line was needed to maintain a sufficiently low conductivity in Tank 111.

*Figure H-7.   Buildup of Chemicals Occurs Between
Tanks Due to Lack of Drip/Drain Board*

Plating racks. The plating racks used at this facility are generally not conducive to good drainage. Most racks are designed such that parts are hung directly above other parts, thus increasing the path that dragout flows before returning to the process tank. As a result, dripping continues to occur for multiple seconds longer than necessary. Considering the short drain times used, a significant amount of dragout enters the subsequent rinse tank.

Poor rack maintenance is also contributing to increased dragout (Figure H-8). On many racks, the plastisol rack coating is damaged causing process chemicals to collect between the rack frame and coating. The trapped solution does not drain freely and is carried over to the next tank. This causes a need for higher rinse flow rates and contaminates subsequent process tanks.

During the study, a drainage sample was collected after a rack with damaged rack coating was removed from Tank 111. The sample had a conductivity of approximately 10 times greater than samples collected from undamaged racks exiting the same rinse tank. Obviously, the Zn/Ni solution (Tank 110) had entered the space between the rack and rack coating and was not completely removed by rinsing.

Other data identified by the *Rinsing Manual* protocols are shown in Table H-3.

Figure 8.   Rack Maintenance Issues

Table 3. Additional Shop Data

Item	Cost or Quantity
Water/sewer cost ($/1,000 gal)	$10.42/Kgal
Water Use, Kgpy	6,080 Kgal/yr
Wastewater treatment cost, $/Kgal	$10.28
Sludge generation	18,600 lbs/yr
Sludge disposal cost, $/lb	$3.36/lb

Evaluation and Recommendations

The facility requested that the P2 project focus on two main objectives:

- Reducing water use.
- Reducing wastewater sludge generation.

With these objectives in mind, evaluations of current rinsing and dragout were performed with a focus on the Zn/Ni bath (Tank 110) and the subsequent rinse system (Tanks 111 and 112).

Rinsing. The current rinse system (Tanks 111 and 112) was compared to an ideal system using the STERC Rinse Systems Calculator. The STERC calculator uses widely accepted formulae for multiple tank rinse systems, but the results are based on idealized conditions. The performance of actual rinsing systems depends on the rinsing efficiency of the tanks, the variability of the introduction rate of drag-out and other factors. In short, few real-world rinsing systems will perform as indicated; most will require a significantly higher rinse water flow to maintain a given criterion.

Using the STERC Calculator, it was determined that the theoretical flow rate of water needed to maintain the current rinse cleanliness is only 0.74 gpm. This is a small fraction of the current water use, which is 4.5 gpm.

The large discrepancy between theoretical and actual water use is likely due to several factors:

- There are two water inlets to the Tank 111/112 rinse system, 3.0 gpm flowing into Tank 112 and 1.5 gpm flowing into Tank 111. The flow into Tank 111 is short-circuiting the counter flow system. For maximum effectiveness, all incoming water should be entering Tank 112.

- Rinse efficiency is hindered due to poor air agitation in Tank 111. This is mainly due to a buildup of solids in the bottom of the rinse tank.

- Damaged rack coatings retain concentrated solution even after rinsing in Tank 111. Therefore, the dragout from Tank 111 into Tank 112 is much higher than with well-maintained racks.

- Large tubes, which are frequently plated on this line, retain solution on the inside diameter which is not removed by the spray rinse.

Dragout. The drainage time and dragout rate following Zn/Ni plating were closely observed. Dragout was collected after the racks were lifted from the Zn/Ni bath, during the draining period (8 seconds) and travel period (1 to 3 seconds). The volume of solution collected during each interval was then measured. This information, together with a model of how the volume of solution dripping from the racks is expected to change with time, can be used to provide an estimate of the amount of dragout that could be avoided with a longer drip time.

A graph of drip volume versus time was published by the Beckman Instrument Company, and was reproduced in an EPA report (*Meeting Hazardous Waste Requirements for Metal Finishers*, EPA/625/4-87/018, September, 1987, p. 25)[4]. The graph appears here in Figure H-9. It shows three curves, one for vertical sheets, another for horizontal surfaces, and an intermediate case. The graph indicates the rate at which solution was observed to drip from each of the surfaces, so that the area

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4 Available on-line at https://nepis.epa.gov/Exe/ZyPDF.cgi/300048GM.PDF?Dockey=300048GM.PDF
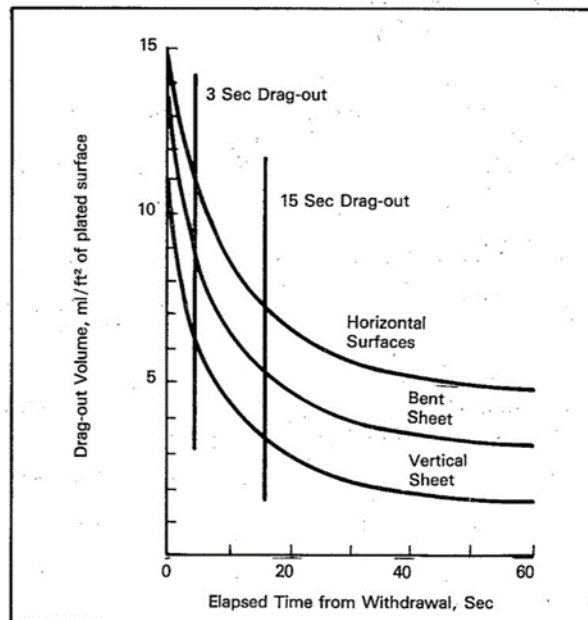
Figure H-9.   Drainage vs. Time Graph for Zn/NI
(from Beckman Rinse Tank Control Handbook)

under each curve between two points in time represents the total volume which would be collected during that time interval. This makes it possible to adjust the curve to the measured volumes, and to read from the curve the volume of dragout that could be decreased by increasing the drip time over the bath.

In order to apply these curves to the data collected during operation of the facility's Zn/Ni line, it proved helpful to develop a mathematical model which reproduced the curves. The model is a formula that reproduces the shape of the curves, but include adjustable parameters that allow the curve to match the specific characteristics of the process being studied. Adjustments are necessary to account for the dependence of drip rates on solution viscosity, as well as on the particular shapes of the parts being plated. But using the model ensures that the qualitative behavior of the adjusted curves will match that of the Beckman graph.

Details of the model may be found in the Appendix. The results indicate that, in the case of the process measured here, a reduction of about 30-35% in avoidable dragout would be expected if the drip time over the plating tank were increased by 10 seconds.

Options for Improving Rinsing

Using the *Rinsing Manual* as a guide, various options for improving rinsing on the Zn/Ni line were evaluated. The most effective and viable options are discussed in this section.

1. **Establish a schedule for cleaning out precipitated solids from rinse tanks.** Solids collect at the bottom of rinse tanks and impede the flow of air from the PVC pipe running along the bottom of the tank, thereby reducing air flow and mixing. A schedule should be established for cleaning the rinse tanks. The most affected tanks, typically the first rinse tank in series (e.g., Tank 111), will likely require cleaning every 1-3 months. The second and third rinse of each counterflow system can be cleaned less frequently (6-12 months). Any parts that have fallen off the racks should be retrieved when rinse tank cleaning is performed.

