Citric Acid & Pollution Prevention
in
Passivation & Electropolishing

A Research & Development Project
by

Control Electropolishing Corp.
Brooklyn, NY

with funding from
The State of New York
Empire State Development
Environmental Management Investment Group
Albany, NY

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Introduction

Control Electropolishing is a forty year-old metal finishing company. It is a registered NYS woman- and minority-owned business enterprise. It has 17 employees and ISO9002 certification. It is located in the Bedford-Stuyvesant section of Brooklyn. The company currently finishes more than 1,000 different kinds of metal parts for some 150 active customers.

Control Electropolishing specializes in *electropolishing* and *passivation*. Electropolishing is a metal finishing process where stainless steel parts are immersed into a chemical solution between electrified copper bars. The result is that the parts are deburred with a bright, shining, mirror-like finish. With this treatment, a nickel-chrome oxide is created improving corrosion resistance and facilitating product sterilization.

Passivation is a metal finishing process by which stainless steel parts are chemically cleaned, nearly always using a nitric acid solution. Under this operation, no deburring and no brightening occur, but there is an increase in corrosion resistance.

With a research and development grant from the Environmental Management Investment Group of New York State's Empire State Development agency, Control Electropolishing undertook an R&D project intended to determine the feasibility of converting its current -- and the metal finishing industry's prevalent -- processing systems for electropolishing and passivation to more environmentally-friendly processes using one of the organic acids, namely citric acid. The current passivating system uses nitric acid. The current electropolishing system uses a blend of phosphoric acid and sulfuric acid for finishing and hydrochloric acid for rinsing.

Project Objectives

In undertaking the R&D project, Control Electropolishing had several aims:

- to meet the new purchasing specifications of global customers in the medical, dental, surgical supply, and defense industries which include citric acid-based processing in the passivation of stainless steel products
- to reduce its process chemical, waste disposal, safety equipment, and insurance costs,
- to reduce its process cycle times,
- to increase its production capacity and productivity,
- to lower its prices and attract new customers,
- to reduce the company's use and disposal of corrosive chemicals,
- to improve the air quality in the workplace, and
- to reduce its discharge of corrosives-laden waste water into the city's sewer system.

In supporting the R&D effort, Empire State Development's Environmental Management Investment Group had three primary goals:

- to retain and create jobs in an inner-city Brooklyn neighborhood
- to strengthen the market linkage between an inner-city Brooklyn company and the

expanding global market for surgical, healthcare and defense industry products, and

- to demonstrate, and communicate information about, effective pollution prevention measures to New York State's metal finishing industry

The Need for Pollution Prevention in Metal Finishing

In New York State and nationally, the metal finishing industry is in need of successful demonstrations of small business conversions to citric acid-based processing systems.

Nationally, the industry is comprised of some 3,000 job shops employing about 60% of the industry's 74,000 workers; more than 90% of all job shops employ fewer than 50 workers.[1] In New York State, there are 150 metal finishing shops with 2,700 employees and 1997 sales of $199 million, an average of $1.3 million in sales and 18 workers per company.[2]

These small and medium-sized job shops are reliant on, and historically locked into, processing systems that are significant sources of pollution and toxics. Manufacturers of the new citric acid-based processing systems estimate that almost none of the job shops have moved toward conversion to the new system.

The metal finishing industry was one of six national industry sectors that accounted for 12.4% of the toxic releases reported by all U.S. industry in 1992.[3] According to the Environmental Defense Funds's Environmental Scorecard, the metal finishing industry is the nation's third highest source of toxic nitric acid releases (402,000 lbs), the twelfth largest source of sulfuric acid releases (130,000 lbs), the fifth largest source of phosphoric acid releases (129,000 lbs), and the thirteenth largest source of hydrochloric acid (282,000 lbs).[4] In New York state, the industry is the third largest source of nitric acid releases (10,000 lbs, all in Brooklyn), the sixth largest source of sulfuric acid (2,200 lbs), the second largest source of phosphoric acid (4,400 lbs), and seventh largest source of hydrochloric acid (16,200).[5]

For that reason, in 1994 the industry was chosen by U.S. EPA's Common Sense Initiative for development of pollution prevention and environmental compliance measures.[6] Part of the initiative involved the Surface Finishing Industry Council's publication of a Guidance Manual to Environmental Compliance. This manual is up-dated by the National Metal Finishing Resource Center, an Internet-based industry-government partnership organization funded by the Commerce Department's National Institute of Standards and Technology and the US EPA. [A copy of this

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[1] US Bureau of the Census, 1997 Economic Census, "Electroplating, polishing, et als: NAICS 332813;" and, Surface Finishing Industry Council, *Guidance Manual to Environmental Compliance*, cited by National Association of Metal Finishers, www.namf.org/publications.

[2] US Bureau of the Census, 1997 Economic Census, "Electroplating, polishing, et als: NAICS 332813"

[3] Surface Finishing Industry Council, *Guidance Manual to Environmental Compliance*, cited by National Association of Metal Finishers, www.namf.org/publications.

[4] Environmental Defense Fund, Environmental Defense Scorecard, "About the Chemicals: Industrial Sectors with Reported Total Environmental Releases," www.scorecard.org/chemical-profiles/rank-industrial-sectors

[5] *Ibid*.

[6] In 1994, the US EPA also published *A Guide to Cleaner Technologies and Alternative Metal Finishes.*

report has been offered to the NMFRC for inclusion in its technical database and dissemination via its listserv to members of the industry, regulatory agencies, and prospective markets for stainless steel.]

According to the Environmental Defense Fund, "the two major pollution issues in [metal] finishing are the techniques used to clean the metal surface and the ways in which metals are deposited on a clean surface." The four chemicals which the company and most job shops rely on – hydrochloric, nitric, sulfuric, and phosphoric acids – rank among the more hazardous according to EDF's hazards scorecard (Figure 1).

EDF's pollution prevention options for the steel industry recommend that alternatives to hydrochloric, [sulfuric, nitric] and other strong acids be used for cleaning and finishing metal surfaces. It indicates that an "organic acid mixture ... derived from food products may provide an even better alternative in the future" [to such other alternatives as pressurized air or water, abrasives, and alkaline agents].[7]

Small Businesses's Need for R&D on Citric Acid-based Metal Finishing

Control Electropolishing selected citric acid-based processing systems for the R&D project for three principal reasons.

The first involved marketing and customers' purchasing specifications. The company knew that stainless steel products finished through citric acid-based processing systems could meet the new purchasing specifications of both U.S. Surgical, a billion dollar global company, and also the U.S. Department of Defense. In 1997, the Defense Department dropped its QQ-P-35c purchasing specification which required the use of nitric acid passivation in favor of ASTM specification A-967 allowing passivation treatments "using either nitric acid or citric acid (which is less hazardous and more environmentally acceptable)."

The second reason was environmental. Citric acid is a preferred alternative metal finishing solution according to the Environmental Defense Fund. In recommending alternatives to hydrochloric acid and other strong acids, EDF notes that an "organic acid mixture ... derived from food products may provide an even better alternative ... [to such other alternatives as pressurized air or water, abrasives, and alkaline agents]."

Citric acid from oranges and other citric fruits is non-toxic, non-corrosive and biodegradable. It is generally regarded as safe for use in food products. It is compatible with the environment and can be blended into sanitary sewage systems.

The third set of reasons was operational. Citric acid-based metal finishing is a proven technology, albeit unfamiliar and underutilized in the United States metal finishing industry. The concept of passivation of stainless steel with citric acid was developed years ago in the beverage industry in

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[7] Environmental Defense Fund, Pollution Prevention Alliance, Industry Sector Community Guides: Iron and Steel Manufacturing - Forming and Finishing," www.edf.org/programs/ppa/cg/is

Germany where it was necessary to provide containers that were free of iron on the surface. Iron causes a bad taste in the beverage, and the nitric acid passivation systems could not provide the degree of passivation required.[8]

Nearly all of the citric acid sold in the U.S. is used in food and beverage products, cleaners, and disinfectants. Other industries have only recently started to use it. One reason for the delay was federal government standard QQ-P-35C which required the use of nitric acid in the passsivation process for stainless steel. There has been little incentive to get rid of nitric acid until the Defense Department dropped QQ-P-35-C in favor of the new ASTM standard for passivation.[9]

According to suppliers's representations, citric acid is organic, safe, and easy to use in passivating. It provides excellent performance at considerable cost savings. It is biodegradable, and rinse waters can go into local sewer systems if they meet local pH regulations. Citric acid emits no nitrous oxide vapors that can be harmful to workers, air quality, and the atmosphere. It does not require special handling equipment, safety equipment, or respirators for employees; and, it may be stored as a nonhazardous chemical. Citric acid does not corrode processing equipment and reduces wear-and-tear. The process also reduces the need for hazardous waste removal. The formulations remove the free iron and iron oxides without removing significant amounts of nickel, chromium, or other heavy materials. Hazardous waste removal costs should be reduced or eliminated.[10]

Because citric acid efficiently removes iron from the surface, much lower concentrations are required than when using nitric acid. Typical solutions range from 4%-to-10% citric acid by weight, thus reducing both chemical costs and the acidity of rinse water and effluent.[11]

Typical times of immersion in the citric acid-based passivation baths are generally less than those for nitric acid and other chemical acid baths, thus reducing both the emission of fumes and the evaporation of solutions. Also, because citric acid-based processing baths retain their potency for a longer period, they require refilling less frequently and they reduce the volume and potential toxicity of effluent and rinse water discharged into the city's sewer system.

