Georgia Metal
Finishing Initiative
Pollution Prevention Assistance Division

Metcam, Inc. Technology Evaluation

Alkaline Cleaner Ultrafiltration and Rinse Counterflow System

Final Project Report

Wastewater Minimization and Process Improvement for a Five-Stage Iron Phosphate Washer

Co-written by:

Mary Beth Schwefel
Metcam Environmental, Health & Safety Manager

Michael Schwefel
Metcam Engineering Technician

Colin Kiefer
P^{2}AD Engineer, Project Manager

Project Timeframe:
January 2003 through June 2003

Report Completion Date:
October 15, 2003

Forward

The Metal Finishing Initiative was designed around the premise that for an innovative solution to become accepted by the majority, the majority needs to receive three levels of outreach and technical assistance:

1) Increased awareness through a written report and/or case study,
2) An understanding of the technical principles behind the innovative solution, and
3) Comprehensive implementation and operation assistance.

Therefore, Metcam has committed to work with P^2AD in providing level 1, level 2, and level 3 outreach and technical assistance in order to help accelerate implementation of the pollution prevention technologies evaluated in this project throughout the metal finishing sector. In addition to preparing this report, Metcam will offer on-site guided tours, present at industry conferences and/or networking meetings, and work with P^2AD in a workshop as a technology mentor.

Acknowledgments

The Pollution Prevention Assistance Division (P^2AD) would like to thank Mary Beth Schwefel and Michael Schwefel of Metcam for their hard work and dedication in making this project a success. P^2AD and Metcam would like to thank Dr. Timothy Lindsey of the Illinois Waste Management & Research Center for providing guidance before and during the project. P^2AD and Metcam would also like to thank Raymond Graffia of Arbortech Corporation for his participation in studying the benefits of the Arbortech Washer Washer ultrafiltration system. Finally, P^2AD and Metcam would like to thank Analytical Services Incorporated for providing an independent third-party laboratory resource to the project.

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Executive Summary

A collaborative partnership between Metcam and the Pollution Prevention Assistance Division of the Georgia Department of Natural Resources was formed to evaluate two innovative pollution prevention (P2) technologies: an ultrafiltration membrane system and a rinse counterflow system. Metcam, a mid-sized metal fabricating and finishing company located in Alpharetta, Georgia, operates a five-stage iron phosphate spray washer to clean and treat steel parts prior to powder coating. The system consists of an alkaline cleaner (Stage 1), a static rinse (Stage 2), an iron phosphate treatment (Stage 3), another static rinse (Stage 4), and a non-chrome seal (Stage 5).

Without access to a sewer line Metcam cannot discharge wastewater generated from the washer. Therefore, Stage 2 was being dumped twice a week to an on-site evaporator system in order to prevent high levels of oil & grease (O&G) from dragging into Stage 3 and causing quality problems. With a cost of $0.31 per gallon evaporated plus an additional $0.84/gallon for tank dump and cleanout of Stage1 and $0.05/gallon for tank dump of Stage 1, Metcam wishes to reduce wastewaters coming from Stage 1 and Stage 2 at the source.

The following technologies were evaluated: An ultrafiltration (UF) membrane system for continuous removal of O&G from Stage 1 and a counterflow system for reuse of Stage 2 rinsewater as makeup for Stage 1. The technology evaluation project, which ran from January 2003 through June 2003, demonstrated that Metcam can reduce washer-related rejects, cleaner chemical use, and wastewater generation significantly through the use of the UF system and rinse counterflow system together. In fact, the Stage 2 rinse lasted three months without needing to be dumped. Stage 1 has been extended from six to twelve months and is expected to last over two years. Equipment and installation costs are expected to pay for themselves in 12 months.

The table below provides a snapshot of the most important results for the technology evaluation.

Summary of Technology Evaluation Project Results

Project Category	**Results**
Wastewater Reduction	76,200 gallons per year
Chemical Use Reduction	234 gallons per year
Natural Gas Reduction	9,740 cubic feet per year
Oil & Grease Reduction	88% average removal rate
Quality Improvement	51% reduction (ft^2 rejected/ft^2 washed)
Net Cost Savings	$29,023 per year
Simple Payback After Taxes & Inflation	1 year (includes installation costs)
Net Present Value @ 4% Interest Rate	$303,895
Internal Rate of Return	104%

In the past, metal finishing companies have expressed concern that UF systems strip out surfactants and can therefore lower the cleaner's effectiveness. The UF system did remove a portion of the nonionic surfactants from the cleaner; however, since washer quality improved (less rejects) during the project, it is thought that the importance of surfactants has diminished. The cleaner chemical supplier did develop a surfactant add package for the Stage 1 cleaner but Metcam has yet to use it.

Based on the findings of the P2 technology evaluation, Metcam recommends the use of a combined UF and rinse counterflow system for other companies that rely on alkaline cleaning before liquid or powder coating metal substrates.

Georgia Metal
Finishing Initiative
Pollution Prevention Assistance Division

Wastewater Minimization and Process Improvement for a Five-Stage Iron Phosphate Washer

1.0 Introduction

This project represents a unique industry-government partnership within the Georgia Metal Finishing Initiative (MFI). Through a U.S. Environmental Protection Agency (EPA) pollution prevention grant, the Pollution Prevention Assistance Division (P^2AD) was able to provide matching funds to Metcam, Inc. in support of their efforts to evaluate technologies that reduce waste at the source, allow for in-process recycling, and conserve natural resources. Metcam volunteered to participate in this project in 2002, and was selected by P^2AD based on their history of looking beyond regulatory compliance as an environmental leader for the State of Georgia. The technology evaluation project ran from January 2003 through June 2003.

1.1 Project Background and Rationale

Metcam, Inc. is a manufacturer of precision sheet metal components and assemblies for a wide variety of industries, including telecommunications, electronics, computers, HVAC, heavy equipment, food service, aerospace, medical and advertising. Metcam uses advanced precision fabricating technologies within its 100,000 square foot facility in Alpharetta, Georgia to meet the needs of a diverse group of customers.

After laser cutting, punching/piercing, bending, welding and hardware insertion operations, parts move to the finishing department. Cold rolled steel and galvanized parts are then pretreated through a five-stage iron phosphate washer and powder coated. Aluminum parts are given a chrome conversion and some of these are powder coated as well. From here parts either go to assembly or are complete as is and are shipped to the customers. In 2002 and through the technology evaluation, Metcam utilized a ten hours per day, four days per week, fifty weeks per year production schedule.

Since Metcam is not connected to a municipal sewer line, and thus cannot discharge their wastewater to a publicly owned treatment works, non-hazardous liquid wastes must either be sent offsite for treatment and disposal in bulk or be reduced by an evaporator system on-site and the sludge sent offsite for proper disposal. While the process of evaporation is very labor intensive and costly, it is still the chosen option for Metcam because it is still less expensive than offsite treatment and disposal. However, the best situation Metcam could hope for is to minimize or eliminate wastewaters at their source, thus reducing their dependence on the evaporator systems.

With the assistance of P^2AD, three pollution prevention (P2) options were considered for reducing alkaline cleaner and rinse wastewaters: ozone treatment, biological cleaning and ultrafiltration.

In-process ozone treatment appeared to be the most innovative approach but was also the least proven of the three P2 options being considered. It employs electrolysis and low concentrations of ozone to convert insoluble organic fatty acids, oils and greases into usable surfactants in order to regenerate a spent cleaner bath and improve the cleaning process as a whole (McGinness, 1994.). However, P^2AD and Metcam thought the ozone treatment system represented a greater degree of risk than the other two options since it was unknown as to what other organic by-products in addition to new surfactants might be created by partially ozonating the cleaner. Furthermore, there was also a concern that excess soap (surfactants) and inorganic solids would build up in the cleaner bath over time, possibly requiring some form of mechanical filtration or even biological treatment as add-ons to the ozone system. Lastly, Metcam was concerned with the amount of alteration that would be required for their cleaner tank and the labor involved for installation, which could be doubled if the system did not work out.

Biological cleaning systems utilize bacteria to break down and consume (biodegrade) oil and grease as it enters the cleaner bath in order to extend the useful life of the solution and improve the cleaning process. A mild alkaline cleaner that operates in a temperature range of 104 to 131 °F and a pH range of 8.8 to 9.2 is needed for the microorganisms to thrive (Callahan, et. al., 2001). In order to evaluate a biological cleaning system, Metcam would need to dump the existing cleaner solution to the evaporator and recharge the tank with an untested, entirely new chemistry. However, Metcam and P^2AD were interested in evaluating a P2 technology that that could regenerate the spent cleaner bath. Metcam was also unsure if their evaporator system would be able to process biological cleaning wastewaters, and thought it might have to be shipped offsite for disposal. Lastly, the biological cleaning system required additional floor space for an inclined plate clarifier, which was also a concern to Metcam.

Ultrafiltration membrane systems rely on physical separation of the cleaner chemistry from oils and greases, as well as other bath contaminants larger than the membrane pores, in order to improve the cleaning process and allow for recovery of the previously unusable spent solution. Metcam found that the UF system would take up very little floor space and could be installed rather easily to the existing cleaner stage; this meant that if the technology evaluation was unsuccessful it could also be removed without much difficulty. Furthermore, Metcam was aware that a UF application similar to their own was successful in improving and extending the life of a combined phosphate/alkaline spray cleaner for a manufacturer of aluminum cafeteria tables (Bilgo, et. al. 2000). In addition, Metcam also had knowledge of several successful UF applications with immersion-type alkaline cleaner baths, such as R.B. White in Bloomington, Illinois (Lindsey, et. al. 1995).

Therefore, Metcam decided to evaluate the performance of a UF membrane system in extending the life of a six month old cleaner bath. Metcam also decided to evaluate the use of a counterflow system that would transport Stage 2 rinsewater to Stage 1 as makeup for dragout and evaporative losses.