2. **Improve air agitation**. Air agitation on the line was observed to be generally poor. Tests performed during the study showed that with improved air agitation, rinse water use could be substantially reduced. The existing air blower may be sufficient for increasing air agitation to Level 4 for all rinses. A higher air agitation rate (5) may be possible, but could result in parts being dislodged from the racks. Light, small parts are more likely to be dislodged than larger heavier parts, such as tubes.

3. **Repair rack coatings**. Some of the racks being used have cracked or broken plastisol rack coatings. Bath chemistry enters these crevices, between the rack and the coating, and significantly increases dragout. Testing showed that the dragout is not well removed by rinsing and it is transferred down the line to subsequent tanks.

    The facility owns roughly around 25 racks. Approximately 20% of these racks require repair. Affected racks could be rotated out of use several at a time and sent offsite for repair. This would prevent having a shortage of racks on-hand. Needed repairs consist mainly of removing the existing rack coating and reapplying a new plastisol coating. Some racks also require repair of contact tips.

4. **Improving racking**. Parts racked directly above one another increase the path that dragout must travel before dripping back into the process tank. When possible, the location of racked parts should be staggered to allow dragout to quickly return to the process tank. This may not be possible for high production parts that require the racks to be fully used.

    When new racks are purchased in the future, the design should take into account the path of dragout to minimize carry over.

5. **Add more spray rinses.** The existing spray rinse on Tank 111 is well designed, it sprays an adequate volume of water at a sufficient velocity to remove dragout from the rack/parts. The spray rinse contributes only 100 gpd of wastewater, which is very small in comparison to the tank 111/112 immersion rinse system (4,320 gpd). The benefit of the spray rinse was measured by collecting rack/part drips after the rack was removed from the rinse tank. This was done with and without the spray rinse being activated. The immersion/spray rinse removed more than twice as much dragout than the immersion rinse alone. The water spray impinges the surface of the rack/parts and removes drag-out that otherwise would be carried over to the next tank.

    Only two rinse tanks on the Zn/Ni line have sprays, Tanks 111 and 118. In both cases, the spray is activated automatically (momentary switch) when the rack is removed from the rinse tank. It is recommended that spray rinses be added to all other first rinse tanks on the line.

    Adding spray rinses to Tanks 104, 107 and 116 will reduce the need for incoming water that enters the last rinse of each counterflow rinse system. Currently, all flow rates are set at 3 gpm.

6. **Adjust drain time.** The amount of drain time over the process tanks is too short and is causing excessive dragout to enter the subsequent rinse system. Overall, this increases rinse water use because it takes more fresh water to dilute the dragout. Also, it increases WWT sludge generation due to a higher mass of dissolved metal discharged to the WWT system. Following Zn/Ni plate, the rack is held in place for about 8 seconds before traveling to the rinse tank. For all other tanks, the drain time is 2 seconds.

The recommendation is to increase drain times to 20 seconds for Zn/Ni plate and 10 seconds for all other process tanks. More drain time is needed for the Zn/Ni bath due to its higher viscosity.

7. **Double dip rinse**. It is likely that the tubes are not being adequately rinsed by the first rinse following Zn/Ni plating (Tank 111). Although the spray rinse is very effective at removing dragout from outer surfaces, it has little effect on inside diameters. Reprogramming the hoist system to include a double dip into Tank 111 would help remove dragout from these inner surfaces.

8. **Add a drip tray after Zn/Ni.** A buildup of Zn/Ni plating solution sludge is present between the process tank and the rinse tank. Some of the chemicals end up seeping into the rinse tank. This can be minimized by locating a drip tray between the Process Tank (110) and Rinse Tank (111). The tray should be slanted in a manner that causes solution to flow back into the Zn/Ni Tank (110).

   This option will provide a small P2 benefit (water use and sludge generation) by reducing the volume of dragout entering rinse Tank 111. However, it is also a small cost item and it will significantly improve the appearance of the plating line.

Summary of recommendations. Table H-4 lists the recommended improvements for the Zn/Ni plating line and associated costs. Table H-5 shows the potential savings/impacts.

In addition to these cost savings, the maintenance of rinse tanks, etc. will likely provide improved work quality, and fewer rejects. These savings could not be determined during the project.

Table H-4. Costs to Implement Recommendations

Recommendation	Description	Cost to Implement
1. Clean out precipitated solids from rinse tanks based on established schedule	Develop schedule based on observations. Rinse following Zn/Ni plating will likely be 1-3 mths. Other rinses likely to be 6-12 mths. Cost is labor for one year.	$2,000/yr
2. Improve air agitation	Increase air flow to rinse tanks. Use maximum air flow that does not dislodge parts from racks.	$0
3. Repair rack coatings	Repair plastisol coatings on 12 racks.	$6,000
4. Improve racking procedure	When possible, instruct staff to arrange parts on racks in a manner that improves dragout drainage.	$0
5. Add more spray rinses	Add spray rinses to rinse tanks 104, 107 and 116.	$2,700
6. Adjust drain time	Reprogram automated hoist system to increase drain time to 15 sec. for all process tanks, except Zn/Ni plate, which should be set at 20 sec.	$10,000
7. Double dip in rinse tank 111.	Reprogram automated hoist system to double dip in rinse tank 111.	Cost included in item 6.
8. Add a drip tray after Zn/Ni	Fabricate and install a drip tray between tanks 110 and 111.	$800

Table H-5. Estimated Potential Savings From Recommended Changes

Recommendation	Water/Sewer		Sludge Transportation/ Disposal		Zn/Ni Process Solution		Total Savings
	Kgal/yr	$/yr	Lbs/yr	$/yr	Gal/yr	$/yr	$/yr
1. Clean out precipitated solids from rinse tanks based on established schedule	608	$12,586	0	$0	0	$0	$12,586
2. Improve air agitation	1,216	$25,171	0	$0	0	$0	$25,171
3. Repair rack coatings	912	$18,878	1,395	$4,687	1,395	$4,185	$27,751
4. Improve racking procedure	304	$6,293	465	$1,562	465	$1,395	$9,250
5. Add more spray rinses (tanks 104, 107 and 116)	454	$9,390	0	$0	0	$0	$9,390
6. Adjust drain time	680	$14,084	2,790	$9,374	2,790	$8,370	$31,828
7. Double dip in rinse tank 111.	227	$4,695	930	$3,125	930	$2,790	$10,610
8. Add a drip tray after Zn/Ni	227	$4,695	930	$3,125	930	$2,790	$10,610

Table 5 notes: Savings for above recommendations were based on testing performed during the project as well as observations. These savings are not cumulative; implementing multiple recommendations will reduce the savings for individual options. The estimated independent savings for each of the above recommendations are based on: 1. Estimated water use reduction of 10% for Zn/Ni line. 2. Estimated 20% reduction of water use for Zn/Ni line 3. Estimated 15% water use, dragout and WWT sludge generation for Zn/Ni line. 4. Estimated 5% reduction of water use, dragout and WWT sludge generation for Zn/Ni line. 5. Estimated 10% water use reduction for rinse systems 104/105, 107/108 and 116/117/118. 6. Based on Appendix model, estimated 30% water use, dragout and WWT sludge generation for tanks 110/111/112. 7. Estimated 10% water use, dragout and WWT sludge generation for tanks 110/111/112. 8. Estimated 10% water use, dragout and WWT sludge generation reduction for tanks 110/111/112.