Citric acid-based line speeds can run up to five times faster in some cases.[12] This promises major increases in production capacity in the same production space, a significant potential bonus in an area with high occupancy costs like New York City.

Finally, suppliers's test data show that citric acid equals the performance of nitric acid in salt spray (B117), copper sulfate, boiling water, and high humidity testing. In sum, suppliers contend, citric acid provides high-quality passivation of stainless steel while providing worker and environmental

[8] Lee Kremer, "Citric Acid Passivation of Stainless Steel" www.pfonline.com/articles/059905.html.

[9] *Ibid.*

[10] *Ibid.*

[11] *Ibid.*

[12] *Ibid.*

safety, versatility, ease of use, less maintenance and lower costs.[13]

The owner of Control Electropolishing had reviewed literature from U.S. EPA and various trade associations describing alternative technologies and processes for metal finishing. She had visited a supplier of citric acid-based systems and observed its in-house, 67-gallon test system do electropolishing of several metal parts she had brought with her for testing. She had also visited an electropolishing job shop in New England to observe its 15-gallon, citric acid-based test system and discuss its operations with that shop's managers.

These preliminary explorations convinced Control Electropolishing's owner that testing the viability of such systems for its operations and particular products would be worthwhile. But, they were insufficient to convince the owner, *prima facie*, that the new processes would be commercially viable and worth the capital costs of conversion.

What the company's owner -- and the owner of any small- to medium-size job shop -- needed to know before investing in the costs of a full-scale conversion of its existing processing systems to the new citric acid-based solutions is whether or not the new processing solutions would work for its particular mix of products and customers, both in terms of product quality and production volumes. This knowledge was critical for passivating and even more critical for electropolishing since there was much less information about the performance of citric acid-based solutions in electropolishing.

Each of the company's 1,000-or-so metal products would require the calibration of a unique table of settings for immersion time and temperature in the electropolishing or passivation baths as well as electric charge voltage in the electropolishing bath. In addition, commercial-scale operations would require, at a minimum, a 900-gallon system for electropolishing or a 270-gallon system for passivation (by comparison to the less-than-100-gallon test systems the owner had seen on site visits). Yet, there was no place to which the company could job out several hundred parts for calibrating and sample testing or from which it could obtain reliable information on commercial scale operations for its product mix.

Further, the manufacturers and suppliers of citric acid-based processing solutions would not warrant the results of their process on any particular products. For example, the manufacturer of CitriSurf, a product used in passivating, cautions on its website, "Testing of your products with CitriSurf before using in production is recommended. *Every product and production facility is different and requires testing* to ensure that CitriSurf is compatible with the particular situation. No warranty is implied or may be given ... without the written permission of [the manufacturer]." (Italics added)

Consequently, Control Electropolishing determined to proceed with an R&D effort, and Empire State Development's Environmental Management Investment Group made it possible. And, if the results of the project proved successful in terms of product quality, production volumes, and cost-effectiveness, the company's owner expected to seek financing to convert the company's

[13] *Ibid.*

operations to processing systems using citric acid-based solutions.

The R&D Process

The company installed and operated pilot-scale production test systems for both passivating and electropolishing. It then solicited several hundred samples of products from customers who were also interested in evaluating the quality of the products produced by the new solutions.

To determine the *technical feasibility of the new processing solutions as well as customer satisfaction with the products they produced,* the company did numerous pilot-scale processing runs to determine and calibrate the length of time of immersion in the processing solution, the temperature of the solution, and voltage of the electric charge to the solution that together are necessary to produce a product that meets the customer's specifications. [The company considers the calibrations for each product to be proprietary and confidential information.] It then performed such in-house, industry-standard quality tests as microscopic surface examination, boiling water corrosion test, copper salt spray test, and customer-supplied gauge tests to determine that the products met the company's standards and the customer's specifications. Finally, it sent the finished sample products back to customers to do their own testing and evaluation and to provide comments and suggestions.

To determine the *financial feasibility* of replacing the company's existing processing systems with the new citric acid-based systems, the company conducted pilot-scale production runs to determine labor time and costs, racking and handling procedures and difficulties, process cycle times, quantities and costs of chemicals and solutions used, quantities and quality of effluent discharged and fumes emitted (if any), and quantities and costs of hazardous waste removal (if any). The company then estimated potential cost-savings and productivity increases which could result from the conversion of its current production-scale processing systems to new citric acid-based systems.

To determine the *environmental benefits and impacts* of replacing the company's existing processing systems with the new citric acid-based systems, the company determined the types and quantities of chemicals used, the quantities and quality of effluent discharged and fumes emitted (if any), and the quantities and costs of hazardous waste removal (if any) during the R&D process. Based on these determinations, it developed annual estimates of chemical use, effluents, fumes, and hazardous waste if the company were to convert its full-scale operations to citric acid-based finishing systems, and it compared these estimates with benchmark data on these variables for its current processing systems.

Passivation

The company installed a production-scale, 270-gallon, passivation system fabricated by the Enequist Chemical Company. This system used the CitriSurf processing solution which is based on citric acid. One part CitriSurf was mixed with, on average, 12 parts water to produce one gallon of passivating solution. Because citric acid efficiently removes iron from the metal's surface, much lower concentrations are required than when using nitric acid.

Typical solutions range from 4%-to-10% citric acid by weight; the company's ran at about 7.7% (Table 1). By comparison, one gallon of nitric acid-based passivating solution requires one part nitric acid to one part water, a 50% concentration of nitric acid.

Table 1 Comparison of Nitric Acid and Citric Acid Passivation Solutions

	Price Chemical Solution Per Pound	Pounds Chemical Solution Per Gallon	Ratio Chemical Solution to Water per gallon Processing Solution	% Chemical Solution per gallon Processing Solution
Nitric Acid	$1.87	11.66	1 : 1	50.0%
Citric Acid Solution	$2.60	10.35	1 : 12	7.7%

The company ran several thousand pieces of fifty-one different products through the citric acid-based passivating process in pilot-scale production test runs. After two or, at most, three runs to calibrate the immersion time and solution temperature, the company achieved satisfactory results for all but four products on thickness gauge tests, microscopic surface examinations, and boiling water corrosion tests. [Figure 1 following.]. (It also determined the steps necessary to correct the deficiencies in the four products that failed the corrosion test.) Subsequently, the company received word from its customers that the quality of the finished test samples was satisfactory.