2.0 Existing Process and Methods

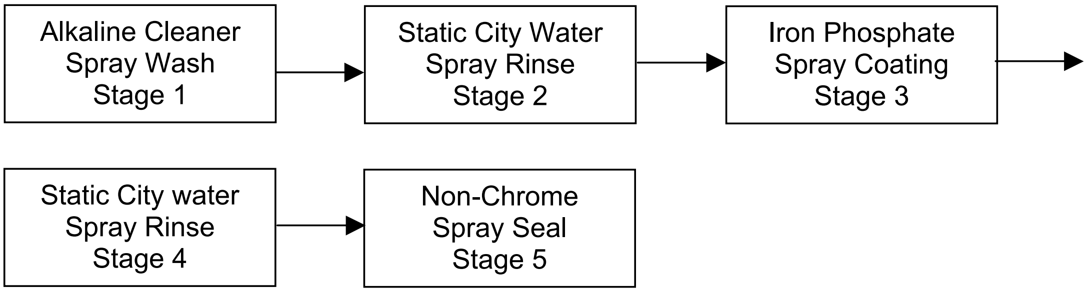
The purpose of this section is to provide a general characterization of Metcam's existing iron phosphate spray wash system and a more specific explanation of the Stage 1 alkaline cleaner and Stage 2 rinse. A description of the cost of generating alkaline cleaner and rinse wastewater will conclude this section.

2.1 Five-Stage Iron Phosphate Washer

Metcam utilizes a conveyorized five-stage iron phosphate spray washer to pretreat cold-rolled and galvanized steel parts prior to powder coating. Spray systems utilize impingement at relatively high pressures to help loosen and remove soils on the parts being processed. The solution and rinse are transported through spray headers with nozzles set at a specific angle to provide overlapping spray patterns (Tulinski, 2003).

Figure 1 helps to visualize the five-stage iron phosphate spray washer system used at Metcam.

Figure 1. Five-Stage Iron Phosphate Washer Process Map



The first stage consists of a 1,250-gallon alkaline cleaner solution with surfactants operating at a 3.5 to 4% concentration. Stage 1 operates at 135 °F with a water pressure of 15 to 18 psi at the nozzles. The second stage consists of a 750-gallon fresh city water rinse operating at ambient temperatures with a water pressure of 10-12 psi at the nozzles. Stage 3 consists of a 900-gallon iron phosphate solution operating at 2.5 to 3% by volume, and 125 °F, with a water pressure of 10 to 12 psi at the nozzles. The fourth stage is a 750-gallon fresh city water rinse operating at ambient temperatures with a water pressure of 15 psi at the nozzles. Stage 5 consists of a 1,100-gallon non-chrome seal solution operating at 0.2 to 0.3% by volume, and ambient temperatures, with a water pressure of 15 psi at the nozzles.

2.1.1 Stage 1 Alkaline Cleaner

The alkaline cleaner removes oil and grease from cold-rolled or galvanized steel parts entering the five-stage washer. Removal of the oils from the parts is essential for proper adhesion of the powder coating; it also allows the part to accept the iron phosphate coating. High pH alkaline cleaners saponify oils and greases and convert them into water rinseable soaps, which enhances their removal and impedes their re-deposition onto the parts being cleaned (Moran, 2002).

Metcam uses a heated sodium hydroxide solution that is purchased as a liquid. The cleaner is formulated with a silicated builder to improve the detergency of the solution. Metcam also uses a proprietary sequestering agent to tie up and prevent metals from interacting with the parts being cleaned.

The cleaner is also formulated with nonionic and anionic surfactants. The surfactant molecules have long-chain hydrophobic tails that penetrate and solubilize in oil, and oxygen-containing heads that are attracted to water molecules (Lindsey, 1995). The nonionic surfactants act as wetting agents, facilitating the removal of oils, metals, and dirt from the surface of a part by lowering the solution surface tension. By arranging themselves into aggregates of 300 or more surfactants, a chemically stable formation known as a micelle is formed, which creates a strong emulsion holding the contaminants in solution and preventing them from re-depositing on the parts being cleaned (Morrison, Boyd, 1973).

Nonionic surfactants also act to reduce foaming, which can become problematic in spray systems that are constantly agitating the solution. A very small amount of anionic surfactant is added as well According to Metcam's chemical supplier, the cleaner also has the ability to encapsulate oils and drop them out as a sludge at the bottom of tank.

2.1.2 Stage 3 Iron Phosphate

Iron phosphate is a coating that promotes corrosion resistance for the part over its useful life. The first step in iron phosphating is the dissolution of the metallic iron in a phosphoric acidic solution. As the acid is attacking the metal surface, it is being consumed, which raises the pH. The change in pH causes phosphate salts to precipitate and react with the metal surface, forming a crystalline coating. The surface of the metal now has thousands of tiny canals that act to mechanically lock paints or powder coats onto the part, providing excellent adhesion. The crystalline iron phosphate coat is also non-conductive, acting as a barrier to the flow of electrons, providing very good under-paint corrosion resistance (Phillips, 1992).

2.1.3 Stage 5 Non-Chrome Seal

The non-chrome seal further enhances under-paint corrosion resistance by sealing the pores present on the surface of the iron phosphate coated steel. The occurrence of flash rusting between the exit of the washer, through the dry-off oven, before the powder coating is applied, is also reduced.

2.2 Alkaline Spray Cleaner & Rinse Unit Processes

Approximately 582.5 gallons of alkaline cleaner was used from July 2001 to June 2002; however, Metcam stated that roughly 18 gallons of the cleaner was added each month to correct for a process in-efficiency. Metcam pretreats 40-50 large metal doors near the end of every month through the five-stage washer. Due to the door's geometry and the chosen method of hanging the parts, large quantities of rinsewater would drain back into Stage 1 causing the solution to become over-diluted. By the time the technology evaluation began in January 2003 the problem was corrected. In order for the results of the technology evaluation to not be skewed, the quantity of cleaner per year used for the baseline was 366.5 gallons (582.5 gal. - (18 gallons/month x 12 months).

2.3 Evaporator System

Metcam operates two gas-fired evaporators to reduce and dispose of all non-hazardous wastewaters generated on-site. The evaporator system is designed for continuous 24-hour operation through a preset 95-hour cycle based on the unique waste stream. Both evaporators are fed automatically from a 9,400 gallon holding tank which is monitored daily. Wastewater volumes discharged to the holding tank dictate evaporator operation time. Wastewater pH is also monitored and adjusted when necessary to maintain specific operating parameters.

Metcam's non-hazardous wastewater generation prior to the project reached approximately 95% of the two evaporator's maximum efficient capacity. Any significant increase in average production levels would require justification and purchase of an additional evaporator or the use of off-site treatment and disposal facilities.

The evaporator cycle begins when bath temperature reaches 212° F and the complete cycle ends approximately 12 hours after the 95-hour cycle count (107 hours total). The additional 12 hours account for time required to evaporate the bath to low level, cool down, labor to clean and recharge, and time required to return bath temperature to 212°F. Through experience with operating the evaporators Metcam has determined that an average of 1,330 gallons of wastewater can be processed in each cycle, which generates approximately 82 gallons of concentrated liquid sludge.

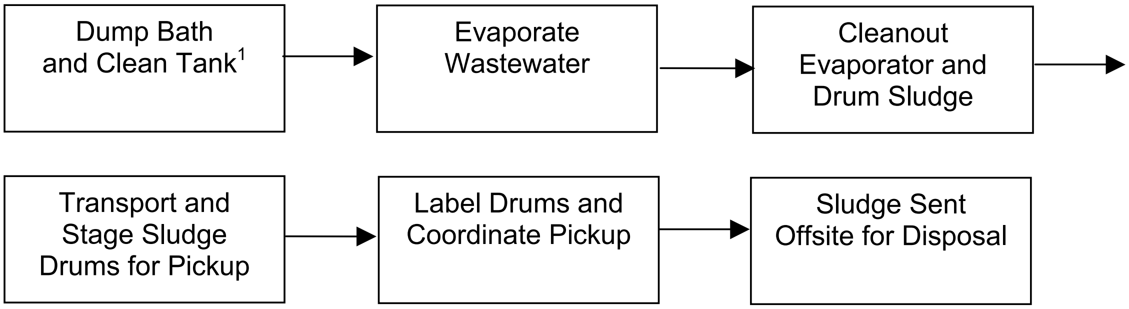
2.4 Cleaner & Rinse Wastewater Generation Cost

Metcam cannot overflow their rinse tanks to keep the water quality at a sufficiently high level because they do not have access to a sewer line. The Stage 2 rinse is especially sensitive to the quantity of oil carried over from the Stage 1 cleaner. Metcam has stated that the Stage 3 iron phosphate process cannot perform effectively if over 100 ml oil per liter of rinse is carried over from Stage 2.

Metcam is faced with having to dump Stage 2 every other production day in order to prevent iron phosphate coating quality problems. Furthermore, as the Stage 1 cleaner ages and begins to approach its six-month bath life, the quality of the solution carrying over to Stage 2 worsens, causing the 100 ml/l oil limit to be reached before the second production day is complete. If not for capacity limitations in the evaporator system and the high cost of bulk offsite treatment and disposal, Metcam would most likely have been dumping Stage 2 daily.

Figure 2 illustrates how the full cost of generating wastewater from Stage 1 and Stage 2 can be mapped out.

Figure 2. Stage 1 & Stage 2 Wastewater Generation Process Map



[1] Tank cleaning is only applicable to the Stage 1 cleaner.

As shown above, the generation of wastewater from both Stage 1 and Stage 2 bath dumps triggers multiple activities. Before working with P^2AD, the costs associated with each activity were not allocated back to the responsible wastewater sources.