Implementation of changes. The facility had the option of implementing any or all recommendations proposed by the project team. All costs associated with implementation were borne by the facility.

The facility decided to implement some of the recommendations immediately and some decisions were deferred. The recommendations that were implemented included:

- Established a cleanout schedule for rinse tanks
- Replaced broken rack coatings (Figure H-10)
- Added spray rinsing to Tanks 104, 107, and 116
- Installed a drip tray after Zn/Ni plating tank (Figure H-11)

Figure H-10.   Racks with New Plastisol Coatings

Figure H-11.   Pictures of Zn/Ni Tank Before and After Installation of Drip Board

Recommended changes that were not implemented during the project included:

- Adding an additional blower to improve air agitation
- Adjusting drain times (reprogramming)
- Adding a double dip (reprogramming

Measurement of Improvements

Following the implementation of the selected changes, the conductivity of the rinse tanks were tested and compared to previous conditions. These data are shown in Table H-6. The results show that adding spray rinses to Tanks 104, 107, and 116 improved rinse efficiency. In each case, the conductivity of the first rinse increased due to the effectiveness of the spray, i.e., more dragout is removed from the racks/parts before they are moved to the second rinse. Since less dragout is now

Table H-6. Conductivity of Rinse Tanks Before and After Changes Implemented

Rinse Tank	Average Conductivity Before Improvements, ms/cm	Conductivity After Improvements, ms/cm	Change After Improvements
104	1.39	1.62	+16.5%
105*	0.28	0.21	-25.0%
107	9.32	15.9	+70.6%
108*	0.41	0.35	-14.6%
111	3.62	1.23	-66.0%
112*	0.36	0.30	-16.7%
116	0.85	0.80	+5.8
117*	0.30	0.23	-23.3%
118	0.26	0.26	0%

Note: city water feeding rinse system has a conductivity of 0.17 ms/cm

going into the second rinse, the second rinse (105, 108, and 117) has less conductivity, with an average improvement of 21%.

Tank 111 was equipped with a spray rinse prior to the study, and therefore was not be expected to show an increase in conductivity. On the contrary, there was a major decrease in conductivity (66%). This change was most likely caused by the repair of rack coatings, the addition of a drip tray between Tanks 110 and 111 and improved air agitation.

Obviously the facility has made substantial progress toward rinsing improvement. Hopefully, the facility will be inspired by these results to implement the remaining recommendations.

Conclusions

The *Rinsing Manual*, developed under this P2 Grant, is an effective tool for evaluating and improving rinse systems. Its systematic approach includes data collection, evaluation of alternatives, implementation of improvements, and measurements of change. The data collection methods outlined in the *Rinsing Manual* include some unique methods including measurements of dragout, rinse efficiency (C1/C2) and adequacy of drain time. The resultant data allow for quantitative evaluation of options.

The *Rinsing Manual* is available free of charge on the Surface Technology Environmental Resource Center (STERC) website http://www.sterc.org/subs/rinseman.php.

Appendix

This section describes how to use measurements of the volume of solution draining from a rack of parts, sampled over successive time intervals, to estimate how much additional solution would have drained if drip time were extended. The drip rate decreases continuously over time, so some knowledge of the shape of the curve of drip rate vs. time is essential in order to calculate from the measured volumes what drip volume would be expected over some future time interval. A set of

curves reproduced in an EPA report[5] provides a set of drip rate vs. time curves for a typical plating solution (unspecified in the report). In the following section, a formula is developed which matches the shapes of the typical curves, and provides the basis for the estimate.

Shape of the Curve

Plots of dragout volume (volume of solution still clinging to rack) vs. time are provided for three different surface orientations (horizontal, vertical, and an intermediate case). The curves begin with a rapid decrease in dragout volume, with the rate of decrease becoming smaller until the curve flattens out. This is qualitatively the kind of behavior that would be expected if the drip rate were proportional to the amount of solution still on the rack. The curve would then have the form of an exponential decay,

$$\text{dragout} = V * e^{-k*t} + V_{end}$$

where V, k, and V_{end} are constants. Specifically,

- V_{start} is the dragout volume on the rack at time $t = 0$
- k is the rate constant, which determines how rapidly the curve flattens out with time
- V_{end} is the solution that remains on the rack after arbitrarily long times.

The exponential decay curve applies in a wide variety of situations, but the case of dragout volume is apparently not so simple. An exponential curve fitted to the first few seconds of the curve will not match the rest of the curve, and vice versa. However, a very close match can be obtained by adding two exponentials, with individual initial volumes and rate constants:

$$\text{dragout} = V_{start1} * e^{-k_1*t} + V_{start2} * e^{-k_2*t} + V_{end}$$

These curves were plotted on a spreadsheet, with the size of the grid adjusted to match the curves in the EPA report. The spreadsheet curves are shown below, superposed on a screenshot of the EPA report curves:
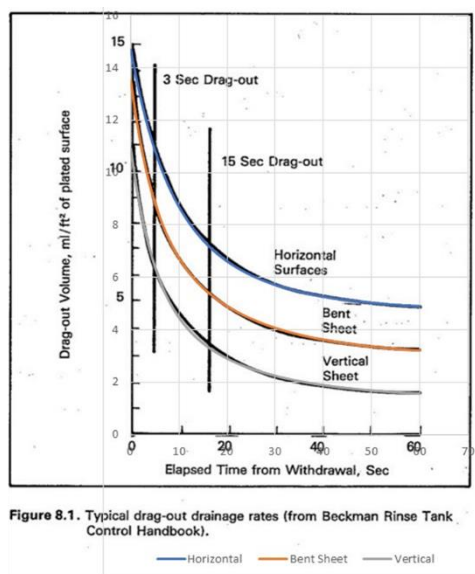
Figure 8.1. Typical drag-out drainage rates (from Beckman Rinse Tank Control Handbook).

——Horizontal ——Bent Sheet ——Vertical

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[5] *Meeting Hazardous Waste Requirements for Metal Finishers*, EPA/625/4-87/018, September 1987, p. 25, available on-line at https://nepis.epa.gov/Exe/ZyPDF.cgi/300048GM.PDF?Dockey=300048GM.PDF

The values of the parameters that provide this fit are:

parameter	horizontal	bent sheet	vertical	units
V_{start1} =	5	5	5.2	ml/ft^2
k_1 =	0.15	0.22	0.22	1/sec
V_{start2} =	5	5.5	4.3	ml/ft^2
k_2 =	0.055	0.055	0.055	1/sec
V_{end} =	4.7	3.0	1.4	ml/ft^2

The volumes are expressed in milliliters per square foot of surface area, to match the units used for the EPA report curves. The rate constants can be expressed simply as "percent per second", since for any single exponential decay curve, where the amount lost is proportional to the amount remaining, a constant percentage of the remaining weight will be lost every second. In this case, where two exponentials are being added, the percent in each case refers to the initial volume for that exponential.