Figure 1.   Passivation R&D Test Results

Part Name/ Number	THICKNESS Unfinished	Citric 2 Process	SURFACE QUALITY Existing Process	Citric 2 Process	CORROSION Existing Process	Citric 2 Process
S/S 316 020358	0.0625	0.0625	Fair	Good	Passed	Passed
37799-00	0.0165	0.0165	Good	Excellent	Passed	Passed
80 Cam Bar	0.0165	0.0165	Fair	Good	Passed	Passed
60 Cam Bar	0.0165	0.0165	Good	Excellent	Passed	Passed
Carrier Clips	0.053	0.053	Good	Excellent	Passed	Passed
Restrictor	0.25	0.25	Good	Fair	Passed	Failed
18695-00	0.025	0.025	Good	Excellent	Passed	Passed
Sub-Assy Rod Artic	0.0405	0.0405	Good	Excellent	Passed	Passed
Filter Discs 22" dia.	0.015625	0.015625	Good	Excellent	Passed	Passed
Drive Arm 99737-00.B	0.0425	0.0425	Fair	Good	Passed	Passed
Filter Discs 30" dia.	0.01562	0.01562	Fair	Good	Passed	Passed
Sternum Wire Assy.	0.0625	0.0625	Good	Excellent	Passed	Passed
Crown Gear Upper	0.125	0.125	Fair	Good	Passed	Passed
Bar Center 10000-12257	0.0781	0.0781	Good	Excellent	Passed	Passed
Left Side Plate Assy.	0.0625	0.0625	Fair	Good	Failed	Passed
Support High Flag	0.03125	0.03125	Fair	Good	Passed	Passed
Nut F/V Adapter	0.25	0.25	Good	Excellent	Passed	Passed
Mandrels	0.0965	0.0965	Good	Excellent	Passed	Failed
80 V2 Cam Bar	0.0165	0.0165	Good	Excellent	Passed	Passed
Right Side Plate	0.0625	0.0625	Good	Excellent	Passed	Passed
10" Rotor	1.00	1.00	Fair	Good	Failed	Passed
72381-00	0.125	0.125	Fair	Good	Passed	Passed
Solution Tank	0.25	0.25	Fair	Good	Passed	Passed
10000-01570	0.0912	0.0912	Good	Excellent	Passed	Passed
10000-06457	0.0912	0.0912	Good	Excellent	Passed	Passed
732 Anvil Frame	0.125	0.125	Fair	Good	Failed	Passed
730 Channel Cartridge	0.0625	0.0625	Fair	Good	Passed	Passed
Spring Assy.	0.0624	0.0624	Good	Excellent	Passed	Passed
60 Knife	0.0165	0.0165	Fair	Good	Passed	Passed
271 Cartridge Support	0.125	0.125	Fair	Fair	Failed	Failed
104975-001	0.0781	0.0781	Fair	Good	Passed	Passed
Bottom Blade	0.0912	0.0912	Fair	Excellent	Passed	Passed
21-5023-101-15 Spacer	0.1875	0.1875	Fair	Good	Passed	Passed
22-16021-00 Spacer	0.1875	0.1875	Fair	Good	Passed	Passed
Crown Gear 3443	0.0625	0.0625	Fair	Excellent	Passed	Passed
GIAP50 Knives	0.0625	0.0625	Good	Excellent	Passed	Passed
GIAP90 Knives	0.0625	0.0625	Good	Excellent	Passed	Passed
34880-00 Knife Assy.	0.0625	0.0625	Fair	Good	Passed	Passed
DIGA Cam Bars	0.03125	0.03125	Fair	Good	Passed	Passed
37920-00 80 Cam Bars	0.03125	0.03125	Good	Excellent	Passed	Passed
37997-00	0.125	0.1245	Excellent	Poor	Passed	Failed
41563-00 Spacer Cam	0.03125	0.03125	Good	Excellent	Passed	Passed
42323 Thrust Bars	0.0781	0.0781	Fair	Good	Passed	Passed
49381-00 Staple	0.0468	0.0468	Good	Good	Passed	Passed
60508-005	0.03125	0.03125	Fair	Good	Passed	Passed
65084-00 Rod Universal	0.15625	0.15625	Good	Good	Passed	Passed
65110-01 Sub-Assy.	0.0625	0.0625	Fair	Good	Passed	Passed
65220-02 Channel 60	0.03125	0.03125	Fair	Good	Passed	Passed
72371-00 Right Side Pl	0.0625	0.0625	Good	Excellent	Passed	Passed
871-01107 Solution	0.125	0.125	Fair	Good	Passed	Passed
87932-00 Carrier	0.0625	0.0625	Good	Good	Passed	Passed

Producers of the citric acid-based solution represent that it can speed up processing by as much five times in some cases.

The company found that the immersion times in the citric acid-based solution generally ran half as long immersion times in its nitric acid solution. This 50% time-saving in process cycle times indicates that the productivity of the company's equipment could increase as much as 100% in the future, allowing for a doubling of sales volume and some new hiring and/or overtime as well. In planning for a future conversion to full production using a citric-acid based solution, the company expects to use a more conservative estimate of a 75% increase in production capacity.

The company did not experience any changes or difficulties with labor, racking and handling procedures using the citric-acid based solution.

Notwithstanding the higher price per pound of the citric-acid based solution (Table 1), the company found that it could achieve significant savings in chemical costs. The primary reason is the much lower concentration of citric acid in the passivating solution (1:12) compared to nitric acid (1:1) which results in a significant reduction in the quantity of chemicals using in filling the processing tank.

The company projects that the initial filling of its full-scale 660-gallon passivating tank would require 44 gallons of CitriSurf at a cost of $1,184. By comparison, filling the same tank requires 330 gallons of nitric acid-based solution at a cost of $7,178. The savings is 81% or $5,811 (Table 2).

Table 2 Comparison of Initial Fill-ups – Passivation Process

	INITIAL TANK FILL-UP					
	Processing Solution Tank Capacity Gallons	Gallons of Chemical Solution per Tank	Gallons of Water per Tank	Pounds of Chemical Solution per Tank	Cost of Chemical Solution per Tank	% Cost Saving
Nitric Acid	660	330	330	3,848	$7,178	
Citric Acid Proposed	660	51	609	525	$1,366	
Cost Savings from Chemical Substitution					$5,811	81.0%

The second reason for the cost-saving is that, because of the shorter immersion times, the citric-acid based solution retained its potency for a longer period of time, incurred less evaporations, and required additional refilling with citric acid less frequently. To estimate a range of potential savings on an annual basis at full production, the company assumed two rates for the frequency of refilling. The "high" rate is the equivalent of the refill rate for the exiting nitric acid solution and would require 440 pounds of citric acid-based solution. The "low" rate, which the company's experience indicates is more likely, assumes that 55 pounds of citric acid-based solution would be added every other month (330 pounds per year) to replenish the 660-gallon passivation tank.

Both rates of refilling would achieve significant savings -- ranging from 81% to 86% -- against the annual costs of replenishing the nitric acid (Table 3).

Table 3. Comparison of Annual Refills

	Annual Cost of Chemical Solution	% Cost Saving	Annual Pounds of Chemical Solution	Pounds Chemical Solution Per Gallon	Gallons Chemical Solution Added Per Year	Parts Chemical Solution per Gallon	Gallons Water Added Per Year
Nitric Acid – annual refills	$6,016		3,225	11.66	277	1 : 1	277
Citric Acid – annual refill range							
Citric Acid – refills high	$1,145		440	10.35	43	1 : 12	511
Citric Acid – refills low	$858		330	10.35	32	1 : 12	383
Chemical Substitution							
Cost Savings – high refill rate	$4,871	81.0%					
Cost Savings – low refill rate	$5,158	85.7%					

Finally, the company found that the quality of the citric acid-based solution could be maintained more easily by adding additional water. The nitric acid-based solution eventually becomes contaminated, requiring disposal and replacement of the entire solution. The company estimates that it would avoid the $13,200 costs of replacing and replenishing the entire contents of the nitric acid solution. And, that even if it fully and replenished the citric acid-based solution, it would achieve overall savings of nearly $11,000 (Table 4).

Total 4. Estimated Chemical Cost Savings from Change in Processing Solutions

	Price Chemical Solution Per Pound	Pounds of Chemical Solution	Cost of Chemical Solution	% Cost Saving
Nitric Acid				
Nitric Acid – initial fill-up	$1.87	3,848	$7,178	
Nitric Acid – annual refills	$1.87	3,225	$6,016	
Nitric Acid – total		7,073	$13,194	
Citric Acid - Proposed				
Citric Acid – initial fill-up	$2.60	525	$1,366	
Citric Acid – refill range				
Citric Acid – refills high	$2.60	440	$1,145	
Citric Acid – refills low	$2.60	330	$858	
Citric Acid – total				
Citric Acid – initial & high refill		966	$2,511	
Citric Acid – initial & low refill		855	$2,224	
Chemical Substitution				
Cost Savings – high refill rate			$10,682	81.0%
Cost Savings – low refill rate			$10,969	83.1%

In addition to these chemical cost savings, the company estimates there will be small, but indeterminate savings in insurance; safety equipment, tank cleaning, electricity and gas expenses. In the R&D process, the citric acid did not require the company's employees to use special handling equipment, safety equipment, or respirators for employees. It was also stored as a nonhazardous chemical.

The company could not evaluate the citric acid-based solution's corrosive or wear-and-tear effects on its processing equipment because the R&D process did not extend over a sufficient period of time.

Accordingly, based on product quality, immersion time-savings, increased equipment productivity, and material costs savings, the company concluded that the conversion to citric acid-based passivation is likely to be both technically and financially feasible as well as satisfactory to customers.

There would also be benefits for the environment and the workplace from the conversion to citric acid-based passivation.

Conversion would eliminate nearly two tons of nitric acid in favor of less than half a ton of citric acid (Table 6 & Table 7).

Table 5 Annual Chemical Use -- Avoidance of Nitric Acid

	Chemical Solution Pounds Avoided	Chemical Solution Tons Avoided	% of Active Ingredient	Pounds Avoided	Tons Avoided
Nitric Acid – initial fill-up	3,848	1.9	52%	2,001	1.0
Nitric Acid – annual refills	3,225	1.6	52%	1,677	0.8
Nitric Acid – total	7,073	3.5	52%	3,678	1.8

Table 6 Annual Chemical Use – Proposed Use of Citric Acid

	Chemical Solution Pounds Proposed	Chemical Solution Tons Proposed	% of Active Ingredient	Pounds Proposed	Tons Proposed
Citric Acid - Proposed					
Citric Acid – initial fill-up	525	0.26	100%	525	0.26
Citric Acid – annual refill range					
Citric Acid – refills high	440	0.22	100%	440	0.22
Citric Acid – refills low	330	0.17	100%	330	0.17
Citric Acid – total					
Citric Acid – initial & high refill	966	0.48	100%	966	0.48
Citric Acid – initial & low refill	855	0.43	100%	855	0.43

Replacing nitric acid in the passivation process will also reduce the volume and lower the acidity of rinse water and waste water discharged into the city's sewer system because of the much lower concentration of citric acid in the passivating solution (1:12) compared to nitric acid (1:1). The company estimates that it will eliminate the discharge of 277 gallons of nitric acid solution annually and, instead, discharge about 32 to 43 gallons of citric acid solution.