As shown in Table 1, the Stage 1 and Stage 2 wastewater generation unit costs were found to be $1.14/gallon and $0.36/gallon, respectively. With 5,600 gallons generated annually from dumping Stage 1 every six months, the wastewater was costing Metcam $6,408 dollars per year. By dumping Stage 2 every other production day, 75,000 gallons was being generated annually at a full cost of $27,108 per year. Therefore, Metcam was spending $35,515 dollars per year to generate Stage 1 and Stage 2 wastewaters.

Table 1. Full Wastewater Cost Summary

Stage 1 Wastewater Generation	Value
Dump wastewater (gal./yr.)	2,500
Tank cleanout wastewater (gal./yr.)	3,100
Chemical recharge cost ($/yr.)	1,160
Dump, cleanout, recharge labor ($/yr.)	760
Tank cleanout chemical use (gal./yr.)	156
Tank cleanout chemical cost ($/yr.)	2,763
Wastewater treatment ($/yr.)	1,725
Full wastewater cost ($/yr.)	**$6,408**
Wastewater unit cost ($/gal.)	**$1.14**

Stage 2 Wastewater Generation	Value
Wastewater dump volume (gal./yr.)	75,000
Makeup water cost ($/yr.)	$225
Wastewater treatment cost ($/yr.)	$23,108
Dump labor cost ($/yr.)	$4,000
Full wastewater cost ($/yr.)	**$27,108**
Wastewater unit cost ($/gal.)	**$0.36**

The wastewater generation costs will now be described in more detail in Sections 2.4.1 and 2.4.2. The following discussion will address the cost associated with bath dumping and tank cleaning activities separately from wastewater evaporation and sludge generation activities.

2.4.1 Bath Dump & Tank Cleanout Cost

The wastewater generation costs associated with bath dump and tank cleanout were estimated before the project began. Dump and cleanout activities include draining the tank, adding 1,250 gallons of 6.25% by volume concentrated tank cleaner (78.13 gal. of cleaner), draining the cleaning wastewater, removing tank sludges, adding 300 gallons of city water to rinse down the tank, and recharging the tank with 1,250 gallons of fresh 3.5% alkaline cleaner (43.75 gal. of cleaner). An average hourly rate of $20/hr. was assumed for the Metcam employees who are performing these activities.

Every six months the solution in Stage 1 was dumped to Metcam's evaporator system and the tank was cleaned out. Metcam estimated that a total of nineteen hours is spent to perform these worksteps. First, the 1,250 gallons is discharged to an underground sump. Next, an operator will physically get into the washer to remove sludges and other debris that have collected over the past six months. The tank is then filled up completely with an alkaline cleaner solution that is pumped through the spray headers. This cleaner, which is a different product than that used during normal operation, is specifically designed to thoroughly clean solids and oils from the tank walls and floor, and to clean off the burner tubes. In some cases, the burner tubes will need to be pressure washed as well. From there, city water is circulated through the Stage 1 spray headers to rinse out the tank. Lastly, the alkaline cleaner solution used during normal operation is prepared and the 1,250-gallon tank is re-filled.

For Stage 1, the bath dump and tank cleanout costs are calculated as follows:

Labor: $20/hour x 19 hours x 2 = $760.0/year

Tank Cleaner: $17.68/gallon x 78.125 gallons x 2 = $2,762.5/year

Stage 1 Recharge: $13.26/gal x 43.75 gallons x 2 = $1,160.25/year

Stage 1 Dump Wastewater: 1,250 gallons x 2 = 2,500.0 gallons/year

Stage 1 Tank Cleanout Wastewater: (1,250 gallons + 300 gallons) x 2 = 3,100 gallons/year

The Stage 1 bath dump and tank cleanout wastewater cost per gallon is:

($760 + $2,762.5 + 1,160.25)/(2,500 gal. + 3,100 gal.) = <u>$0.836/gallon</u>

For Stage 2, there is not a need to clean the tank following the rinse dump. However, since the tank was being dumped every other production day, the cost to production was still very high. Metcam has estimated that it takes two hours total to completely dump and re-fill Stage 2 and this activity can only be performed after production stops. Since there is no chemical additions or cleaning of the tank, the cost for dumping and filling the tank is primarily labor, at $40 per 750 gallons or $0.05/gallon.

2.4.2 Wastewater Evaporation and Sludge Disposal Cost

Table 2 illustrates how the cost of wastewater evaporation can be broken down. For Stage 1 and Stage 2, the unit cost to evaporate wastewaters and dispose of the residual sludge was determined to be $0.31 per gallon. In theory, Stage 1 bath dump wastewater should create a higher quantity of sludge and reduce the energy efficiency of the evaporators due to the high amount of solids and O&G. However, since Stage 1 wastewater is mixed in a 9,400 gallon holding tank with dilute rinse wastewater, primarily from Stage 2, before it is evaporated, it is assumed that an equal amount of energy is used and an equal amount of sludge is generated for Stage 1 and Stage 2.

Table 2. Full Cost Summary - Wastewater Evaporation

Sludge Activities	*$/gal. Sludge*
Labels and paperwork	$0.091
Drum handling	$0.488
Sludge analysis cost	$0.455
Sludge disposal	$1.364
Total	**$2.40**

Wastewater Activities	*$/gal. Wastewater*
Evaporator energy cost	$0.074
Evaporator cleanout	$0.045
Wastewater defoamer	$0.041
Sludge generation	$0.148
Total	**$0.31**

Note that Table 2 breaks down the cost of generating sludge in the evaporator and incorporates this into the full wastewater evaporator cost. The methodology used for determining both the sludge generation cost and the evaporator operation cost will be described below.

Each of the two evaporators can process 1,330 gallons of wastewater in 107 hours or 4.4 days. Since Stage 2 was generating 1,500 gallons of wastewater per week, one evaporator was always dedicated to this wastewater stream. By knowing that on average 82 gallons of sludge is generated in each 1,330-gallon evaporation cycle, Metcam was able to incorporate the sludge generation unit cost ($2.40/gallon of sludge) into the total cost to operate the evaporator per gallon of wastewater ($0.148/gallon of wastewater).

A very important component of the total cost to evaporate Stage 1 and Stage 2 wastewater is energy consumption. The evaporators' natural gas efficiency can be measured in 100 cubic feet (ccf) of natural gas used per 1,330 gallons of wastewater evaporated in each cycle. Throughout the year, the natural gas efficiency of the evaporators can vary from 160 to 180 ccf per cycle, depending on the relative humidity and temperature. Therefore, an average value of 170 ccf was chosen for use as a baseline in the technology evaluation. Metcam has determined that $0.56/ccf is the average unit cost for natural gas at the plant. This gives a cost of $95.20 per evaporation cycle. The electricity cost per 1,330-gallon evaporation cycle is estimated to be $3.50.

Therefore, the total energy cost to run the evaporators is calculated as follows:

Natural Gas: $0.56/ccf x 170 ccf/1,330 gallons = <u>$0.0716/gallon of wastewater</u>

Electricity: $3.50/1,330 gallons = <u>$0.0026/gallon of wastewater</u>

Total Energy: $0.0716 + $0.0026 = <u>$0.074/gallon of wastewater</u>

Another aspect of operating the evaporator relates to analysis of the concentrated sludge. This cost comes from the Toxicity Characteristic Leaching Procedure (TCLP) test that must be performed for the sludge to verify that the sludge contains no hazardous materials. A certified laboratory runs the TCLP tests for Metcam's disposal company at a cost of $150.00/test. Two random grab samples are pulled from each 10 to 14 drum shipment (average 12 drums).

Therefore, the unit cost associated with sludge analysis is calculated as follows:

$150/test x 2 tests/12 drums x 1 drum/55-gal. sludge = <u>$0.455/gal. of wastewater</u>

The use of wastewater defoamer is yet another cost of operating the evaporator system. Defoamer keeps the wastewater, when heated in the evaporator, from foaming to a level that the high water level sensor is set off causing the evaporator to fault out and stop in the middle of a cycle. Each gallon of defoamer is $13.76 and four gallons are used on average for every 1,330-gallon evaporation cycle.

Therefore, the cost per gallon of using wastewater defoamer was calculated as follows:

$13.76/gallon x 4 gallons/cycle x 1 cycle/1,330 gallons = <u>$0.041 per gallon of wastewater</u>

With every complete cycle, sludge must be cleaned out from the evaporators; therefore, this activity represents another wastewater generation cost for Metcam. Cleaning out the sludge from an evaporator takes one employee three hours.

Therefore, the cost to clean out sludge from the evaporators was calculated as follows:

$20/hour x 3 hours/cycle x 1 cycle/1,330 gallons = $<u>0.045 per gallon of wastewater</u>

Next, an operator spends approximately two hours per week handling sludge drums. Each 55-gallon drum of evaporator sludge is transported to a storage area for non-hazardous waste and staged for pickup by the company Metcam uses for offsite treatment and disposal.

Therefore, the cost for drum handling was calculated as follows:

$20/hour x 2 hours/cycle x 1 cycle/82 gallons of sludge = <u>$0.488 per gallon of sludge</u>

The environmental manager must also ensure that each sludge drum to be stored on-site is properly labeled. Offsite disposal must then be coordinated and the necessary paperwork completed and maintained as a record of the waste (manifests). To generate labels, coordinate sludge pickup, and complete the required paperwork Metcam spends $5.00 per 55-gallon drum.

Therefore, the cost to generate labels, coordinate pickup and complete paperwork was calculated as follows:

$5/55 gallons of sludge = <u>$0.091 per gallon of sludge</u>

For disposal of the evaporator sludge, Metcam is charged $25.00 per 55-gallon drum as a transportation (hauling) fee and $50.00 per 55-gallon drum as a treatment and disposal fee.