For example, for the case of the vertical sheet, the total dragout volume left on the rack after the first second will be

$e^{-0.22} * 5.2 =$ **4.17** ml/ft^2 from the first term, plus

$e^{-0.055} * 4.3 =$ **4.07** ml/ft^2 from the second term.

After the next second, the remaining dragout volume will be

$e^{-0.22} *$ **4.17** $= 3.35$ ml/ft^2 from the first term, plus

$e^{-0.055} *$ **4.07** $= 3.85$ ml/ft^2 from the second term,

and so on for each subsequent second. (Note where the boldface terms in the first pair of equations show up in the second pair.)

In other words, the model behaves as if there are two separate exponential decays occurring, each starting with its own initial volume of solution. For one of the components, the remaining volume at any point in time will be $e^{-0.22} = 80.3\%$ of what it was one second before, or equivalently, it loses 19.7% of its volume every second. For the other component, the corresponding percentage will be $e^{-0.055} = 94.6\%$, or a loss of only 5.4% of its volume per second. The total dragout volume seems to consist of one portion that drips off relatively quickly, and a second portion that drips more slowly. After a long time, both of those exponentials will have decayed to nearly zero, leaving a third portion still on the rack that remains constant. (The other surface orientations have different parameter values, but the behavior is similar.)

This is consistent with the interpretation that some portion of the initial dragout volume is subject to bulk flow (V_{start1}), another portion is strongly influenced by surface forces (V_{start2}), and a third portion will remain clinging to the surfaces and never drip off (V_{end}). In practice, there wouldn't be sharp boundaries between layers, but the close agreement between the model and the measured curves suggests that a three-layer model is sufficient to produce a good estimate.

Data Collected at Michigan Electroplating Facility

Dragout samples were collected from an automated Zn/Ni plating line without interrupting normal operation. On this line, two racks travel side-by-side through a sequence of tanks. Racks remain in the plating tank longer than in other dip and rinse tanks, so the plating tank has the capacity to hold four rack sets (each set consisting of a pair of racks). When a rack set is to be moved into the first rinse tank, a lift raises the rack set completely out of the tank, and suspends it for eight seconds. The lift then moves the rack to a position over the rinse tank, holds for two seconds, and then lowers the rack set into the rinse. Depending on their position in the tank, racks will have spent 9, 10, 11, or 12 seconds with drip falling back into the plating tank. Solution dripping after that time will fall into the rinse tank, and will therefore be counted as dragout.

For these measurements, two identical sampling tubes were prepared. Each tube consisted of a two-foot section of PVC pipe, with a slot cut along the tube, extending nearly the entire length of the tube. The tube was capped on the ends. The tubes were positioned under a rack, and the solution draining from a representative length of the rack was collected. After collecting the sample, one end cap was then removed, and the collected solution was drained into a graduated cylinder and measured.

Each rack is about four feet wide, so the sampling tube collected about a quarter of the total drip from each rack set. On some racks, particularly those where the rack coating was peeling, more drip could be observed toward the corners of the racks than along mid-section of the bottom. Each tube collected the drip from a corner plus about half of the bottom edge of one rack; scaling up by a factor of about 4 was thus considered to provide a good indication of the total drip from the rack set.

As soon as a rack had been lifted from the plating tank, a sampling tube was placed under the rack, and moved under the rack until it had reached the edge of the plating tank. The tube was then removed and a second tube positioned under the rack until it began descending into the rinse tank. The volumes of solution collected over the plating and rinse tanks for three different rack sets, and the time intervals at the end of each sample collection, are tabulated below. (Start time for the plating sample was $t = 0$, so t_1 also equals the time interval in seconds over which V_P was collected. The corresponding interval for V_r was $t_2 - t_1$, or two seconds in all cases.)

MI plating facility data	Rack #			units
	1	**2**	**3**	
Volume collected over plating tank (V_P)	21	47	35	ml
Volume collected over rinse tank (V_R)	3	9	4	ml
Time at end of plating tank sample collection (t_1)	9	10	11	sec
Time at end of rinse tank sample collection (t_2)	11	12	13	sec

Estimate of Potential Dragout Reduction

These data can be used along with the drip curve model described above to estimate how much dragout could be reduced with a longer drain time over the plating tank. In this section, the method used to generate the estimate is summarized, and the results are presented. The full details of the calculations involved are provided in the concluding section.

The drip curve example available from the EPA report can help establish the validity of the model, but the specific numerical values found above for the rate constants k_1 and k_2, and the initial volumes

V_{start1} and V_{start2} and V_{end} that match the curve, cannot be carried over directly to solutions other than the particular solution used for the given curve, tested under the conditions used for that measurement. (This information is not provided in the EPA report.) Solutions with a different viscosity from the solution tested for the EPA report will have different values for all of these parameters. The same applies to any factors, such as solution temperature, which affect the viscosity.

For this estimation method, we assume that the qualitative behavior of the model, with two independent exponential decays, remains valid over the range of typical plating solutions, as long as the values of the parameters are chosen to reflect the particular solution and conditions being tested. We use the data gathered at the Michigan plating facility to determine the parameters. We can then use the model to determine how much solution will remain on the rack at any specified time, and thus how much dragout can be reduced by lengthening the drip time over the plating tank for any specified number of seconds.

The model requires five parameters. One of them, V_{end}, does not enter into the calculation – as far as the drip is concerned, it behaves as if it were part of the rack. That leaves two rate constants, and two initial volumes.

Ideally, rather than two samples for each rack set tested, it would be useful to have samples over four or more different time intervals. If more than four measurements are available to determine four unknowns, the system is overdetermined, and the extra measurements can serve as a further test of the validity of the model. Under the circumstances, more frequent measurements, or measurements over additional time intervals, would not have been possible without interrupting the process. With two measurements and four unknowns, the system is underdetermined, and two additional assumptions are necessary. The two assumptions used in this case are that the ratio of V_{start1} to V_{start2} is the approximately the same for typical plating solutions, and that this is also true for the ratio of rate constants. The ratios for the example curves are then used to provide two additional equations to the two generated from the facility data. With four equations and four unknowns, the values of all four parameters can be calculated.

Note that each of the three rack sets must be treated as separate cases, with different values for the parameters. Although the composition of the solution, the temperature, and most other factors were similar for each of the measurements, the parts being plated were different, with different surface areas and orientations, and the racks were not all in uniformly good condition. The values of the parameters calculated for each of the rack sets are tabulated below:

Model parameters	Rack #			units
	1	2	3	
V_{start1}	111.9	1949.5	173	ml
K1	0.1000	0.0086	0.0900	1/sec
V_{start2}	122.0	2038.0	197.4	ml
K2	0.025	0.002	0.023	1/sec

When these values are put into the model equation, the dragout remaining on the rack can be calculated as a function of time. The results are listed below:

Time (sec)	"Avoidable" dragout (ml) Rack #		
	1	2	3
0	234	3988	370
1	220	3966	351
2	208	3946	333
3	196	3925	317
4	185	3904	301
5	176	3884	287
6	166	3863	273
7	158	3843	261
8	150	3823	249
9	143	3803	238
10	136	3784	228
11	130	3764	218
12	124	3744	209
13	119	3725	201
14	114	3706	193
15	109	3687	186
16	104	3668	179
17	100	3649	172
18	96	3631	166
19	93	3612	160
20	89	3594	154
21	86	3575	149
22	83	3557	144
23	80	3539	139
24	77	3521	135
25	74	3504	131

The total dragout from a rack will include the tabulated values above, plus V_{end}. An average value for V_{end} can be estimated from the total measured dragout (given above as 0.21 gallons per rack set). However, this will differ significantly among racks, carrying differently shaped and oriented parts. Additional drip time will not affect this value. The values in the table refer only to the portion of the dragout that can be avoided by extending the time the rack remains over the plating tank.