Table 7 Comparison of Annual Waste Water Discharge

	Refills Annual Pounds of Chemical Solution	Pounds Chemical Solution Per Gallon	Gallons Chemical Solution Added Per Year	Parts Chemical Solution per Gallon	Gallons Water Added Per Year	Total Gallons Disposed & Added Per Year
Nitric Acid						
Nitric Acid – annual refills	3,225	11.66	277	1 : 1	277	554
Citric Acid – annual refill range						
Citric Acid – refills high	440	10.35	43	1 : 12	511	554
Citric Acid – refills low	330	10.35	32	1 : 12	383	415

The company could not evaluate the effects on the presence of hazardous materials, free iron, and iron oxides, nickel, chromium, or other heavy metals in its waste stream since it could not segregate the R&D waste from the waste generated by the company's conventional processing systems.

Finally, replacing nitric acid in the passivation process will eliminate the emission of nitrous oxide vapors which can be harmful to the company's workers and the environment. The company estimates the reduction in fumes to be approximately 1,000 cubic feet a year.

Electropolishing

The company installed a production-scale, 900-gallon, electropolishing system fabricated by a Massachusetts manufacturer of metals finishing equipment. The manufacturer represented that it would supply the company with a citric-acid based processing solution which contained no, or almost no, phosphoric and sulfuric acids as well as a wetting agent that would reduce the amount of hydrochloric acid needed in the rinsing process.

The use of citric acid was intended to have several benefits. In processing, it was expected to reduce the amounts of phosphoric and sulfuric acids used in the processing solution. As a result, it was expected to shorten the immersion times because citric acid is more efficient in removing iron from the metal's surfaces. It was also expected to reduce the density of the processing solution making it easier to rinse off the sticky green residual film of iron phosphate that covers the metal when it is removed from the processing bath. In turn, in rinsing, it was expected that there would be reduction in the quantity of hydrochloric acid that is needed to rinse the film from the metal when it is placed in the rinsing tank. This would enable the rinsing solution to retain its potency for a longer period and require less frequent refilling with hydrochloric acid.

Upon receiving the processing solution from the manufacturer, the company had an independent chemical firm inspect the solution and it discovered that the solution contained both contaminants from a prior use and much higher percentages of the phosphoric and sulfuric acids than had been represented. Because the contamination made the solution unusable, the company rejected the shipment, and it sued the manufacturer for misrepresentation and other grounds. The company also sought other sources of a citric acid-based electropolishing solution, but it was unable to locate a solution which contained more than trace amounts of an organic acids like citric acid.

The company did identify a proprietary processing solution which it anticipated could achieve many of the environmental benefits it was aiming at. The supplier indicated that the proprietary solution produced a different electrolyte and had better conductivity than the company's conventional solution. As a result, the proprietary solution should produce a better quality finish in shorter immersion time using less electrical power as well as possibly less solution depending on the cleanliness of the processing bath. The supplier also indicated that the proprietary solution would be less viscous, enabling the metal parts to be rinsed more easily and possibly reducing the amounts of hydrochloric acid refills as well. Finally, the supplier indicated that the solution would alter the composition of the company's effluent discharge, reducing the amounts of phosphoric acid and phosphates which are not soluble in water and increasing the quantities of sulfuric acid and sulfate salts which are.

On that basis, the company elected to proceed with the R&D effort using the proprietary solution although it contained only a trace amount of organic acid and no citric acid.

Table 8 compares the chemical composition of the company's current electropolishing solution with the proprietary solution used in its R&D process. The existing processing solution is 80% phosphoric acid and 20% sulfuric acid. The active ingredient in the phosphoric acid is 85%, and in the sulfuric acid it is 93%.

By comparison, the company estimates that the proprietary R&D test solution is 55% phosphoric acid and 45% sulfuric acid.[14] The supplier indicates that he active ingredient in the phosphoric acid is 85%, and in the sulfuric acid it is 93%.

Table 9 summarizes the net effects of these different formulas. The company's current processing solution contains 68% active phosphoric acid, 19% active sulfuric acid, and 13% water. By comparison, the R&D test solution contains 47% active phosphoric acid, 42% active sulfuric acid, and 11% water.

[14] The supplier reports that the proprietary solution is a blend of between 50% to 60% phosphoric acid and between 40% to 50% sulfuric acid with a trace of an unspecified organic acid. For convenience, this report uses the midpoint in both ranges: 55% phosphoric and 45% sulfuric.

Table 8. Chemical Composition of Processing Solutions

	% Chemical Solution per gallon		% of Active Ingredient in Chemical Solution		% of Water	
	CURRENT	R &D TEST	CURRENT	R &D TEST	CURRENT	R &D TEST
Processing solution						
Phosphoric Acid	80%	55%	85%	85%	15%	15%
Sulfuric Acid	20%	45%	93%	93%	7%	7%

Table 9. Proportions of Net Active Chemical Ingredients in Processing Solutions

	CURRENT			R & D			Difference	
							Active Ingredient	Water
	Chemical Solution	Active Ingredient	Water	Chemical Solution	Active Ingredient	Water	% Increase (Decrease)	% Increase (Decrease)
Processing solution								
Phosphoric Acid	80	68	12	55	47	8	-31%	
Sulfuric Acid	20	19	1	45	42	3	125%	
total solution	100	87	13	100	89	11	2%	-15%

The company ran several thousand pieces of 104 different products through the R&D electropolishing process in pilot-scale production test runs. After two or, at most, three runs to calibrate the immersion time, solution temperature, and electrical charge, the company achieved satisfactory results for all but four products on thickness gauge tests, micro-inch finish examinations, and deburring tests [Figure 2 following]. (The four unsatisfactory products were rated “fair” on the micro-inch finish examination.) Subsequently, the company received word from its customers that the quality of the finished test samples was satisfactory.

The company found that immersion times for products in the electropolishing R&D processing solution were an average of 28.5% less than the processing times in its conventional processing solution. The R&D process also ran at lower temperatures and required a lower electrical charge than the conventional process.

This 28.5% time-saving in process cycle times indicates that the productivity of the company’s equipment could increase by as much as 40% in the future, allowing for increased sales and some new hiring and/or overtime as well. In planning for a future conversion to full production using the R&D test solution, the company expects to use a more conservative estimate of a 25% increase in production capacity.

The company did not experience any changes or difficulties with labor, racking and handling procedures using the R&D test processing solution.

Figure 2. Electropolishing R&D Test Results

Part Name/Number	**Thickness** Unfinished	Citric 1 Process	**Micro-inch finish** Existing Process	Citric 1 Process	**Deburring** Existing Process	Citric 1 Process
Pan Shell	0.252	0.251	Fair	Good	Unacceptable	Acceptable
Flat pieces 3" x 5"	0.301	0.305	Fair	Good	Unacceptable	Acceptable
Box 24" x 12" x 12"	0.125	0.124	Good	Acceptable	Fair	Good
Washer	0.25	0.2475	Fair	Good	Unacceptable	Acceptable
Washer	0.25	0.245	Good	Acceptable	Good	Excellent
Fixture #19	1.00	0.9575	Fair	Good	Good	Excellent
Fixture #20	1.00	0.957	Good	Acceptable	Good	Excellent
Screws 5/10- 18 x 3/4"	0.75	0.745	Unacceptable	Fair	Fair	Good
Standup Brackets XACB-C02	0.248	0.246	Fair	Good	Fair	Good
Leg Base Brackets	0.249	0.245	Fair	Good	Fair	Good
Guide Rail Brackets	0.275	0.274	Good	Acceptable	Good	Excellent
Wire Prototypes	0.125	0.124	Fair	Good	Fair	Good
Wire Prototypes	0.125	0.1225	Good	Acceptable	Good	Excellent
Small Retaining Rings	0.0625	0.062	Unacceptable	Fair	Unacceptable	Acceptable
Small Retaining Rings	0.0625	0.0575	Good	Acceptable	Fair	Good
Small Retaining Rings	0.0625	0.0575	Fair	Good	Good	Excellent
Tricor	0.045	0.044	Fair	Good	Fair	Good
Shield Standoff	0.06	0.055	Fair	Good	Fair	Good
Scale Pan	0.25	0.245	Unacceptable	Fair	Unacceptable	Acceptable
Sample Set	0.335	0.332	Fair	Good	Fair	Good
Sample Set	0.335	0.33	Good	Acceptable	Good	Excellent
Sample #1	0.25	0.245	Fair	Good	Fair	Good
Sample #2	0.25	0.244	Fair	Good	Fair	Good
Sample #3	0.25	0.24	Good	Acceptable	Good	Excellent
Fastener 61401	0.125	0.124	Fair	Good	Fair	Good
Fastener 61401	0.125	0.1275	Good	Acceptable	Good	Excellent
Short Mandrels 1000-01570	0.125	0.1245	Good	Acceptable	Good	Excellent
Long Mandrels 10000-01570	0.125	0.1245	Fair	Good	Fair	Good
R412-1	0.25	0.245	Fair	Good	Good	Excellent
R412-2	0.25	0.245	Fair	Good	Good	Excellent
Bracket 33219	0.0625	0.0622	Fair	Good	Excellent	Excellent
5380-202-000	0.335	0.334	Good	Excellent	Good	Excellent
Brackets	0.245	0.244	Fair	Acceptable	Fair	Good
Flanges	0.1665	0.166	Good	Acceptable	Good	Excellent
Flanges	0.1665	0.1655	Good	Excellent	Good	Excellent
Bracket, Handle 33219	0.25	0.245	Good	Acceptable	Fair	Good
5380-202-000	0.315	0.31	Fair	Good	Fair	Good
5380-202-000-1	0.315	0.305	Good	Acceptable	Good	Excellent
286	0.0105	0.01	Fair	Good	Good	Excellent
25-0764A2	0.025	0.02	Fair	Good	Fair	Good
13-8 Rod Drive	0.105	0.102	Fair	Good	Fair	Good
Endo Handle Universal	0.033	0.032	Good	Acceptable	Good	Acceptable
57410 Sub 9 KDF Rack	0.255	0.25	Fair	Good	Fair	Good
57410-1 Sub 9 KDF Stand	0.245	0.24	Good	Acceptable	Good	Excellent
Capillary Device DNA	0.054	0.053	Good	Excellent	Good	Excellent
Mounting Plate 1/16"	0.0625	0.062	Good	Acceptable	Good	Excellent
129129 G1	0.0665	0.0662	Fair	Good	Fair	Good
87364-00	0.125	0.124	Good	Acceptable	Good	Excellent
Bracket Swivel "U"	0.25	0.245	Good	Acceptable	Good	Excellent
MC=0224-01	0.25	0.24	Good	Acceptable	Good	Excellent
Chamber Head	0.335	0.333	Fair	Good	Fair	Good
Chamber Head	0.335	0.331	Good	Acceptable	Good	Excellent