Therefore, the full offsite treatment and disposal cost is calculated as follows:

($25 + $50)/55 gallons of sludge = <u>$1.364 per gallon of sludge</u>

To have Stage 1 and Stage 2 wastewater shipped offsite in bulk for treatment and disposal Metcam is charged $0.41 per gallon of wastewater. Therefore, while evaporation is expensive at $0.31 per gallon of wastewater, offsite treatment and disposal was more costly.

3.0 Technology Description

The purpose of this section is to provide the reader with the necessary technical principles for the P2 practices evaluated. In doing so, a description of the technology's P2 classification is provided along with an explanation of how the technology works and how it was applied in this project. Lastly, a description of the key equipment components and important design factors for the technology is provided as well.

3.1 Crossflow UF Membrane Systems

The membrane filtration system installed on Stage 1 allows Metcam to reduce both Stage 1 and Stage 2 wastewater at the source; therefore, the P2 classification for this technology is source reduction. Ultrafiltration (UF) and microfiltration (MF) membrane systems are beginning to gain wider acceptance, having proven an ability to extend alkaline cleaner bath lives and reduce dump and recharge costs. Membrane filtration systems have also demonstrated the ability to improve cleaning by continuously removing oil and grease from the bath while reducing bath maintenance chemical additions.

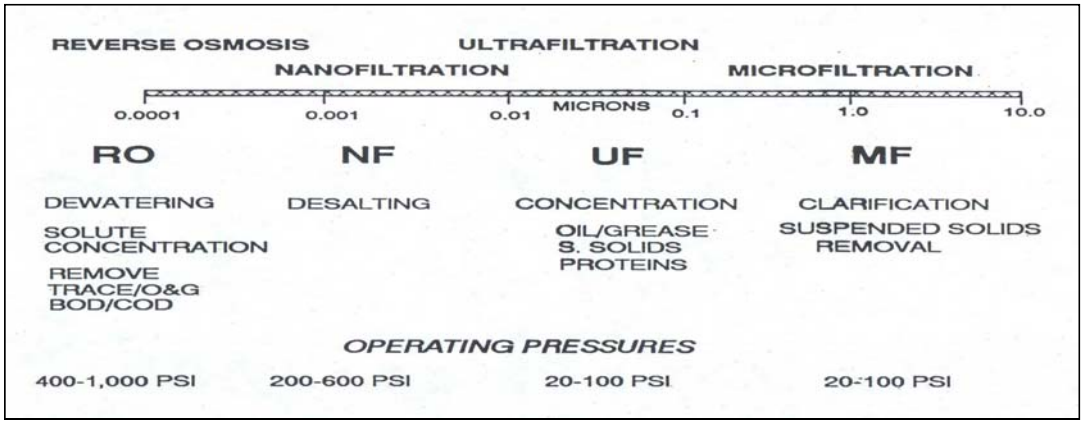
3.1.1 Technical Principles

In a crossflow UF system, the contaminated cleaner solution being processed is pumped across the membrane at relatively low pressures. The solution flow is parallel to the filter pores instead of perpendicular as is the case in traditional depth filtration systems. A tangential pressure transports water, dissolved salts/metals and low molecular weight cleaner constituents (e.g., surfactant package and detergent components) through the membrane pores to be returned to the cleaner bath; this is known as the permeate stream. Soluble materials larger than the membrane pore size and all suspended solids are rejected by the membrane and moved away continuously due to the turbulent flow at the membrane surface (Bailey, 1977); this is known as the retentate stream.

Crossflow filtration allows the membrane surface to be continuously "sweeped", limiting filter cake buildup and providing longer processing times (Lindsey, et al. 1999). The pores of a traditional depth filtration system have a tendency to plug up and foul in a short period of time, which drives up operating and maintenance costs due to a high backwashing, cleaning, and filter replacement frequency.

As shown in Figure 3, membrane filtration has many applications that call for different pore sizes and operating pressures. In general, the smaller the pores size, the greater the removal of oil and grease (O&G) and the greater the rejection of the cleaner's surfactant package. However, if designed properly a UF membrane system should be removing O&G at a rate close to what is coming in with the dirty parts, and therefore the cleaner can work just as well with a lower concentration of surfactants.

Figure 3. Membrane Filtration Characteristics



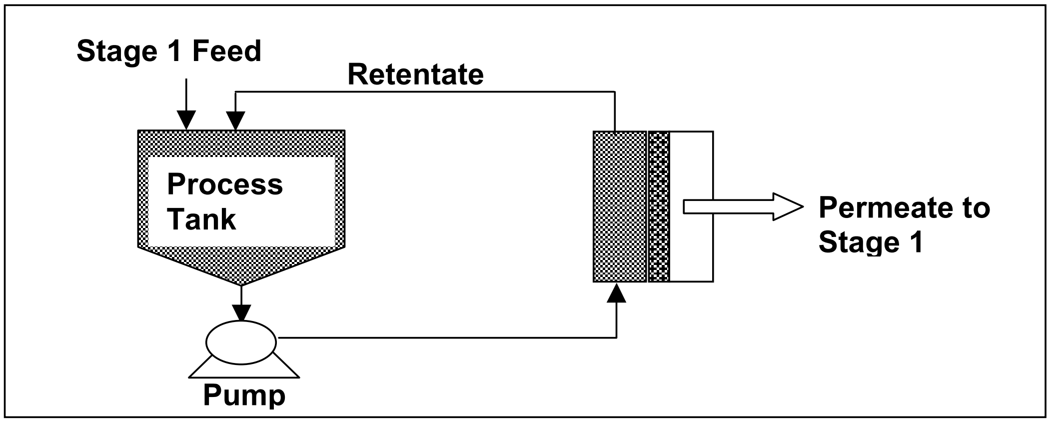
It should be noted that UF and MF pores are not small enough to remove dissolved metals or other salts such as calcium, and for some metal finishing applications, this may prevent the company from having a cleaner that never needs to be dumped. However, gradual increases in total dissolved solids (TDS) are much less critical than rapid increases in O&G when trying to keep a cleaner bath functioning optimally for a prolonged period of time.

3.1.2 UF System Design

The UF system being used at Metcam was designed to separate high molecular weight, colloidal or suspended solids from water-based cleaning solutions. It is constructed of a semi-permeable sintered titanium dioxide membrane cast on a tubular stainless steel substructure with a nominal pore size of 0.1 microns. Therefore, the membrane is at the upper UF classification limit. The UF system is furnished with two 0.75 ft^2 membranes; one to act as a standby that can be put in use while the other is being cleaned.

As shown in Figure 4., the system configuration chosen for Metcam is known as batch with recirculating loop, top-off (Cheryan, 1998).

Figure 4. Batch Filtration with Recirculating Loop, Top-Off



In this configuration, the feed rate to the process tank from Stage 1 is equal to the permeate flux rate. The UF system's process tank is gravity fed by Stage 1 and then the solution is pumped through the membrane where the cleaner is fractionated into the "dirty" retentate stream and "clean" permeate stream.

At some point the concentration of O&G and suspended solids that are re-circulating from the process tank to the UF membrane become a limiting factor for the rate of permeate flux (i.e., the flow of solution through the membrane pores per unit time per unit membrane surface area). The decline in flux is typically slow and steady, often taking more than two weeks and occasionally even more than a month in certain applications. The UF equipment supplier suggests that once the flux rate drops below 30% of the initial flux rate achieved, the membrane should be exchanged for a second membrane (provided with the system) or cleaned-in-place. At this time, the dirty solution in the 55-gallon process tank is removed, which is referred to as a batch-out.

Depending on the materials that are clogging the membrane pores, the cleaning regimen can vary from a very mild acid or base solution to a more concentrated, stronger caustic solution or multiple cleaning regimens. In some cases, the alkaline cleaner itself, the very product in use within the washer, is effective at cleaning the membrane and restoring flux. Hence, a batch-out is recommended prior to a membrane cleaning/exchange, just in case the batch-out alone restores a satisfactory flux rate. The open-tube arrangement of the UF system makes cleaning-in-place possible and the process can be relatively easy to accomplish using chemical and/or physical means. The equipment supplier also offers a cleaning program as an option, where the end user simply pays for shipping of the membrane plus a nominal fee per membrane cleaning.

Figure 5 on the following page shows a photograph of the UF system sitting by Metcam's Stage 1 alkaline cleaner tank. In this photograph, the stainless steel UF membrane is shown sitting on top of the UF system's 55-gallon process tank. The footprint for the UF system requires roughly 13 square feet of floor space. A vertical vent pipe allows Metcam to visually inspect the quality of the retentate to help assess batch-out and cleaning needs, as well as indicate if the gravity flow from Stage 1 is working properly.

Figure 5. Ultrafiltration Membrane Recycling System

For Metcam, the UF system equipment supplier did not recommend the use of suspended solids prefiltration. In general, tubular membrane designs are fairly tolerant of suspended solids and can handle feed streams with moderate levels. However, for companies processing aluminum through an alkaline cleaner, some degree of solids pre-filtration is recommended to avoid premature fouling of the membrane.

3.2 Rinse Counterflow System

The rinse counterflow system ties Stage 2 and Stage 1 together; this allows for reuse of Stage 2 water as make up for Stage 1 evaporation and dragout losses. Therefore, the rinse counterflow system is also a P2 practice with a classification of in-process reuse.

Figure 6 illustrates how the rinse counterflow system connects Stage 2 with Stage 1 and how it functions synergistically with the UF system.

Figure 6. Rinse Counterflow System

Note that the tank on the left in the photograph is Stage 2, and that piping and a small pump transport rinsewater back to the tank on the right, which is Stage 1. A conceptual design drawing and process diagram of the rinse counterflow system are located in the appendix of this report.