It will be noted that Rack #2 seems anomalous, in that it exhibits a significantly larger initial volume of dragout, and significantly slower drip time, than the other two racks. It is probable that the drip curve model is not applicable in this case. Liquid trapped in tubes, draining more slowly than solution dripping from open surfaces, could account for this behavior, delivering an overall greater volume that decreases more slowly with time. The values obtained for Racks #1 and #3 have rate constants slower than the curves from the EPA report, but not drastically so, as would be expected from the relatively high viscosity of the Zn/Ni bath.

From the table, we can calculate how much of the "avoidable" dragout can be avoided. For example, after nine seconds over the plating tank, Rack #1 is carrying 143 ml that could potential be removed with a longer drain time. Had it remained over the plating tank an additional 10 seconds, that portion of the dragout would have decreased to 93 ml, a 35% reduction. For Rack #3, the corresponding

reduction in avoidable dragout would be 32%. (For Rack #2, the decrease would only be 5%, since the initially larger dragout volume decreases more slowly with drip time. The apparent problem with this case would have to be addressed by some means other than extending the drip time.)

Calculation Details

Starting with the model equation,

$$\text{dragout} = V_{start1} * e^{-k_1 * t} + V_{start2} * e^{-k_2 * t} + V_{end}$$

with five unknown parameters, the goal is to determine what values of the parameters best match the measured values of the volume of solution dripping from a rack set. Since we are only interested in the difference in dragout volume for two different values of t, the V_{end} term will cancel out of the difference, and will not be considered further.

$$\text{dragout difference} = V_{start1} * (e^{-k_1 * t_1} - e^{-k_1 * t_2}) + V_{start2} * (e^{-k_2 * t_1} - e^{-k_2 * t_2})$$

For each of the three racks measured, we have two measurements of the total drip volume collected from a 24" length of a rack set with a total bottom edge length of 104". The measured volumes were scaled up by a factor of $104/24 = 4.3$.

Two measurements were obtained for each rack set: the volume collected over the plating tank, scaled up over the entire length of the rack (V_P), and the corresponding scaled-up volume collected over the rinse tank (V_R). This provides two equations, with four unknown parameters. Two additional equations are necessary to derive a unique solution.

The values of the parameters derived above for the curves in the EPA report will change if the model is applied to a solution with a different viscosity. For small changes in viscosity, it is reasonable to assume that the changes in the parameters will be linear functions of the viscosity change. Each parameter will have a different proportionality constant (change in value vs. change in viscosity). But the ratio of two parameters will stay approximately the same over a range of viscosities, since the viscosity change cancels out of the ratio. To the extent this approximation is valid, we can use the ratios measured in the EPA report curves to represent the ratios characterizing the parameter values for the facility data. The following equations use the ratios for the intermediate ("bent sheet") curve in the EPA report:

$$V_{start2} / V_{start1} = 5.5 / 5.0 = 1.1$$

$$k_2 / k_1 = 0.055 / 0.22 = 0.25$$

The other two equations can now be written in terms of only two parameters. The values for times t_1 and t_2 are known for each measurement. We can simplify the equations further by noting that t_1 for the plating tank measurements is 0, that t_2 for a plating time measurement equals t_1 for a rinse tank measurement, and that $(t_2 - t_1)$ for the rinse tank measurements is always 2 seconds. Thus only one value of time is needed in each equation (with a value of 9, 10, or 11 seconds for Racks #1, 2, and 3 respectively. With these simplifications, the system to be solved is (dropping subscripts on k and t):

$$V_P = V_{start1} * (1 - e^{-k * t}) + V_{start2} * (e^{-0.25 * k * t} - e^{-0.25 * k * (t + 2)})$$

$$V_R = V_{start1} * (e^{-k * t} - e^{-k * (t + 2)}) + V_{start2} * (e^{-0.25 * k * t} - e^{-0.25 * k * (t + 2)})$$

Although the system has been considerably simplified, with only three unknowns (V_{start1}, V_{start2}, and k), the presence of several different exponentials precludes an analytic solution by elementary means. The system can be solved numerically, but dealing with two coupled equations still presents computational complications.

However, it is possible to decouple the equations by solving for the unknowns, expressing each in terms of known quantities. The schematic form of the equation set is:

$$V_P = V_{start1} * A + V_{start2} * B$$

$$V_R = V_{start1} * C + V_{start2} * D$$

where

$$A = 1 - e^{-k*t}$$

$$B = e^{-0.25*k*t} - e^{-0.25*k*(t+2)}$$

$$C = e^{-k*t} - e^{-k*(t+2)}$$

$$D = e^{-0.25*k*t} - e^{-0.25*k*(t+2)}$$

The system can then be solved for V_{start1} and V_{start2} as functions of known quantities and k:

$$V_{start1} = det * (D * V_P - B * V_R)$$

$$V_{start2} = det * (C * V_P - A * V_R)$$

where det is the determinant, $(A*D - B*C)$. It is then convenient to form the ratio of V_{start2} to V_{start1}. The determinants cancel, and the quantity V_{start2}/ V_{start1} can be calculated as a function of k. Now the problem can be solved numerically, by finding the value of k that makes the ratio equal to the value from the EPA report curve. The values found for each of the three rack sets are those tabulated in the "Model parameters" table above.

It only remains to determine either one of V_{start1} or V_{start2}, since the ratio between the two is assumed known. Adjusting either of the starting volumes up or down simply scales each of the terms proportionally. It is convenient to create a spreadsheet table with time in seconds starting from t=0 and continuing at least as far as the time intervals during which samples were collected. Values for all parameters are entered in reference cells, with V_{start1} undetermined. In an adjacent column, the formula is entered to compute the dragout from the adjacent time value and the information in the reference cells. Some starting value is entered into the cell for V_{start1}. The formulas column will then indicate the total amount of dragout calculated to be left on the rack for each second that has elapsed. The difference between any two dragout values represents the amount of dragout that would be collected in that time interval. That can be compared with the amount actually collected (scaled up to account for the entire rack set). The value of V_{start1} can then be adjusted until the quantities match. As a cross check, it will be noted that the same value of V_{start1} that satisfies the value for V_P also matches the amount collected for V_R. This is guaranteed by the way the value of k was calculated, as long as the assumptions behind the model are valid.

Appendix I – Capsule Report: Coventya Low Nickel EN Bath Chemistry

Introduction

This capsule report was prepared under EPA Grant Number 00E02050, funded through the EPA Source Reduction Assistance Grant Program. This program funds Pollution Prevention (P2) assistance projects that provide technical assistance and/or training to businesses/facilities to help them adopt source reduction approaches.