Figure 2. Electropolishing R&D Test Results continued

Part Name/Number	Thickness Unfinished	Thickness Citric 1 Process	Micro-inch Finish Existing Process	Micro-inch Finish Citric 1 Process	Deburring Existing Process	Deburring Citric 1 Process
100mm Bar Cam	0.0625	0.0624	Fair	Good	Fair	Good
Premium II Surgiclip	0.125	0.124	Good	Acceptable	Good	Excellent
Mounting Plate 0.25"	0.25	0.244	Fair	Good	Fair	Good
Channel Cartridge 45 4.8	0.0625	0.0622	Good	Acceptable	Good	Excellent
S/S Letter "A"	0.125	0.124	Good	Acceptable	Good	Excellent
87193-00 U Channel	0.125	0.124	Good	Acceptable	Good	Excellent
34915-00 Carriers	0.0625	0.0622	Good	Excellent	Good	Excellent
10000-12941	0.062	0.06	Fair	Good	Fair	Good
10000-00351	0.125	0.125	Fair	Good	Good	Excellent
3187790	0.0615	0.06	Fair	Good	Good	Excellent
3187794A	0.0625	0.06	Good	Acceptable	Good	Excellent
10000-03592	0.009	0.0085	Fair	Fair	Fair	Good
Stars	0.1875	0.1873	Good	Acceptable	Good	Excellent
430 FR Valves	0.064	0.062	Fair	Good	Fair	Good
53196-00	0.0625	0.062	Good	Excellent	Good	Excellent
97244-00	0.007	0.007	Fair	Acceptable	Good	Excellent
Shelf, Monitor Arm	0.25	0.245	Fair	Good	Good	Excellent
E00000-1253 Rev. D	0.335	0.331	Fair	Good	Good	Excellent
S/S Letter "B"	0.1875	0.187	Good	Excellent	Good	Excellent
Threaded Shaft	0.125	0.1245	Fair	Good	Good	Excellent
Cutter Flanges	0.1975	0.197	Fair	Good	Good	Excellent
Tube	0.06125	0.612	Good	Acceptable	Good	Excellent
316L Filter Bodies	0.125	0.122	Fair	Good	Good	Excellent
#125 Nozzle	0.125	0.124	Good	Acceptable	Good	Excellent
#140 Nozzle	0.1406	0.1402	Fair	Good	Fair	Good
#180 Nozzle	0.145	0.144	Fair	Good	Fair	Good
#187 Nozzle	0.156	0.155	Good	Excellent	Good	Excellent
#225 Propeller	0.25	0.245	Good	Excellent	Good	Excellent
#260 Nozzle	0.1725	0.172	Fair	Good	Good	Excellent
#265 Nozzle	0.1875	0.187	Fair	Good	Good	Excellent
#370 Nozzle	0.2032	0.203	Fair	Good	Good	Excellent
One Meter Arch Bar	0.2187	0.2182	Good	Excellent	Good	Excellent
IA Body	0.03125	0.0312	Fair	Good	Good	Excellent
IA Handle	0.01562	0.0156	Fair	Good	Good	Excellent
0334-142-00	0.09375	0.0937	Good	Acceptable	Good	Acceptable
0334-1148-01	0.07821	0.078	Fair	Good	Good	Excellent
090-212	0.0625	0.062	Good	Acceptable	Good	Excellent
090-606	0.09375	0.0937	Fair	Good	Good	Excellent
Hangers	0.15625	0.1562	Fair	Good	Good	Excellent
10000-04369 Channel 30	0.03125	0.0312	Good	Acceptable	Good	Excellent
10000-04883 Pusher Bar 30	0.008	0.0075	Fair	Good	Good	Excellent
10000-05371 Insert	0.015625	0.01562	Fair	Good	Good	Acceptable
10000-09244 Channel 60	0.03125	0.0312	Fair	Good	Fair	Good
10000-12940 Chan. Cartridge	0.03125	0.0312	Fair	Good	Fair	Good
10000-12941 Chan. Cartridge	0.03125	0.0311	Fair	Good	Good	Acceptable
1005037 Housing	0.3125	0.312	Fair	Good	Good	Excellent
Rail, Hand	0.1875	0.1873	Fair	Good	Good	Excellent
Cross Bar	0.375	0.373	Good	Acceptable	Good	Excellent
Support	0.25	0.25	Fair	Good	Good	Excellent
Locking Hood Hinge	0.125	0.125	Fair	Good	Good	Excellent
Hood Hinge Arm	0.0625	0.0622	Good	Acceptable	Good	Acceptable
Staple	0.1562	0.156	Fair	Good	Good	Excellent

Looking ahead, the company anticipates that the productivity gains resulting from the increased efficiency of processing in the R&D test acid will offset the increases in the costs of chemicals resulting from the replacement of its conventional processing solution.

The R&D test processing solution is more expensive than the chemicals in its conventional electropolishing solution, $0.76 per pound compared to $0.62 per pound for phosphoric acid and $0.24 per pounds for sulfuric acid (Table 10).

Table 10. Price of Chemical Solutions

	Price Chemical Solution Per Pound
Phosphoric Acid	$0.62
Sulfuric Acid	$0.24
R&D test solution	$0.76

The company estimates that the cost of the initial fill-up of its full-scale, 1,800-gallon processing tank would be $19,710 using the R&D test solution, 40% more than the $14,113 cost of the initial fill-up using its conventional blend. (Table 11). No difference is expected in the quantity or cost of hydrochloric acid used in the initial fill-up of the rinsing tank.

Table 11. Comparison of Costs for Initial Fill-Up of Electropolishing Tanks

	Price Chemical Solution Per Pound	Fill-up Cost Chemical Solution CURRENT	R&D TEST SOLUTION	Increase (Decrease)	%
Processing solution					
Phosphoric Acid	$0.76	$12,740			
Sulfuric Acid	$0.76	$1,373			
R & D Solution	$0.76	$0	$19,710		
total processing		$14,113	$19,710	$5,597	40%
Rinsing solution					
Hydrochloric Acid	$0.33	$391	$391	$0	0%
Total Chemical Costs		$14,504	$20,101	$5,597	39%

Because the R&D test solution resulted in shorter immersion times and used lower temperatures, the company expects that full-scale, annual processing with such a solution should incur lower rates of evaporation and should require refilling less frequently than its conventional blend so long as it maintains the cleanliness of the processing bath. It also anticipates that rinsing will be easier so the rinsing tank should require less refilling.

Because it is difficult to estimate the extent of the possible reductions in annual refills, the company developed two sets of estimates to provide a range of possible annualized financial and operating impacts. One assumes that there are no annual savings in processing and rinsing solutions. The other assumes top annual savings of 14%, which represents half of the 28.5% average reduction in immersion times.

Because of the higher price of the R&D test solution, the company estimates that the annual cost of refilling its processing solution will increase from $16,332 to $23,000 – a 47% increase – if there were no reduction in the amount of solution used (Table 12). It estimates that the increase will be less -- up to $19,723 or 37% increase – if there were a 14% savings in solution.