3.2.1 Technical Principles

Similar to a traditional multiple stage counterflow rinse system, Metcam's system allows for reuse of rinsewater from one tank in another tank rather than simply overflowing to a drain. However, the water to be counterflowed is going to a cleaner bath rather another rinse. With the UF membrane removing a majority of the bath contaminants continuously from Stage 1, the rinse counterflow system is only returning city water and the alkaline cleaner itself back to Stage 1. The counterflow system also acts as a source of makeup water for the heated Stage 1 cleaner solution, replenishing evaporative losses with fresh city water flowing through the Stage 2 rinse tank. Therefore, the counterflow system maintains the cleanliness of the Stage 2 rinse tank, while reducing cleaner drag out losses to subsequent stages of the five-stage washer.

3.2.2 Automated Rinse Counterflow System Design

An electrically controlled rinse counterflow system was designed and installed to automatically transfer solution carried out of the Stage 1 cleaner tank back to where it belongs, in the cleaner tank not the rinse tank. The system is composed of a small relay logic control, four float sensors (high and low level in each tank), two water control solenoids, two stainless steel ball valves (flow adjustment), and a 20-25 gallons per minute (gpm) transfer pump. The float sensors were adjusted to trigger after a 60-70 gallon loss in Stage 1 and a 30-40 gallon loss in Stage 2. Incoming city water flow was adjusted to 20 gpm, which resulted in a continuous 3-4 minutes on/15-30 minutes off cycle based on normal operating conditions.

4.0 Technology Installation

As the UF system and rinse counterflow system were implemented in phases, the installation for each system occurred separately. The installation for both systems is detailed below.

4.1 UF System Installation

Before installation, Metcam's alkaline cleaner bath was pumped to a holding tank with the exception of the bottom 2-3 inches of sludge. Approximately 300 gallons of sludge and dirty solution were removed in total. After opening the tank's marine door, the layer of sludge was flushed out with water and the interior walls were thoroughly cleaned. Openings were cut in one interior wall and the overhanging drain zone to aid cleaning of inaccessible areas. The tank wall and drain zone were drilled, tapped, and removable steel covers fabricated and installed to ease access for future cleaning. Immediately after cleaning, the soiled bath was pumped back from the holding tank, a titration was performed, and water and cleaner were added to compensate for an approximate 300-gallon loss from the cleaning process. One 120-volt AC 20 amp ground fault interrupter circuit was added to power the filtration system pump.

The UF system was installed with the process tank positioned to be gravity fed. The bottom of the original cleaner tank overflow channel was perforated with 2" diameter holes and the channel discharge pipe was connected to the UF system process tank with 1-1/4" barbed fittings and high temperature chemical resistant hose. A new overflow hole was bored in a different location to prevent overfilling the cleaner tank and a second hole was bored in the top of the tank to insert the membrane filter. Conceptually, a portion of the contaminated cleaner returning from the nozzle spray area to the cleaner tank is continually intercepted by the UF system.

The clear acrylic overflow tube, provided by the equipment supplier, was installed in the top of the UF process tank and the fill valve opened to allow the cleaner bath to flow into the tank. Because gravity forces the liquid to seek it's own level and the top of the process tank was lower than the liquid level in the cleaner tank, the complete system liquid level could be visually monitored through the clear acrylic tube. Graduation marks were placed on the acrylic tube to collect baseline evaporation and drag out data (See Figure 5).

Metcam also installed a flow meter/totalizer to monitor fresh water consumption. A calibrated bronze tee and flow sensor were inserted in the incoming city water line servicing both the cleaner tank (Stage 1) and the rinse tank (Stage 2). Brackets were fabricated to mount the meter control and display directly to the Stage 2 rinse tank at eye level for easy data collection. A 120 VAC 10 amp circuit was installed for power requirements.

4.2 Rinse Counterflow Installation

A steel mounting plate was fabricated and attached to the Stage 1 tank for installation of the transfer pump. The plumbing to the transfer pump is similar to the installation of the UF system itself. Stage 2 is gravity fed to the suction side of the transfer pump and the discharge side was plumbed to the top of Stage 1 with an inline strainer and control solenoid to prevent inadvertent siphoning. A second solenoid was installed in the city water line that supplies Stage 2, to control fresh water addition.

Mounting plates were fabricated and installed in the top of both Stage 1 and 2 for installation of float level sensors. Because of turbulence created by the high volume process pumps and the need to accurately control the transfer pump on/off cycle time, the system required two sensors per tank. The high and low level sensors can be adjusted independently to create the desired operating range and prevent short cycling and damage to control relays.

The main counterflow system control and operator interface was installed adjacent to the main five-stage washer control. Liquid tight conduit was routed parallel to that of the main five-stage control and circuits pulled and terminated to complete the installation.

5.0 Technology Evaluation Plan

With assistance from P^{2}AD, Metcam developed an evaluation workplan primarily to determine the suitability and effectiveness of the UF and rinse counterflow systems in extending the life of the Stage 2 rinse. The goal was to establish a monitoring, measurement and testing strategy that would allow Metcam to identify the degree in which each system contributed to process and environmental improvement.

Metcam has in-house capabilities for performing chemical bath titrations and crosshatch adhesion testing, measuring conductivity and pH, and checking color and gloss according to American Society of Testing and Measurements (ASTM) specifications. Metcam's pretreatment supplier has a certified lab capable of conducting coating weight studies and their primary powder supplier has a certified lab that can conduct salt spray testing. Metcam also chose to use a certified lab to perform the analytical tests for evaluating the performance of the UF membrane filtration system.

5.1 Membrane Filtration Performance

Metcam and P^2AD were interested in evaluating the performance of the UF system in terms of its ability to improve Stage 1 bath quality by removing certain contaminants and recovering certain components of the chemistry.

Table 3 below provides a summary of the laboratory analysis tests methods used by the certified outside laboratory in evaluating membrane filtration performance.

Table 3. Laboratory Analysis Test Methods

Analysis	Test Method
Anionic Surfactants (MBAS) (as LAS) (mg/l)	EPA 425.1
Nonionic Surfactants (CTAS) (mg/l)	SM 5540 B,D
Oil & Grease (mg/l)	EPA 1664
Total Suspended Solids (mg/l)	EPA 160.2
Total Alkalinity (as $CaCO_3$) (mg/l)	EPA 310.1

Metcam has written work instructions for pulling grab samples from their process baths to ensure they are well mixed and representative of current solution conditions. The work instruction can be found in the Appendix of this report.

5.2 Five-Stage Washer Process Quality

Washer-related rejects were tracked during the technology evaluation to ensure that the system was not adversely affecting process quality and therefore, product quality. Visual inspections of the iron phosphate coat and powder coat were conducted. Flash rust prior to powder coating and blistering after applying the powder coat were evaluated by visual inspection. Metcam provided P^2AD with monthly non-conformance reports that described the rejects produced as a result of problems in the five-stage washer and powder coating operation. All washer-related rejects were normalized to production.

Salt spray (ASTM B 117) and coating weight destructive testing were also conducted after the UF system was installed. Salt spray testing measures the long term corrosion resistance characteristics of a part that has been plated or painted. It is one of the most widely used and well-understood quality tests in the metal finishing sector. Coating weight is not as widely used and therefore will be explained in greater detail. Coating weight is a test that measures the amount of phosphate coating by weight that is on the surface of the substrate before applying the powder topcoat. A certified lab weighs the test panel on a scale, removes the coating with an acid, and then weighs the test panel again. The difference in the weight before and after removal of the coating is the coating weight. Some manufacturing facilities have attempted to run this test in-house; however, this is not recommended because the concentration of the acid solution and the time the test panels must be in the solution must be exact to insure that none of the steel substrate is removed with the phosphate coating.

Conductivity, which is measured in siemens, characterizes a solutions ability to conduct electricity and is directly proportional to the quantity of TDS in solution. Since the UF system will not remove dissolved materials, tracking conductivity in Stage 1 was deemed important to ensure that an increase in TDS does not compromise process quality. Metcam measured conductivity by purchasing a hand-held electrodeless conductivity meter.

5.3 Systems Operation & Environmental Metrics

From an operations perspective, Metcam monitored the UF system, rinse counterflow system, and the evaporator system closely throughout the technology evaluation. Metcam tracked the following operations data: Stage 1 chemical additions, bath temperature, pH, conductivity, permeate flow rate, process tank batch out frequency, membrane cleaning frequency, Stage 2 dump frequency, and operation and maintenance labor for the five-stage washer. Once the counterflow system was installed Metcam installed a city water flow meter to track the rate at which Stage 2 was turning over by providing makeup water to Stage 1.

Since a majority of the O&G is removed by the UF system, Metcam also measured conductivity in the Stage 2 rinse to help determine if TDS would become the limiting factor in controlling Stage 2 tank dump frequencies. Finally, during the project Metcam also tracked the number of evaporator cycles run, evaporator energy usage, the amount and type of non-hazardous wastewater sent to the evaporator system, evaporator sludge generation, and operation and maintenance labor for the five-stage washer.

6.0 Technology Evaluation Results

A decision was made early on to stagger implementation of the UF system and rinse counterflow system in order to be able to quantify the actual benefit gained from each individually during the technology evaluation. From January 2, 2003 to March 10, 2003 the UF system was on-line by itself. Since March 10, 2003 the UF system has worked in tandem with the automated rinse counterflow system.

Metcam and P^{2}AD were interested in testing the UF system's ability to rejuvenate the dirty cleaner bath and evaluate how long it could be extended without needing to be dumped and recharged. At the time the project began, the cleaner was considered to be in the condition of a six-month bath even though it had not been dumped for nine months, because Metcam removed 300 gallons in December 2002 in order to clean out tank sludges. If the UF system could rejuvenate Stage 1 to that of a new bath, then it surely could keep the bath operating for a very long period of time without needing to be dumped and recharged.