Various tasks have been performed under this EPA grant. The purpose of this particular project was to demonstrate certain pollution prevention (P2) aspects of a new electroless nickel (EN) bath chemistry. The new EN solution contains approximately 50% less nickel than a conventional EN bath. The P2 project focused on the potential reduction of water use, reduction of nickel discharges to the treatment system, reduction of sludge generation, reduction of off-site disposal, and reduction of air emissions.

The project was performed at a metal finishing facility in Michigan that operates an automated EN barrel line for plating small automotive parts. During the P2 demonstration a conventional mid-phosphorus 6 g/l nickel bath was replaced with a mid-phosphorous 3 g/l nickel concentration bath (RI8712) formulated by Coventya Chemicals Company.

Background Information

EN plating is an autocatalytic process used to deposit nickel-phosphorus or nickel-boron alloy onto metal or plastic substrates to impart corrosion and/or wear resistance. Performed without the use of an electric current, this process gained commercial popularity in the 1950s and has grown into an immensely popular surface coating technology.

The majority of EN plating is done using nickel phosphorus chemistry with resulting deposits that provide a low coefficient of friction, are anti-galling and have superior as-plated hardness that can be further hardened by post-plating heat treatment processes. These deposits also have excellent corrosion performance in many types of environments. Nickel boron alloys are widely used in electronics and aerospace applications. The deposits provide high electrical conductivity, low contact resistance, excellent as-plated hardness, a high melting range, outstanding wear resistance, and are easily soldered or brazed. For some applications nickel boron is used as a replacement for hard chrome plating.[1]

EN is often referred to as a self-limiting process, because chemical reactions taking place during its use cause the formation of by-products that eventually force replacement of the bath. The main constituents of a nickel phosphorus EN bath are nickel ions (added as nickel sulfate other nickel salt), sodium hypophosphite, buffers and complexors. During use, while nickel is being deposited, sodium hypophosphate reacts with water to form sodium orthophosphate and hydrogen gas. Chemical additions of nickel solution and hypophosphate will allow the EN bath to continue working, but eventually the buildup of sodium orthophosphate and other constituents reduces the deposition rate and affects the quality of the deposit (e.g., reduction in smoothness and brightness) as well as physical properties such as magnetics and solderability. At some point, the EN bath is

partially (bleed and feed) or entirely replaced with fresh chemistry. Used EN solution is treated on-site or sent off-site for recovery or disposal.[2]

The conventional EN phosphorus chemistry is formulated with 6 g/l nickel and 25 g/l or higher sodium hypophosphate. EN bath use is measured in metal turnovers (MTO). One MTO occurs for each 6 g/l of nickel added back to the system. In a sodium hypophosphite bath using nickel sulfate, the by-products include sulfate, sodium and orthophosphite. About 45-60 g/l of reaction by-products are formed every MTO. Because of the buildup of bath impurities and ensuing deposition problems, the practical number of MTOs before disposal is necessary is 4 to 10 MTOs. Therefore, over the course of the bath's life, a total of approximately 24 to 60 g/l nickel is deposited as a useful surface coating.[1]

Evaluation

An evaluation of potential P2 benefits and associated cost savings was conducted using existing facility data, established emission factors, information provided by the chemical supplier, and testing. This work is discussed in this section.

The project was performed at a metal finishing facility in Michigan that operates an automated EN barrel line for plating small automotive parts. On the average, this facility operates their EN line two days per week and processes approximately 40 barrels per day.

Dragout and Rinsing Test. Dragout volumes were measured during the study for both the high nickel and low nickel bath chemistries using the methodology presented in the *Rinsing Manual*.

The rinse system (Figure I-1) consists of a stagnant dragout rinse, followed by a two stage counterflow flowing rinse (1.9 gpm). The dragout tank is drained to the wastewater treatment (WWT) system after each day of processing. The counterflow rinse is operated continuously during production and shut off during idle periods.

Prior to the start of each test, the dragout and rinse tanks were emptied and refilled with fresh water. Then, barrels were processed through the plating line. After removal from each process and rinse tank, the barrels were rotated above the tanks to improve drainage. The time between barrels being processed was approximately the same in each case, about 15 minutes. Samples were collected from the dragout tank and first counterflow rinse tank after each barrel was processed.

This procedure was performed for both the high and low nickel concentration baths. A total of 12 barrels were processed for the high nickel bath and 11 barrels for the low nickel bath. The data for the dragout rinse and flowing rinse are presented respectively in Tables I-1 and I-2.
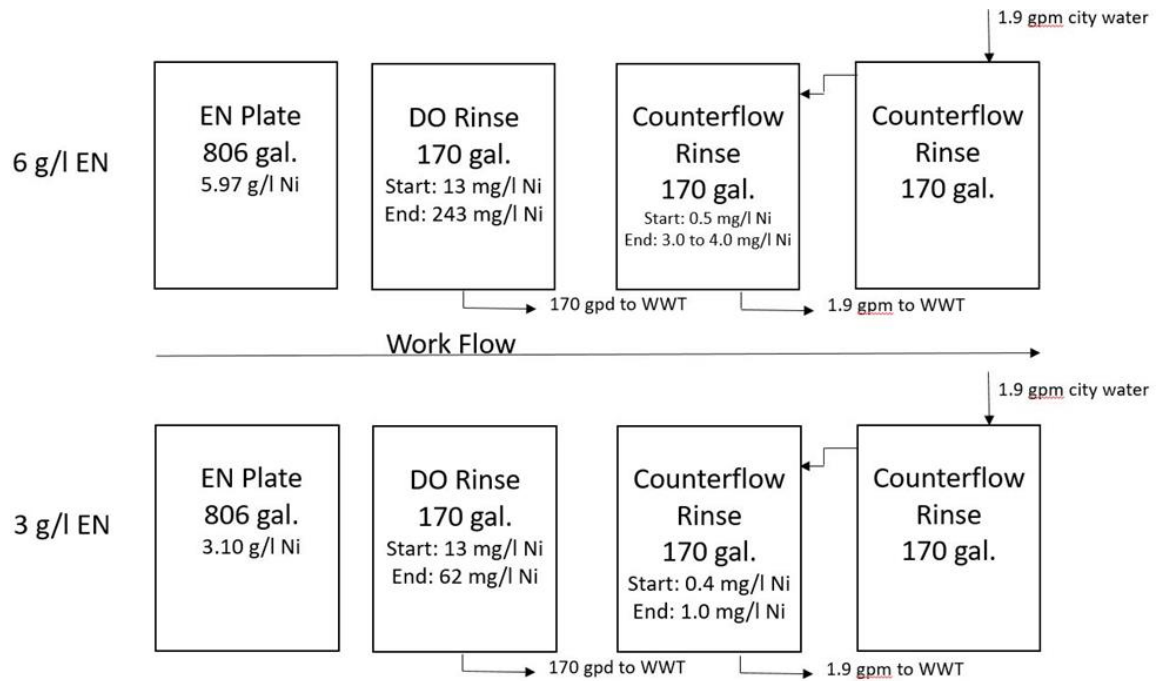
Figure I-1. EN Barrel Plating and Rinse System