Table 12. Comparison of Costs for Annual Refills of Electropolishing Tanks

	Price Chemical Solution Per Pound	Refills Annual Cost of Chemical Solution CURRENT	R&D TEST SOLUTION WITH 0% Solution Savings	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings	Increase (Decrease)	%
Processing solution								
Phosphoric Acid	$0.62	$14,730						
Sulfuric Acid	$0.24	$1,602						
R & D Solution	$0.76	$0	$23,000			$19,723		
total processing		$16,332	$23,000	$6,669	47%	$19,723	$3,391	21%
Rinsing solution								
Hydrochloric Acid	$0.33	$1,015	$1,015	($0)	0%	$870	($145)	-14%
Total Chemical Costs		$17,347	$24,015	$6,669	38%	$20,593	$3,246	19%

As indicated, the company anticipates that the potential 40% gain in the productivity of its processing system using the R&D test solution will offset both the 40% increase in the initial fill-up cost and the possible 21% to 47% increase in annual refill cost. This is the case for two reasons. First, although the percentage increases in chemical costs are significant, the absolute dollar amounts are relatively small, less than $7,000. Second, the costs of chemicals is a small percentage of the company's costs of sales. Hence, incurring a modest increase in a small fraction of operating costs to reap a potential 40% gain in overall production volume appears to be a viable trade-off.

As additional offsets to the increases in chemical costs, the company estimates that there will also be small, but indeterminate savings in tank cleaning, electricity and gas expenses.

The company could not evaluate the corrosive or wear-and-tear effects of the R&D test solution on its processing equipment because the R&D process did not extend over a sufficient period of time.

In sum, because the increases in chemical costs are likely to be offset by immersion time-savings and increases in system productivity, the company concludes that conversion to full-scale production with the R&D test solution is likely to be both technically and financially feasible. And, based on product quality and customer reaction to test samples, it concludes that conversion will be satisfactory to its customers as well.

Conversion to the R&D test processing solution will benefit both the environment and the workplace as well.

Although the volume of solution used in the initial fill-up of the company's 1,800 gallon processing tank would be the same, the mix and quantity of acids differ significantly (Tables 13, 14 & 15). The company estimates that filling its 1,800 gallon tank with the R&D test solution would:

- reduce the amount of phosphoric acid solution by 31% -- down 450 gallons, 6,291 pounds, or 3.1 tons to 990 gallons, 14,349 pounds, or 7.2 tons; and,

- increase the amount of sulfuric acid solution by 125% -- up 450 gallons, 6,100 pounds, or 3.1 tons to 810 gallons, 11,740 pounds, or 5.9 tons.

Tables 16 & 17 adjust these figures in terms of the estimated net weights of the active chemicals in the processing solutions. Table 8 above presented the net active ingredients in the processing solution. The hydrochloric acid rinsing solution is 31% acid.

Using the R&D test solution, the company estimates that the net active chemical ingredients in its 1,800 gallon tank would include:

- 31% less net active phosphoric acid -- a reduction of 5,347 pounds (2.7 tons) to 12,197 pounds (6.1 tons);

- 108% more net active sulfuric acid – an increase of 5,673 pounds (2.8 ton) to 10,918 pounds (5.5 tons); and,

- a 1.4% overall increase in the aggregate net weight of active processing chemicals (phosphoric and sulfuric acids) – an increase of 326 pounds (0.2 tons) up to 23,115 pounds (11.6).

Table 13. Estimated Volume of Chemical Solutions Used in Electropolishing - Initial Fill-up

	Fill-up Gallons Chemical Solution per Tank			
	CURRENT	R&D TEST SOLUTION	Increase (Decrease)	%
Processing solution				
Phosphoric Acid	1,440	990	(450)	-31%
Sulfuric Acid	360	810	450	125%
total solution	1,800	1,800	0	0%
Rinsing solution				
Hydrochloric Acid	120	120	0	0%

Table 14. Estimated Pounds of Chemical Solutions Used in Electropolishing - Initial Fill-up

	Pounds Chemical Solution Per Gallon	Fill-up Pounds Chemical Solution			
		CURRENT	R&D TEST SOLUTION	Increase (Decrease)	%
Processing solution					
Phosphoric Acid	14.33	20,640	14,349	(6,291)	-31%
Sulfuric Acid	15.67	5,640	11,740	6,100	108%
total solution	14.49	26,280	26,090	(190)	-1%
Rinsing solution					
Hydrochloric Acid	9.67	1,160	1,160	0	0%

Table 15. Estimated Tons of Chemical Solutions Used in Electropolishing - Initial Fill-up

	Fill-up Tons Chemical Solution			
	CURRENT	R&D TEST SOLUTION	Increase (Decrease)	%
Processing solution				
Phosphoric Acid	10.3	7.2	(3.1)	-31%
Sulfuric Acid	2.8	5.9	3.1	108%
total solution	13.1	13.0	(0.1)	-1%
Rinsing solution				
Hydrochloric Acid	0.6	0.6	0.0	0%

Table 16. Estimated Net Active Weight of Chemicals Used in Electropolishing - Initial Fill-up

	Fill-up Pounds Active Chemicals CURRENT	R&D TEST SOLUTION	Increase (Decrease)	%
Processing solution				
Phosphoric Acid	17,544	12,197	(5,347)	-31%
Sulfuric Acid	5,245	10,918	5,673	108%
total solution	22,789	23,115	326	1%
Rinsing solution				
Hydrochloric Acid	360	360	0	0%

Table 17. Estimated Net Active Weight of Chemicals Used in Electropolishing - Initial Fill-up

	Fill-up Tons Active Chemicals CURRENT	R&D TEST SOLUTION	Increase (Decrease)	%
Processing solution				
Phosphoric Acid	8.8	6.1	(2.7)	-31%
Sulfuric Acid	2.6	5.5	2.8	108%
total solution	11.4	11.6	0.2	1%
Rinsing solution				
Hydrochloric Acid	0.2	0.2	0.0	0%

With respect to annual refills of processing solution, there would be changes in the company's use of chemicals as a result of the difference in the formulas for the processing solutions. Because of the shorter immersion times and lower processing temperatures in the R&D solution, the company expects that there could also be reductions in its annual chemical refills. As indicated above, company developed a range of estimates for these possible reductions, at the bottom end assuming no annual savings in processing and rinsing solutions and the high end assuming a 14% annual savings. Tables 18 - 21 illustrate the possible effects on chemical use at the low and high ends.

If there were no savings in the amount of processing solution (by weight) refilled annually, the company estimates that full-scale production using the R&D test solution would have no effect on the aggregate weight of chemical solution refills (Tables 18 & 19). It would:

- increase the aggregate net weight of active processing chemicals (phosphoric and sulfuric acids) by 2% – up 570 pounds (0.3 tons) to 26,974 pounds (13.5 tons)

(Tables 20 & 21);

- reduce annual refills of phosphoric acid solution by 30% -- down 7,180 pounds (3.6 tons) to 16,745 pounds (8.4 tons) (Tables 18 & 19);
- reduce the net weight of annual refills of phosphoric acid by 30% -- down 6,052 pounds (3.0 tons) to 14,233 pounds (7.1 tons) (Tables 20 & 21).;
- increase annual refills of sulfuric acid solution by 108% -- up 7,120 pounds (3.6 tons) to 13,700 pounds (6.9 tons) (Tables 18 & 19); and,
- increase the net weight of annual refills of sulfuric acid by 108% -- up 6,622 pounds (3.3 tons) to 12,741 pounds (6.4 tons) (Tables 20 & 21).

If there were a 14% reduction in the amount of processing solution (by weight) refilled annually, the company estimates that full-scale production using the R&D test solution would:

- reduce the aggregate weight of chemical solution refills by 14% -- down 4,338 pounds (2.2 tons) to 26,107 pounds (13.1 tons) (Tables 18 & 19);
- reduce the aggregate net weight of active processing chemicals (phosphoric and sulfuric acids) by 12% – down 3,274 pounds (1.6 tons) down to 23,130 pounds (11.6 tons) (Tables 20 & 21);
- reduce annual refills of phosphoric acid solution by 40% -- down 9,506 pounds (4.8 tons) to 14,359 pounds (7.2 tons) (Tables 18 & 19);
- reduce the net weight of annual refills of phosphoric acid by 40% -- down 8,080 pounds (4.0 tons) to 12,205 pounds (6.1 tons) (Tables 20 & 21).;
- increase annual refills of sulfuric acid solution by 79% -- up 5,168 pounds (2.6 tons) to 11,748 pounds (5.9 tons) (Tables 18 & 19); and,
- increase the net weight of annual refills of sulfuric acid by 79% -- up 4,806 pounds (2.4 tons) to 10,926 pounds (10.5 tons) (Tables 20 & 21).

As to the rinsing solution, the company estimates that there would be no change in the amount of hydrochloric acid refilled annually if there were no savings in the amount of processing solution refilled annually. It estimates that there would be a 14% reduction in the amount of hydrochloric acid used annually if there were a 14% reduction in the amount of processing solution (Tables 18 - 21).