The UF system turned the entire 1,250 gallons over in approximately 10 days. By appearance the bath went from a very cloudy orange-brown to a much clearer orange-yellow after one month. However, it was not until April 2003 that Metcam began to really see steady performance in contaminant removal and cleaner recovery.

6.1 Membrane Filtration Performance

In terms of evaluating membrane filtration performance the primary goal was to determine if the UF system was able to remove bath contaminants, most importantly O&G, while maintaining critical cleaner components, namely total alkalinity and the surfactant package. The results presented in this section are organized to illustrate the amount of O&G, total suspended solids, total alkalinity, nonionic surfactants, and anionic surfactants found in Stage 1 and the percent rejection or recovery of each respective parameter listed. To establish a baseline, a sample of the spent bath and a batch of unused neat cleaner were collected and analyzed by a certified lab before the UF system was installed on January 2, 2003.
To analyze the rejection and recovery rates the quantity of each constituent in the Stage 1 bath was compared to the quantity being returned to the bath in the permeate stream. In addition, later on in the technology evaluation (2-27-03) a decision was made to consider recovery and

rejection rates by comparing the quantity of each constituent in the retentate stream with the quantity in the permeate stream. This made sense because the retentate stream is continually re-circulated and processed across the membrane and eventually can become greater in concentration than Stage 1 prior to batching out the process tank. This is particularly true for constituents being rejected from the bath, such as O&G and total suspended solids.

The following calculations were used to determine recovery and rejection rates:

$$\%\ \text{Recovery/Rejection} = \left\{\frac{(\text{Stage 1 (mg/l)} - \text{Permeate (mg/l)})}{\text{Stage 1 (mg/l)}}\right\} \text{X } 100$$

$$\left\{\frac{(\text{Retentate (mg/l)} - \text{Permeate (mg/l)})}{\text{Retentate (mg/l))}}\right\} \text{X } 100$$

6.1.1 Stage 1 Oil & Grease Removal

High levels of O&G in Stage 1 can impair the cleaners ability to continually remove incoming O&G from the parts, and can also contaminate all subsequent washer stages with O&G leading to an increase in washer-related rejects. When O&G is not properly removed from the part during pretreatment it can become trapped between the substrate and the surface coating, causing poor adhesion and blistering. Therefore, evaluating the O&G removal efficiency of the UF system was critical to Metcam.

The baseline O&G level found on January 2, 2003 in Stage 1 was 250 mg/l. This may not appear to be a high level of O&G contamination, for example when compared to what might be found in a six-month old soak cleaner on a plating line. However, since the rinse stages cannot be overflowed, Metcam would likely have to dump Stage 2 once or twice per shift and/or dump Stage 1 more frequently if an oil load of 1,000 mg/l or more was ever reached in Stage 1. Metcam's pretreatment chemical supplier claims that in order to prevent O&G concentrations from reaching these high levels, the cleaner chemistry is designed to encapsulate O&G, causing it to drop out and settle on the bottom of the tank as a sludge. To remove the oily sludges from the bottom of the tank prior to the start-up of the project, Metcam installed access plates on the side of the Stage 1 tank.

Table 4 shows the trend for Stage 1 O&G levels from January through June 2003.

Table 4. Stage 1 Oil & Grease Levels

Date	(mg/l)	Date	(mg/l)
1/2/03 [1]	254	2/27/2003	42
1/7/2003	13	3/17/2003	30
1/13/2003	153	3/26/2003	44
1/16/2003	130	4/9/2003	84
1/23/2003	116	6/12/2003	6
1/30/2003	172	6/23/2003	10
2/7/2003	114	**Average**	76

[1] **Spent cleaner concentration**

The average O&G concentration from samples collected between January 2003 and June 2003 was 76 mg/l. However to assess the performance of the UF system, the technology evaluation must be broken down into several shorter time frames.

A dramatic decrease from 250 mg/l to 13 mg/l was realized in the first week of the technology evaluation. This was primarily due to the fact that Metcam was running the UF system without any production up to January 7, 2003. Once production started the UF system was stressed with having to remove O&G coming into the washer on parts while cleaning up a six-month old bath. During the initial month of production the O&G concentration averaged 137 mg/l. The UF system had decreased O&G levels in Stage 1 by 46%.

By late February and all the way through the month of April, the O&G level dropped considerably. When the counterflow system was installed on March 10, 2003 the UF system was now tasked with removing an additional quantity of oils that were once lost as carryover to Stage 2. A slight increase to 84 mg/l was realized on April 9, 2003 but the O&G levels would not get any higher through the remainder of the technology evaluation. From February through March, the average O&G concentration was approximately 50 mg/l, an 80% reduction from the six-month baseline.

After April 2003, the UF system began to operate at a higher level of consistency; the system appeared to be acclimating to Metcam's production process. Stage 1 was also beginning to reach the performance of a newly charged cleaner. On June 12, 2003 and June 23, 2003, O&G levels in Stage 1 were only 6 mg/l and 10 mg/l, respectively, a 97% reduction from the initial six-month baseline value.

On January 7, 2003, the permeate O&G concentration was higher than the concentration found in Stage 1. It was test results such as this that eventually led to a change in the sampling program to evaluate the concentration of cleaner components and contaminants in the 55-gallon process tank (retentate stream).

Table 5 illustrates the actual rejection rates realized during the technology evaluation.

Table 5. Oil & Grease Removal Efficiency

Date	Stage 1 (mg/l)	Permeate (mg/l)	% Removed
1/7/2003	13	20	
1/13/2003	153	13	92%
1/16/2003	130	16	88%
1/23/2003	116	21	82%
1/30/2003	172	28	84%
		Average	**86%**
Date	**Retentate (mg/l)**	**Permeate (mg/l)**	**% Removed**
2/27/2003	396	61	85%
3/26/2003	73	5	93%
4/9/2003	284	17	94%
		Average	**91%**

The O&G removal efficiency was evaluated by comparing O&G concentrations in Stage 1 against O&G concentrations in the permeate stream, as well as a comparison of the retentate levels versus permeate levels. The removal rates were similar, with the retentate - permeate analysis being a little more favorable at a 91% removal rate. The gray shaded cell shown for January 7, 2003, was left empty because the % removal would have shown a removal efficiency of greater than 100%. As mentioned in Section 6.1, one possible explanation is the concentration of the O&G within the retentate process tank rose to the point that it exceeded the concentration in Stage 1 at the time the sample was collected. Overall, the UF membrane system performed well in removing O&G from Metcam's cleaner bath with a combined average removal rate of 88%.

Eventually, O&G concentrations in the retentate process tank will increase to a point where the UF membrane begins to foul and the permeate flux rate decreases rapidly. Table 6 below illustrates the results of retentate samples collected and analyzed for O&G concentrations near the point at which Metcam would batch out the process tank and clean the UF membrane. An average O&G concentration of 171 mg/l was found for the retentate samples shown.

Table 6. UF Retentate Wastewater Oil & Grease Levels

Date	O&G (mg/l)
2/27/2003	396
3/17/2003	83
3/26/2003	73
4/4/2003	133
4/9/2003	284
Average	**171**

At Metcam, the 55 gallons of oily wastewater generated from batching out the retentate process tank is transported to the evaporator system for volume reduction. A more typical practice would be to have this small volume of oily wastewater hauled offsite for treatment and disposal. If the oil concentration is high enough in the retentate wastewater, such that it can be reclaimed or fuels blended rather than treated, some waste management companies will offer a reduced charge or possibly even pick up the waste at no cost to the company.

6.1.2 Stage 1 Total Suspended Solids Removal

As with O&G but to a lesser extent, total suspended solids (TSS) that are not properly removed from the part during pretreatment can become trapped between the substrate and the surface coating, leading to poor adhesion and blistering. Excessive buildup of TSS in Stage 1 can contaminate all subsequent washer stages as well, making it likely that some TSS will still be on the parts after exiting the five-stage washer.

The baseline TSS concentration for the spent cleaner bath turned out to be 27 mg/l. Table 7 illustrates the TSS profile of Stage 1 from January to April 2003, plus two additional tests completed in June 2003. As shown, the TSS levels rose above and fell below 27 mg/l three times during the technology evaluation. Further samples drawn in June show the same trend, a high value of 58 mg/l and then a sharp decrease to 10 mg/l.

Table 7. Stage 1 Total Suspended Solids Levels

Date	(mg/l)	Date	(mg/l)
1/2/03 [1]	27	2/27/2003	12
1/7/2003	28	3/17/2003	30
1/13/2003	33	3/26/2003	36
1/16/2003	22	4/9/2003	22
1/23/2003	18	6/12/2003	58
1/30/2003	31	6/23/2003	10
2/7/2003	38	**Average**	**28**

[1] **Spent cleaner concentration**

Table 8 below illustrates the actual rejection rates realized during the technology evaluation. As shown, there is a marked difference in the average removal rate when comparing Stage 1 and permeate TSS levels versus comparing retentate and permeate levels. Table 8 also shows that the retentate TSS concentrations increased considerably as the UF system processed Stage 1 cleaner. High TSS concentrations in the retentate process tank (e.g., 1,020 mg/l on February 27, 2003) can contribute to membrane fouling and cause permeate flux rates to drop. Since the UF system has no suspended solids pre-filtration, Metcam expected TSS levels to buildup in the process tank between retentate batch outs; however, they do not believe it will adversely affect the long-term performance of the UF system.