Table I-1. Dragout Rinse Tank Measurements

	Nickel, mg/l	
Barrels Rinsed	6 g/l Electroless Nickel Bath	3 g/l Electroless Nickel Bath
0	13	13
1	22	18
2	92	20
3	125	23
4	131	24
5	151	30
6	165	35
7	170	42
8	190	44
9	202	50
10	219	56
11	232	62
12	243	-

Table I-2. Flowing Rinse Tank Measurements

Barrels Rinsed	Nickel, mg/l		Ratio of Nickel Concentration 6 g/l:3 g/l
	Following the 6 g/l Electroless Nickel DO Tank	Following the 3 g/l Electroless Nickel DO Tank	
0	0.5	0.4	1.3
1	0.8	0.5	1.6
2	1.0	0.6	1.7
3	2.0	0.6	3.3
4	1.0	0.6	1.7
5	2.0	0.8	2.5
6	1.0	0.9	1.1
7	3	0.9	3.3
8	3	1	3.0
9	4	1	4.0
10	4	1	4.0
11	4	1	4.0
12	3	-	-
Average Ratio			2.6

The volume of dragout for the test was calculated using the equation:

$$D_{total} = (C_{end} - C_{start}) * V / C_{bath}$$

And the average dragout volume per barrel was calculated as follows:

$$D_{avg} = D_{total} / N$$

where:

- D_{total} = Total dragout volume during test (gal.)
- D_{avg} = Average dragout volume per barrel (gal.)
- C_{start} = Concentration of nickel in the dragout rinse tank at start of test (mg/l)
- C_{end} = Concentration of nickel in the rinse tank at end of test (mg/l)
- N = Number of barrels processed through the dragout rinse tank during the test
- V = Volume of rinse tank (gal.)
- C_{bath} = Concentration of nickel in the process bath (mg/l)

The results of the dragout test show that the average dragout per barrel (D_{avg}) for the two baths were:

- D_{avg} for 6 g/l bath = 0.55 gal/barrel
- D_{avg} for 3 g/l bath = 0.24 gal/barrel

The dragout volume for the 6 g/l nickel bath is 2.3 times greater than for the 3 g/l bath. This difference is due to the higher total dissolved solids and resultant higher viscosity of the 6 g/l nickel bath. Liquids with high viscosity drain slowly and therefore more dragout is retained by the plated parts and barrel.

Data for the flowing rinse (Table I-2) show that the concentration of nickel in the first counterflow rinse reaches equilibrium after approximately 6 to 8 barrels being processed. The concentration of nickel at equilibrium is 3 to 4 mg/l for the high nickel bath and 1 mg/l for the low nickel bath. The

ratio of nickel concentration for the two baths (nickel concentration of 6 g/l divided by 3 g/l) in the flowing rinse is shown in the last column. The average ratio was 2.6, which is similar to the dragout volume ratio discussed above.

Air Emissions. Nickel air emissions were evaluated during the project using emission factors generated by the Metal Finishing Association of Southern California (MFASC), with collaboration of the South Coast Air Quality Management District (SCAQMD) and the California Air Resources Board (Table I-3). As shown, air emissions from EN plating are approximately an order of magnitude lower than nickel electroplating with air agitation, which is presented here for comparison.

Emissions are proportional to the concentration of the "pollutant" of concern in the process tank.[3] Therefore, assuming that the SCAQMD emission factors were based on a conventional 6 g/l nickel bath, the approximate emissions from a 3 g/l nickel bath is 3.8×10^{-7}.

Table I-3. SCAQMD Emission Factor Summary From Test Reports

Process	Pollutant	Emission Factor
Electroless Nickel (6 g/l bath)	nickel	7.5×10^{-7} lb./hr-ft^2 tank
Nickel Plating w/ air agitation*	nickel	6.5×10^{-6} lb/hr-ft^2 tank

The EN tank surface area at Finishing Services is 46 ft^2. Typical operation of the EN bath is 16 hrs/week, 50 wks/yr. Therefore, for the two EN baths, estimates of annual nickel emissions are:

- 6 g/l EN Bath: 0.0276 lb Ni/yr.
- 3 g/l EN Bath: 0.0138 lb Ni/yr.

Bath Disposal. As discussed previously, EN baths can be replenished with nickel and reused up to a point and then must be discarded due to a buildup of by-products. At the demonstration facility, the average life of the 6 g/l bath is 8 MTOs. Theoretically, the 3 g/l bath will be able to be operate 9 to 9.5 MTOs if the operating contamination level is the same as the 6 g/l bath. This is due to the lower dissolved solids present in a new 3 g/l bath, which results in a chemical system that is able to hold more reaction by-products than a 6 g/l solution.[1], [4]

Historically, the volume of spent 6 g/l bath shipped off-site for disposal is approximately 21,000 gal/yr. The cost is $1.53/gal, including freight and disposal. Assuming an increase from 8 MTOs to 9 MTOs for the 3 g/l bath, the disposal rate for the lower nickel solution will be approximately 18,700 gal/yr. The annual disposal projections for the two baths are:

- 6 g/l EN Bath: $32,130/year
- 3 g/l EN Bath: $28,611/year

This information, as disclosed to the EPA, shall be protected as the proprietary and confidential information of NCMS and its members named herein in accordance with this agreement and applicable laws and regulations.

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When discarded, the baths contain approximately 100% of their operational nickel concentration or 6.0 g/l and 3.0 g/l respectively for the 6 g/l and 3 g/l baths.[6] The volume of the EN bath is 806 gal., therefore, the mass of nickel annually discarded is:

- 6 g/l EN Bath: 1,050 lb Ni/yr.
- 3 g/l EN Bath: 468 lb Ni/yr.

Wastewater Treatment

Wastewater from the EN plating line includes daily discharges the dragout tank and the continuous discharge from the counterflow rinse. The annual volume of wastewater generated by the 6 g/l bath is 108.2 Kgal. The projected annual volume for the 3 g/l bath is 52.1 Kgal.

Dragout tank discharges are pretreated using a high pH process to precipitate the complex nickel and then processed through the general WWT system. The discharge of the counterflow rinse goes directly to the general WWT system (pH adjustment, precipitation/clarification and sludge dewatering).

P2 Benefits and Cost Savings

Projected pollution prevention benefits and cost savings attributed to the 3 g/l bath are shown in Table I-4.

Table I-4. Pollution Prevention Benefits and Cost Savings

EN Bath	Water/Sewer		WWT (dragout and rinse)		WWT Sludge Disposal		Bath Replenishment		Bath Disposal	
	Kgpy	$/yr	Kgpy	$/yr	Lbs./yr	$/yr	gpy	$/yr	gpy	$/yr
6 g/l	108.2	$866	108.2	$1,499	448	$892	21,000	$84,000	21,000	$32,130
3 g/l	52.1	$417	52.1	$722	216	$430	18,700	$65,450	18,700	$28,611
3 g/l Savings	56.1	$449	56.1	$777	232	$462	2,300	$18,550	2,300	$3,519

Water and sewer cost ($8.00/Kgal) based on actual cost. WWT costs ($13.85/Kgal) and sludge generation (4.14 lbs/Kgal treated) based on industry averages from PRIM survey. EN solution cost is $4.00/gal for 6 g/l bath and $3.50/gal for 3 g/l bath.