Table 18. Estimated Annual Refills of Chemical Solutions for Electropolishing - Pounds

	Refills Pounds Chemical Solution CURRENT	R&D TEST SOLUTION WITH 0% Solution Savings	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings	Increase (Decrease)	%
Processing solution							
Phosphoric Acid	23,865	16,745	(7,120)	-30%	14,359	(9,506)	-40%
Sulfuric Acid	6,580	13,700	7,120	108%	11,748	5,168	79%
total solution	30,445	30,445	0	0%	26,107	(4,338)	-14%
Rinsing solution							
Hydrochloric Acid	3,045	3,045	0	0%	2,611	(434)	-14%

Table 19. Estimated Annual Refills of Chemical Solutions for Electropolishing - Tons

	Refills Tons Chemical Solution CURRENT	R&D TEST SOLUTION WITH 0% Solution Savings	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings	Increase (Decrease)	%
Processing solution							
Phosphoric Acid	11.9	8.4	(3.6)	-30%	7.2	(4.8)	-40%
Sulfuric Acid	3.3	6.9	3.6	108%	5.9	2.6	79%
total solution	15.2	15.2	0.0	0%	13.1	(2.2)	-14%
Rinsing solution							
Hydrochloric Acid	1.5	1.5	0.0	0%	1.3	(0.2)	-14%

Table 20. Estimated Net Active Weight (Lbs) of Chemicals in Electropolishing - Annual Refills

	Refills Pounds Active Chemical Ingredient CURRENT	R&D TEST SOLUTION WITH 0% Solution Savings	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings	Increase (Decrease)	%
Processing solution							
Phosphoric Acid	20,285	14,233	(6,052)	-30%	12,205	(8,080)	-40%
Sulfuric Acid	6,119	12,741	6,622	108%	10,926	4,806	79%
total solution	26,404	26,974	570	2%	23,130	(3,274)	-12%
Rinsing solution							
Hydrochloric Acid	944	944	0	0%	809	(135)	-14%

Table 21. Estimated Net Active Weight (tons) of Chemicals in Electropolishing - Annual Refills

	Refills Tons Active Chemical Ingredient CURRENT	R&D TEST SOLUTION WITH 0% Solution Savings	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings	Increase (Decrease)	%
Processing solution							
Phosphoric Acid	10.1	7.1	(3.0)	-30%	6.1	(4.0)	-40%
Sulfuric Acid	3.1	6.4	3.3	108%	5.5	2.4	79%
total solution	13.2	13.5	0.3	2%	11.6	(1.6)	-12%
Rinsing solution							
Hydrochloric Acid	0.47	0.47	0.00	0%	0.40	(0.07)	-14%

Conversion to full-scale production using the R&D test solution would affect the volume of effluent and rinse water discharged into the city's sewer system as well as its acidic composition. (Tables 22 - 24).

If there were no savings in the amount of processing solution refilled annually, the company estimates there would be a 1% increase in the gallons (15) of chemical solution discharged (based on the difference in weight per gallon of the two formulas) (Table 22). If there were a 14% reduction in the amount of processing solution refills, there would be an estimated 14% decrease in the gallons (329) of chemical solution discharged annually (Table 22).

The composition of the effluent discharge would experience a significant change. If there were no reduction in the amount of processing solution refills, discharges of phosphoric acid solution and phosphates would decrease by 30% – down 510 gallons to 1,155. If there were a 14% savings in refill solutions, the decrease would be 40% – down 674 gallons to 991. These decreases would be offset by increases in discharges of sulfuric acid solution and sulfate salts. If there were no reduction in the amount of processing solution refills, increases in sulfuric acid and sulfate discharges would be 125% – up 525 gallons to 945. If there were a 14% savings in refill solutions, the increase would be 93% – up 391 gallons to 811. (Tables 22 -24)

Table 22. Estimated Annual Discharge of Chemical Solutions from Electropolishing

	Refills Gallons Chemical Solution Added & Discharged Per Year CURRENT	R&D TEST SOLUTION WITH 0% Solution Savings	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings	Increase (Decrease)	%
Processing solution							
Phosphoric Acid	1,665	1,155	(510)	-30%	991	(674)	-40%
Sulfuric Acid	420	945	525	125%	811	391	93%
total solution	2,085	2,100	15	1%	1,801	(284)	-14%
Rinsing solution							
Hydrochloric Acid	315	315	0	0%	270	(45)	-14%
Total Effluent	2,400	2,415	15	1%	2,071	(329)	-14%

No water in addition to that which is included as the inactive ingredient in the chemical solution needs to added to the processing solution under either formula. By contrast, the rinsing solution is 1 part hydrochloric acid to 4 parts water.

If there were no reduction in the processing solution refills and, therefore, no reduction in rinsing solution refills, the rinsing tank would add and discharge an estimated 1,260 gallons of water annually. If there were a 14% savings on processing solution refills, the company estimates the amount of water added to, and discharged from, the rinse tank would be reduced by 14% (180 gallons) to 1,080 gallons annually (Table 23).

Table 23. Estimated Additional Annual Waste Water Discharge

	Refills Gallons Water Added & Discharged Per Year CURRENT	R&D TEST SOLUTION WITH 0% Solution Savings	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings	Increase (Decrease)	%
Processing solution							
Phosphoric Acid	0	0			0		
Sulfuric Acid	0	0			0		
total solution	0	0			0		
Rinsing solution							
Hydrochloric Acid	1,260	1,260	0	0.0%	1,080	(180)	-14%
Total Effluent	1,260	1,260	0	0.0%	1,080	(180)	-14%

Table 24 summarizes the estimated combined discharge of chemical solutions and water annually.

If there were no savings in the amount of processing solution refilled annually, the company estimates there would be less than a 1% decrease in the gallons (15) of total effluent discharged (Table 24). If there were a 14% reduction in the amount of processing solution refills, there would be an estimated 14% decrease in the gallons (508) of total effluent discharged annually, including a 40% decrease in phosphates and phosphoric acid and a 93% increase in sulfate salts and sulfuric acid (Table 24).

Table 24. Estimated Additional Annual Effluent Discharge

	Refills Gallons Chemical Solution & Water Added & Discharged Per Year CURRENT	R&D TEST SOLUTION WITH 0% Solution Savings	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings	Increase (Decrease)	%
Processing solution							
Phosphoric Acid	1,665	1,155	(510)	-30%	991	(674)	-40%
Sulfuric Acid	420	945	525	125%	811	391	93%
total solution	2,085	2,100	15	1%	1,801	(284)	-14%
Rinsing solution							
Hydrochloric Acid	1,575	1,575	0	0%	1,351	(224)	-14%
Total Effluent	3,660	3,675	15	0%	3,152	(508)	-14%

The company could not evaluate the effects on the presence of hazardous materials, free iron, and iron oxides, nickel, chromium, or other heavy metals in its waste stream since it could not segregate the R&D waste from the waste generated by the company's conventional processing systems.

Finally, the changes in proportions of phosphoric and sulfuric acids in the processing solution will alter the mix of vapors to which the company's workforce may be exposed (Table 25). Assuming generally 1 cubic foot of fumes per every 0.08 pound of chemical solution, the company estimates that there could be:

- no change in the annual emission of fumes from hydrochloric acid if there were no reduction in the amount of processing solution refilled annually;
- a 14% reduction in the emission of fumes from hydrochloric acid, from an estimated 257 cubic feet a year to 220 cubic feet if there were a 14% reduction in the amount

of processing solution refills

- an annual 30% reduction in the emission of fumes from phosphoric acid, from an estimated 2,014 cubic feet to 1,156 cubic feet if there were no reduction in the amount of processing solution refilled annually;
- an annual 40% reduction in the emission of fumes from phosphoric acid, from an estimated 2,014 cubic feet to 1,223 cubic feet if there were a 10% reduction in the amount of processing solution refilled annually;
- an annual 108% increase in the emission of fumes from sulfuric acid, from an estimated 555 cubic feet to 1,156 cubic feet if there were no reduction in the amount of processing solution refilled annually;
- an annual 97% increase in the emission of fumes from sulfuric acid from an estimated 555 cubic feet to 991 cubic feet if there were a 14% reduction in the amount of processing solution refilled annually;
- overall, no change in the annual emission of fumes from the processing and rinsing solutions if there were no reduction in the amount of processing solution refilled annually;
- overall, an annual 14% reduction in the aggregate emission of fumes from the processing and rinsing solutions from an estimated 2,826 cubic feet to 2,423 cubic feet if there were if there were a 14% reduction in the amount of processing solution refilled annually.