Table 8. Total Suspended Solids Removal Efficiency

Date	Stage 1 (mg/l)	Permeate (mg/l)	% Removed
1/7/03	28	8	71%
1/13/03	33	16	52%
1/30/03	31	5	84%
2/7/03	38	10	74%
		Average	**70%**
Date	**Retentate (mg/l)**	**Permeate (mg/l)**	**% Removed**
2/27/03	1020	7	99%
3/17/03	246	8	97%
3/26/03	60	12	80%
4/9/03	445	14	97%
		Average	**93%**

Since TSS will concentrate in the retentate tank overtime, and the retentate and permeate represent the two streams separated at the membrane surface, it is thought that an average TSS removal efficiency of 93% is a more realistic removal efficiency than 70%. Regardless, the fact that Metcam never even approached 100 mg/l in Stage 1, suggests that TSS is not a bath contaminant of concern.

6.1.3 Stage 1 Total Alkalinity Recovery

Maintaining the alkalinity of a cleaner is import because of its ability to saponify fats and oils, disperse oily contaminants so they do not redeposit on parts, and neutralize acidic contaminants. The total alkalinity is a measure of a solution's acid neutralizing capacity and acts as an indicator of the strength of an alkaline cleaner.

Alkalinity can be defined as the sum effect of all bases present in solution (Langmuir, 1997) and the general equation for calculating total alkalinity is shown below.

Total Alkalinity = $HCO_3^- + 2CO_3^= + OH^- - H^+$

In most waters that are near pH 7, the alkalinity is chiefly due to the bicarbonate ion HCO_3^- (Langmuir, 1997).

Table 9 on the following page illustrates the profile for total alkalinity in the Stage 1 cleaner during the length of the technology evaluation. In the neat cleaner before use, the total alkalinity was found to be 2,840 mg/l. The total alkalinity concentration in the spent six-month old bath was found to be 2,300 mg/l.

The average total alkalinity in Stage 1 found in samples analyzed from January through April 2003 was 2,072 mg/l, which is 90% of the initial concentration found in the dirty bath before the UF system was installed. Only three samples out of eleven (27%) fell below the lower acceptable total alkalinity limit for Stage 1 of 2,000 mg/l set by Metcam.

When production finally began on January 7, 2003 a sample was collected from Stage 1 and the total alkalinity had risen to 2,500 mg/l, which was the highest value realized during the technology evaluation.

Table 9. Stage 1 Total Alkalinity Levels

Date	(mg/l)	Date	(mg/l)
1/2/03[1]	2,840	1/30/2003	1,665
1/2/03[2]	2,300	2/7/2003	2,200
1/7/2003	2,500	2/27/2003	1,570
1/13/2003	2,250	3/17/2003	2,100
1/16/2003	2,250	3/26/2003	2,010
1/23/2003	1,810	4/9/2003	2,360
		Average	**2,072**

[1] Neat cleaner concentration

[2] Spent cleaner concentration

As the UF system continued to purify a highly contaminated cleaner bath while receiving new contaminants from incoming parts, the total alkalinity gradually dropped to 1,665 mg/l on January 30, 2003 and then 1,570 mg/l on February 27, 2003. After the counterflow rinse system was installed on March 10, 2003 the total alkalinity remained above 2,000 mg/l. In fact, the last sample analyzed was above the initial reading of 2,300 mg/l.

Table 10 below illustrates the recovery efficiencies realized for total alkalinity during the technology evaluation. As shown, only two of the six tests comparing Stage 1 and permeate total alkalinity concentrations were usable for determining recovery efficiency. Once again, the most probable conclusion is that certain samples were drawn after the retentate stream had concentrated past the concentration level of Stage 1.

Table 10. Total Alkalinity Recovery Efficiency

Date	Stage 1 (mg/l)	Permeate (mg/l)	% Recovered
1/7/2003	2500	2550	
1/13/2003	2250	2450	
1/16/2003	2250	2150	96%
1/23/2003	1810	2010	
1/30/2003	1665	1812	
2/7/2003	2200	2100	95%
		Average	**95.5%**
Date	**Retentate (mg/l)**	**Permeate (mg/l)**	**% Recovered**
2/27/2003	2410	1630	68%
3/17/2003	1820	1280	70%
3/26/2003	2190	1410	64%
4/9/2003	3280	2560	78%
		Average	**70%**

The recovery efficiencies found when evaluating the retentate stream versus the permeate stream collected from February 27, 2003 to April 9, 2003 averaged 70%. However, the alkalinity in the bath was being consumed slowly, as evident by a decreased need to add cleaner during the technology evaluation. A close examination of the test results comparing the permeate and Stage 1 stream show a relatively small difference in concentration between the two. Therefore, it is thought that the average total alkalinity recovery efficiency of the UF system is likely to be greater than 90%.

6.1.4 Stage 1 Surfactant Recovery

Metcam and P^{2}AD believed it was important to evaluate surfactant recovery since this was the first time that a UF system was used on Stage 1. Both parties agreed that it was important until a confidence was gained that that the UF system is keeping-up with production in terms of O&G removal such that part quality is not diminished and rejects rates do not rise.

6.1.4.1 Nonionic Surfactants

Nonionic surfactants accomplish more than just oil emulsification; they play a key role in preventing foam generation, which can be a major problem in spray wash systems if left un-addressed. The nonionic concentration of Metcam's surfactant package is thirteen times greater than the anionic surfactant concentration. According to the results of our baseline analysis, the nonionic surfactant concentration in the neat cleaner and the spent bath were 27.2 mg/l and 66.8 mg/l respectively.

One reason the nonionic surfactant levels in the 6 month old cleaner were much higher than what is found in the neat cleaner may be due to an increase in surfactants tied up with O&G and the existence of surfactant micelle aggregations. In other words, the total surfactant concentration continually grows as the bath ages, but a significant portion is not available to assist with incoming contaminants any longer since it is already holding O&G and other contaminants in solution.

Table 11 illustrates the profile for nonionic surfactant levels in Stage 1 during the technology evaluation. With an average concentration of 24.3 mg/l, only 2.9 mg/l below the neat cleaner concentration, the cleaner bath did not appear to suffer a major loss in nonionic surfactants.

Table 11. Stage 1 Nonionic Surfactant Levels

Date	(mg/l)	Date	(mg/l)
1/2/03 [1]	27.2	1/30/2003	36.5
1/2/03 [2]	66.8	2/7/2003	38.4
1/7/2003	14.8	2/27/2003	29.0
1/13/2003	20.9	3/17/2003	11.9
1/16/2003	34.4	6/12/2003	6.8
1/23/2003	12.3	6/23/2003	38.3
		Average	**24.3**

[1] **Neat cleaner concentration**

[2] **Spent cleaner concentration**

Furthermore, bath addition requirements dropped considerably during the technology evaluation, and the 3.5% cleaner concentration was not increased. There were a few samples however that exhibited low surfactant concentrations as indicated in Table 11 but the majority of the readings were actually above the neat cleaner concentration.

Table 12 on the following page illustrates the recovery efficiencies realized for nonionic surfactants during the project. As shown, permeate concentrations were higher in the first two samples than nonionic surfactant concentration in Stage 1. Early on in the technology evaluation, it is likely that a large amount of surfactant was tied up with O&G aggregated in micelles and therefore simply too large to pass through the membrane pores. This would cause the process tank to quickly become more concentrated with nonionic surfactant than Stage 1.

However, permeate levels in the first two samples were still below the initial 67 mg/l found in the spent bath.

Table 12. Nonionic Surfactant Recovery Efficiency

Date	Stage 1 (mg/l)	Permeate (mg/l)	% Recovered
1/7/2003	14.8	43.8	
1/13/2003	20.9	24.8	
1/16/2003	34.4	16.6	**48.3%**
1/23/2003	12.3	1.3	**10.6%**
1/30/2003	36.5	5.7	**15.6%**
2/7/2003	38.4	19.7	**51.3%**
2/27/2003	29.0	17.1	**59.0%**
		Average	**37%**

A low recovery efficiency for nonionic surfactants during the first two months of the technology evaluation is also likely associated with the stress placed on the UF membrane system as it processed a highly contaminated solution. Early on, processing runs were relatively short (i.e., the time between membrane cleanings) and the cleaning regimen being used was not sufficiently restoring permeate flux.

In addition, Metcam had discovered that the temperature in Stage 1 was inadvertently being maintained 10-20 °F below optimum levels (135 °F) during most of the technology evaluation due to temperature control problems with their furnace. While researching oil-water-surfactant systems, Bhattacharyya, et. al. (1979) found that at 77 °F physical adsorption and micelle formation of free nonionic surfactants contributed to fouling and flux decline within the membrane pores, but at 104 °F surfactant permeation increased without sacrificing oil rejection. Therefore, it can be surmised that the lower temperatures in Stage 1 may have also adversely affected surfactant recovery rates.

An average nonionic surfactant recovery rate of 55% for the final two tests suggests that as Stage 1 continues to approach the quality of a new alkaline cleaner bath, and Metcam gains more experience with operating and maintaining the UF system, higher nonionic surfactant recovery rates can be achieved. In fact, with most of the O&G found in Stage 1 at the start of the project now filtered out, and new O&G being removed almost as quickly as it is introduced into the bath, Metcam believes that much of the surfactant in the bath is now existing in an unbound state and thus is being recovered at a higher rate. Therefore, the importance of the nonionic surfactant is more to control foaming than to keep oils from re-depositing onto parts.

Additional tests were run to compare nonionic surfactant concentrations in the retentate and permeate streams. However, the laboratory results showed higher surfactant concentrations in the permeate stream than in the retentate stream, which is the opposite of what is expected. It is thought that sample collection and/or laboratory analysis difficulties may have led to erroneous test results.

Overall, even when the bath was operating at lower nonionic surfactant levels, cleaning effectiveness remained high. In fact the washer-related reject rate was 51% lower from January to April 2003 when compared to the previous four months before installing the UF system. Furthermore, during the technology evaluation, Metcam did not use a surfactant add package to makeup for the percentage retained by the UF system.