The projected overall cost savings for the 3 g/l system is $23,757 per year.

Additional Information

This project focused on certain potential P2 benefits of a low nickel EN bath. Coventya Chemicals Company has conducted other testing related to the production aspects of the technology. A useful article written by Coventya Chemicals Company, entitled *Reduced Ion Electroless Nickel to Meet a Sustainable Future* is available at no cost on the Surface Technology Environmental Resource Center (STERC) at http://www.sterc.org/subs/rinseman.php.

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[6] EN baths at this facility are replenished continuously and therefore when spent, the bath contains the normal operating concentration of nickel (i.e., 3 or 6 g/l Ni).

References

[1] Barnstead, Mike and Morcos, Boules; Electroless Nickel Plating, Products Finishing, Feb., 2011.

[2] USEPA, Extending Electroless Nickel Bath Life Using Electrodialysis.

[3] Zinkus, Glenn A. and Klink, Kevin; Air Emission Factors for Metals Finishing Operations, AESF/EPA Conference for Environmental & Process Excellence, 2003.

[4] Schaffer, Ambrose; Reduced Ion Electroless Nickel to Meet a Sustainable Future, Surface Technology Environmental Resource Center (STERC), Technical Articles, Nov. 2018.

Appendix J – Demonstration Plan: Eductor Technology

Eductor Study at ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮

Background

Like many metal finishing shops, ▮▮▮▮▮▮▮▮▮▮▮▮▮▮▮ uses an air blower for solution agitation in plating processes. This method of solution agitation may be less effective for mixing, which can decrease plating efficiency and increase energy use. Also, air agitation contributes to air emissions and can deplete elements of bath chemistry, such as brightners. In alkaline plating baths, air agitation may also cause carbonate buildup.

The eductor demonstration at ▮▮▮▮▮▮▮▮▮ will be performed on an acid copper plating tank. The existing air agitation on this tank creates noticeable acidic fumes and adds electrical resistance to the tank's "plating circuit." The acid copper tank temp is 70-85°F. Cooling is required at times when the tank is operational. The dimensions of the tank are 56" wide, 120" long and 60" deep. A center divider panel is present, making each plating compartment 28" wide. The volume of the tank is 1,600 gallons.

The demonstration will be conducted to investigate the benefits of replacing air agitation with a solution pump and eductor system. Although a single plating tank will be selected for the demonstration, the results of the study will be extrapolated to all applicable process tanks to estimate shop-wide benefits.

How Eductors Work

An eductor consists of a nozzle that is tapered at the end, a flow-through chamber, and a diffuser. Its operation is based on the Venturi principal. When solution is pumped into the eductor nozzle, it exits at a higher velocity due to the tapered design (i.e., pressure is converted to velocity when the solution is forced through the restricted nozzle). As it passes into the flow-through chamber, the high velocity solution draws surrounding solution into the chamber. This additional solution flow mixes with the pumped solution and therefore multiplies its volume. Typically, the volume of solution existing the diffuser is 4-6 times greater than the nozzle inlet flow rate.

Eductor System Design

Eductor systems are designed for specific applications. An initial consideration is the turnover rate, which is the number of times per hour that the tank volume is recirculated through the eductor system. Turnover rates for plating solutions vary from 4 to as high as 60. Viscous solutions and those with high particulates require a greater number of turnovers. Most chemical suppliers can provide guidance on turnover requirements.

Other design considerations are the flow rate into individual eductors and number of eductors, which are mainly dependent on tank dimensions. A sufficient number of eductors must be used to provide effective circulation throughout the tank, with an objective of maximize solution shearing action at the surface of the part to be plated. Typically, eductors are spaced approximately 12 inches apart.

Measuring Pollution Prevention Benefits

Potential benefits to measure:

- Rectifier electricity use (less electricity used in plating process because solution movement reduces resistance).

- Plating rate (better solution circulation reduces diffusion boundary layer and therefore permits increased current density).

- Plating quality (better distribution, including low current density areas and fewer rejects due to gas pitting, etc.)

- Reduction of brightener consumption.

- Reduction in acid fume emissions.

Additional potential benefits for other applications include:

- Reduced solution heating for baths operated at elevated temperatures.
- Reduction of carbonates in alkaline baths.

Rectifier energy use. To be added.

Plating rate. To be added.

Plating quality. To be added.

Reduction of brightner consumption. The composition of an acid copper bath includes proprietary chemical additives used to increase the brightness of the deposit, which are referred to as brighteners. The brighteners, which are typically organic compounds, will decompose in the bath and require periodic replenishment. Air agitation introduces oxygen into the solution, which hastens brightener decomposition. Eductors are expected to reduce the brightener decomposition rate because oxygen is not being pumped into the solution.

▉▉▉▉▉▉▉▉ performs routine analyses of plating baths, including a test of brightener concentration. Historical data for the acid copper bath will be used as a baseline for the air agitation system. Once the eductor system is installed, brightener additions will be tracked using exiting procedures and brightener use will be compared to baseline data.

Reduction of acid fume emissions. The existing air agitation system used on the acid copper plating tank causes emissions of acid fumes into the workplace. The fumes are created when air bubbles supplied by the air agitation system reach the surface of the liquid and burst, releasing an acid aerosol. Most of the acid fumes are removed from the air by the tank exhaust system, however, some fumes escape into the workplace. Acid fumes in the workplace are regulated by federal Occupational Safety and Health Administration (OSHA) rules. The OSHA permissible exposure limit (PEL) for sulfuric acid is 1 mg/m^3 (https://www.osha.gov/dts/chemicalsampling/data/CH_268700.html).

During this demonstration, the concentration of sulfuric acid in the air will be measured using the Draeger tube method. This test involves the use of a small air pump that passes a measured volume of air through a glass tube containing reagents. A color change in the tube registers the concentration of sulfuric acid. This method is useful over a concentration range of 1-5 mg/m^3 sulfuric acid. The test will be performed for both the air and eductor agitation systems and the results will be compared to determine if a difference of acid emissions occurs.

Appendix K – PRIM Pollution Reduction and Dollar Savings

Case Study	Pounds of Haz Materials Reduced (annual)	Thousands of Gallons of Water Conserved (Kgal) (annual)	MTCO2 Reduced (annual)	Dollars Saved by Businesses (annual)
Implementation of rinse system improvements	3,100	1,543	0	$48,852
Coventya low nickel EN bath chemistry	20,932	56	0	$23,757
Coventya Zn/Ni 3S Technology	1,414	0	2.4	$272
Totals	**25,446**	**1,599**	**2.4**	**$72,881**

Notes:

Implementation of rinse system improvements. See Table 5 of report. Improvements are dependent upon all recommendations being implemented. As savings cannot be cumulative, there is a one third reduction and savings for each recommendation.

Coventya low nickel EN bath chemistry. See Table 4 of report. Hazardous materials reduction includes WWT sludge (232 lbs/yr) and partial avoidance of bath disposal (2,300 gpy = 20,700 lbs/yr.).

Coventya Zn/Ni 3S Technology. Includes hazardous materials reduction for cyanide only. Reductions in zinc and nickel are likely but were not quantified. Additionally, there were CO_2 equivalent and cost savings from reduced power use.