Table 25. Estimated Fumes Emitted from Electropolishing Annually

	Estimated Fumes from Chemical Use Per Year CURRENT fumes/cu ft	R&D TEST SOLUTION WITH 0% Solution Savings fumes/cu ft	Increase (Decrease)	%	R&D TEST SOLUTION WITH 14% Solution Savings fumes/cu ft	Increase (Decrease)	%
Phosphoric Acid	2,014	1,413	(601)	-30%	1,212	(802)	-40%
Sulfuric Acid	555	1,156	601	108%	991	436	79%
Hydrochloric Acid	257	257	0	0%	220	(37)	-14%
total	2,826	2,826	0	0%	2,423	(403)	-14%

Summary & Conclusions

With a research and development grant from the Environmental Management Investment Group of New York State's Empire State Development agency, Control Electropolishing has determined the feasibility of converting its current -- and the metal finishing industry's prevalent -- processing system for passivation of steel to a more environmentally-friendly process using citric acid in place of nitric acid. It has also determined the feasibility of converting its current electropolishing processing solution from a blend whose active ingredients are 68% phosphoric acid and 19% sulfuric acid to one whose active ingredients are 47% phosphoric acid and 42% sulfuric acid. This conversion also has the potential for achieving significant environmental benefits.

Passivation

The company installed a production-scale, 270-gallon, passivation system fabricated by the Enequist Chemical Company and using the the CitriSurf processing solution. Because citric acid efficiently removes iron from the metal's surface, much lower concentrations are required than when using nitric acid. The company's R&D processing solution ran at about 7.7% citric acid. By comparison, one gallon of nitric acid-based passivating solution requires one part nitric acid to one part water, or a 50% concentration of nitric acid.

The company ran several thousand pieces of fifty-one different products through the citric acid-based passivating process in pilot-scale production test runs. The company achieved satisfactory results on thickness gauge tests, microscopic surface examinations, and boiling water corrosion tests. Subsequently, the company received word from its customers that the quality of the finished test samples was satisfactory.

The company found that the immersion times in the citric acid-based solution generally ran half as long immersion times in its nitric acid solution. This 50% time-saving in process cycle times indicates that the productivity of the company's equipment could increase as much as 100% in the future.

Notwithstanding the higher price per pound of the citric-acid based solution, the company found that it could achieve an estimated 81% to 85% savings in chemical costs because of the much lower concentration of citric acid in the passivation solution compared to nitric acid and because of shorter immersion times. On account of the latter, the citric-acid based passivation solution retained its potency for a longer period of time, incurred less evaporation, and required additional refilling with citric acid less frequently.

Based on product quality, immersion time-savings, increased equipment productivity, and material costs savings, the company concluded that the conversion to citric acid-based passivation is likely to be both technically and financially feasible as well as satisfactory to customers.

Electropolishing

The company installed a production-scale, 900-gallon, electropolishing system fabricated by a Massachusetts manufacturer of metals finishing equipment who represented that it would also supply the company with a citric-acid based processing solution containing no, or almost no, phosphoric and sulfuric acids as well as a wetting agent that would reduce the amount of hydrochloric acid needed in the rinsing process.

Upon delivery of the processing solution, the company's testing firm discovered that it contained contaminants from a prior use and much higher percentages of the phosphoric and sulfuric acids than had been represented. Because the contamination made the solution unusable, the company rejected the shipment.

It then sought other sources of a citric acid-based electropolishing solution, but was unable to locate a solution which contained more than trace amounts of an organic acids like citric acid. Rather, the company identified a proprietary processing solution containing phosphoric and sulfuric acids which it anticipated could achieve some of the environmental benefits which the citric acid-based solution was intended to provide.

The supplier indicated that the proprietary solution produced a different electrolyte and had better conductivity than the company's conventional solution. As a result, the proprietary solution should produce a better quality finish in shorter immersion time using less electrical power as well as possibly less solution refills depending on the cleanliness of the processing bath. The supplier also indicated that the proprietary solution would be less viscous, enabling the metal parts to be rinsed more easily and possibly reducing the amounts of hydrochloric acid refills as well. Finally, the supplier indicated that the solution would alter the composition of the company's effluent discharge, reducing the amounts of phosphoric acid and phosphates which are not soluble in water and increasing the quantities of sulfuric acid and sulfate salts which are.

On that basis, the company elected to proceed with the R&D effort using the proprietary solution although it contained only a trace amount of organic acid and no citric acid. The R&D proprietary test solution contains 47% active phosphoric acid, 42% active sulfuric acid, and 11% water. By comparison, the company's current processing solution contains 68% active phosphoric acid, 19% active sulfuric acid, and 13% water.

The company ran several thousand pieces of 104 different products through the R&D electropolishing process in pilot-scale production test runs. The company achieved satisfactory results on thickness gauge tests, micro-inch finish examinations, and deburring tests. Subsequently, the company received word from its customers that the quality of the finished test samples was satisfactory.

The company found that immersion times for products in the electropolishing R&D solution were an average of 28.5% less than the processing times in its conventional processing solution. The R&D process also ran at lower temperatures and required a lower electrical charge than the conventional process. This 28.5% time-saving in process cycle times indicates that the productivity of the company's equipment could increase by as much as 40% in the future.

Because the R&D test solution resulted in shorter immersion times and used lower temperatures, the company expects that full-scale, annual processing with such a solution should incur lower rates of evaporation and should require refilling less frequently than its conventional blend so long as it maintains the cleanliness of the processing bath. It also anticipates that rinsing will be easier so the rinsing tank should require less refilling.

Estimating the possible reductions in annual chemical refills is difficult. Consequently, the company developed two sets of estimates. One assumes that there are no annual savings in processing and rinsing solutions. The other assumes top annual savings of 14%, which represents half of the 28.5% average reduction in immersion times.

Because of the higher price of the R&D test solution, the cost of chemicals for the initial fill-up of the company's 1,800-gallon processing tank will increase by 47% increase. The annual costs of refilling will also increase by an estimated 21% to 47% depending on the possible reductions in amount of refilling.

The company anticipates that the productivity gains resulting from the increased efficiency of processing in the R&D test acid will offset the increases in the costs of chemicals resulting from the replacement of its conventional processing solution. Although the percentage increases in chemical costs are significant, the absolute dollar amounts are relatively small, less than $7,000. And, the cost of these solutions is a small percentage of the company's costs of sales. Hence, incurring a modest increase in a small fraction of operating costs to reap a potential 40% gain in overall production volume appears to be a viable trade-off.

In sum, because the increases in chemical costs are likely to be offset by immersion time-savings and increases in system productivity, the company concludes that the conversion to full-scale production with the R&D electropolishing solution is likely to be both technically and financially feasible. And, based on product quality and customer reaction to test samples, it concludes that conversion will be satisfactory to its customers as well.

Anticipated Impacts

Looking ahead, the company is developing plans for conversion to commercial-scale processing using the citric acid-based solution for passivation and the R&D proprietary solution for electropolishing. After such conversions, the company estimates that the following could result:

- annual use of between 330 to 440 pounds of citric acid solution for passivation
- annual reduction in the use of nitric acid solution from 3,225 pounds to 0
- annual reduction in the use of hydrochloric acid solution of between 0% to 14%, from 3,045 pounds to between 2,747 (-14%) to 3,045 (-0%) pounds
- annual reduction in the use of phosphoric acid solution of between 30% to 40%, from 23,865 pounds to between 14,359 (-40%) to 16,745 (-30%) pounds
- annual increase in the use of sulfuric acid solution of between 79% to 108%, from 6,580 pounds to between 11,748 (79%) to 13,700 (108%) pounds

- annual reduction in the volume of passivation and electropolishing (processing and rinsing) effluents discharged into the city's sewer system of between 0% to 15%, from 4,214 gallons to between 3,567 (-15%) to 4,229 (0%) gallons

- annual elimination of nitric acid and nitrates from the company's effluent discharge

- annual reduction of phosphates and phosphoric acid from the company's effluent discharge of between 30% to 40%, from 1,665 gallons to between 1,155 (-30%) to 991 (-40%) gallons

- annual increase in sulfate salts and sulfuric acid in the company's effluent discharge of between 93% to 125%, from 420 gallons to between 811 (93%) to 945 (125%) gallons

- annual reduction of hydrochloric acid from the company's effluent discharge of between 0% to 14%, from 315 gallons to between 315 (0%) to 270 (-14%) gallons

- annual reduction in the emission of nitrous oxide fumes from an estimated 1,000 cubic feet to 0

- annual reduction in the emission of fumes from hydrochloric acid of between 0% to 14%, from an estimated 257 cu. ft. a year to between 257 cu. ft (0%) to 220 cu. ft. (-14%)

- annual reduction in the emission of fumes from phosphoric acid of between 30% to 40%, from an estimated 2,014 cu. ft. to between 1,413 (-30%) to 1,212 cu. ft. (-40%)

- annual increase in the emission of fumes from sulfuric acid of between 79% to 108%, from an estimated 555 cu. ft. to between 991 cu. ft. (79%) to 1,156 cu. ft. (108%)

- annual savings on the chemical costs for passivation of 81% to 86%, upwards of $11,000 for replacing and refilling processing chemicals, as well as indeterminate savings for insurance, safety equipment, and tank cleaning)

- annual increases in the aggregate chemical costs for electropolishing (processing and rinsing) of between 19% to 38%, ranging between $3,246 to $6,669

- 50% reduction in process cycle times for passivation, yielding a potential increase in processing equipment capacity of 100%; and,

- 28.5% reduction in process cycle times for electropolishing, yielding a potential increase in processing equipment capacity of 40%.