6.1.4.2 Anionic Surfactants

Anionic surfactants play a lesser role in Metcam's Stage 1 alkaline cleaner but it was still important to determine if the UF system would be able to recover them. Just as with the nonionic surfactant, the concentration of the anion surfactants in the spent bath (16.0 mg/l) was much higher than what is formulated in the neat cleaner (2.1 mg/l).

Table 13 illustrates the anionic profile for Stage 1 during the technology evaluation.

Table 13. Stage 1 Anionic Surfactant Levels

Date	(mg/l)	Date	(mg/l)
1/2/03 [1]	2.1	1/30/2003	1.2
1/2/03 [2]	16.0	2/7/2003	2.4
1/7/2003	2.9	2/27/2003	3.0
1/13/2003	2.9	3/17/2003	2.9
1/16/2003	2.4	3/26/2003	4.6
1/23/2003	2.1	4/9/2003	3.1
		Average	2.8

[1] Neat cleaner concentration

[2] Spent cleaner concentration

Table 13 demonstrates that the anionic surfactant package remained relatively stable, with only one reading dropping below 2.0 mg/l (1/30/03; 1.2 mg/l) and only one reading going above 4.0 mg/l (3/26/03; 4.6 mg/l).

Table 14 shows the percent recovery rates for anion surfactants.

Table 14. Anionic Surfactant Recovery Efficiency

Date	Stage 1 (mg/l)	Permeate (mg/l)	% Recovered
1/7/2003	2.9	1.7	58.6%
1/13/2003	2.9	2.7	93.1%
1/16/2003	2.4	1.4	58.3%
1/23/2003	2.1	2.8	
1/30/2003	1.2	1	83.3%
2/6/2003	2.4	1.1	45.8%
		Average	68%
Date	**Retentate (mg/l)**	**Permeate (mg/l)**	**% Recovered**
2/27/2003	5.6	1.3	23.2%
3/17/2003	5.0	1.1	22.0%
3/26/2003	5.1	2.5	49.0%
4/9/2003	6.8	1.7	25.0%
		Average	53%

The anionic recover efficiency when comparing the permeate levels with that found in Stage 1 was slightly erratic. On January 13, 2003 the membrane was recovering 93% of the anionic surfactant and on February 6, 2003 the recovery rate dropped all the way to 46%.

The variation in recovery rates shown when comparing retentate and permeate anionic surfactant levels is less dramatic. The UF system's average anionic surfactant recovery efficiency for permeate-Stage1 tests and permeate-retentate samples were 68% and 53%, respectively. With the fact that Stage 1 anionic surfactant levels were relatively stable, and the small role played by these surfactants, Metcam is content with the performance of the UF system.

6.2 Five-Stage Washer Process Quality

Metcam relies upon a variety of visual criteria to assist in identifying if a coated part has conformed to quality specifications. In general, coated parts can be rejected for problems linked to pretreatment, coating and curing operations. Pretreatment-based washer rejects will exhibit a blistered look due to oil, water or particulates getting trapped between the substrate and the surface coating, leading to poor adhesion. The root cause for this type of reject is inadequate cleaning and phosphating.

If residual cleaner remaining on the parts is not effectively rinsed off in Stage 2 the part will not accept the phosphate coating in Stage 3. This can cause flash rusting to occur after the part exits the five-stage washer system, as it travels to and from the dry-off oven, before receiving the powder coat at the spray booth. This layer of flash rust between the substrate and the coating diminishes adhesion and corrosion resistance. A brown gold or purple gold appearance with streaking is a sign of flash rust. A part that has been cleaned properly and has a sufficient coating of phosphate will appear gun-metal blue (blue gray).

The synergistic relationship between all five stages of Metcam's iron phosphate washer help to ensure a proper pretreatment coating and this makes it difficult to pinpoint one stage of the washer as the reason why parts were rejected. However, parts rejected for powder coating or cure problems were not considered here since the P2 systems could not have played a role.

Table 15 below details the level of production and the quantity of parts rejected in square feet by month for the five-stage iron phosphate washer.

Table 15. Washer Rejects Normalized to Production

Time Frame	Month	Washer Rejects (ft^2)	Production (ft^2)	Rejects (ft^2) /1000 ft^2 Production
Before Project	October-02	6.67	16,779	0.40
	November-02	82.14	26,696	3.08
	December-02	199.43	26,127	7.63
During Project	January-03	72.27	19,233	3.76
	February-03	7.38	21,961	0.34
	March-03	132.07	32,031	4.12
	April-03	0	31,714	0.00
Average Before Project		**288.25**	**69,602**	**4.14**
Average During Project		**211.72**	**104,940**	**2.02**

With rejection rates normalized to production, a quality improvement is shown when comparing timeframes before and after installation of the P2 systems. Metcam has realized a 51% reduction in washer-related rejects since implementing the UF and counterflow system.

In 2001, Metcam began using two types of destructive tests as a part of their ISO 9001 Quality Management System; a coating weight test and salt spray test. These destructive tests are conducted as an added level of quality assurance above and beyond the visual examinations discussed above. For each destructive test, a minimum of six panels are sent to an outside certified lab and the results are denoted as the average of the panels tested.

The iron phosphated panels must be within a coating weight range of 30 to 60 mg/ft^2. If the coating weight is below 30 mg/ft^2, flash rusting can become a problem. When a layer of flash rust develops on the steel substrate before applying the powder coating the powder will not adhere well and this diminished the corrosion resistance of the coating. Conversely, if the coating weight is above 60 mg/ft^2, a heavy chalk-like film can develop causing inner-coat adhesion problems between the steel substrate and the powder coating, thus the powder coating will peel off the substrate like masking tape. Metcam's most demanding customer requires the powder-coated steel to pass this test at 1,000 hours in the chamber.

Table 16 highlights the non-destructive test results for parts processed through the five-stage washer after installation of the UF system.

Table 16. Salt Spray & Coating Weight Quality

Quality Metric	Result	Requirement
Salt Spray Test (Powder Coat)	1,750 hours as of 6-1-03	1,000 hours
Coating Weight (Iron Phosphate)	44 mg/ft^2	30-60 mg/ft^2

As of June 1 2003, salt spray testing was still ongoing at 1,750 hours, which far exceeds Metcam's 1,000 hour requirement. The coating weight test results were also good at 44 mg/ft^2.

Metcam also felt it was important to measure conductivity in Stage 1 order to see if TDS would increase above the point where quality problems such as spotting would begin to limit bath life extension. In general, dissolved solids such as incoming city water hardness and metals entering the bath from parts being cleaned or from the tank itself are smaller than the membranes 0.1 micron pores, and can slowly concentrate in the cleaner bath.

As a part of the baseline evaluation for Stage 1, the conductivity of the alkaline cleaner was calibrated to the concentration of the alkaline cleaner at various % dilutions. The alkaline cleaner used by Metcam is maintained in a concentration range of 3 to 4% by volume. At 3% by volume, the conductivity of the cleaner was 8.0 mSiemens. At 3.5% and 4% by volume, the cleaner conductivity was 9.45 and 9.95 mSiemens, respectively. Therefore, Metcam deduced that any conductivity reading in the bath above ten mSiemens could be attributed to a buildup of TDS.

During the technology evaluation the conductivity in Stage 1 rose above ten mSiemens once on April 10, 2003 (10.06 mSiemens) but then dropped to 9.26 mSiemens on the following day. In fact, over a three and a half month time period, the average conductivity in Stage 1 was 8.0 mSiemens. Furthermore, Metcam did not see any washer-related quality problems over this time period that could be attribute to excess levels of heavy metals or dissolved salts. Based on the results of the conductivity measurements, Metcam does not believe that TDS will become a limiting factor in the life of the cleaner bath or the quality of the washing operation.

6.3 Operation & Maintenance Evaluation

The operation and maintenance (O&M) of the P2 technologies, Stage 1 and Stage 2 of the washer system, and the evaporator system will now be discussed. In general, the O&M for Stage 1, Stage 2, and the evaporator system decreased considerably while the O&M for the P2 technologies proved to be minimal.

6.3.1 Washer Stage 1 and Stage 2

Daily monitoring of Stage 1 pH, temperature and % solution through titration remained constant before, during and after the technology evaluation. The changes realized in operating Stage 1 were related to a reduced frequency of bath dumps, tank cleaning and sludge removal. In fact, Metcam has reported that oily sludge, which used to buildup on the bottom Stage 1, is no longer an issue because the UF membrane is removing it from the cleaner. Stage 1 and Stage 2 contain screens to prevent large suspended solids from getting trapped in the spray circulation pumps. The screens used to be removed and cleaned weekly yet have not needed to be changed since the start of the project. Periodic Stage 2 oil split tests remained constant before, during, and after the technology evaluation. Stage 2 tank dumps have virtually been eliminated.

6.3.2 UF & Rinse Counterflow Systems

For about fifteen minutes every day (62.5 hrs./yr.), Metcam manually measures the permeate flowrate in milliliters per minute (ml/min.) and checks the permeate pH, temperature, and inlet and outlet membrane feed pressures. The permeate flux, which can be defined as the volumetric rate of flow of the permeate through the membrane pores (e.g., liters/m^2/hour or gallons/ft^2/day), was also tracked by Metcam during the project. Permeate flowrate and permeate flux are both critical operational parameters because they act as indicators of the membrane's performance in processing the cleaner solution.

When the UF membrane system was initially put on-line at 9:00AM on January 2, 2003, the permeate flowrate was measured to be 990 ml/min., but by 6:00PM, the permeate flowrate had dropped down to 260 ml/min. The UF equipment supplier suggested that 800 ml/min. be used as a starting point or realistic expectation for a permeate flowrate after each cleaning and restoration of the membrane's performance.

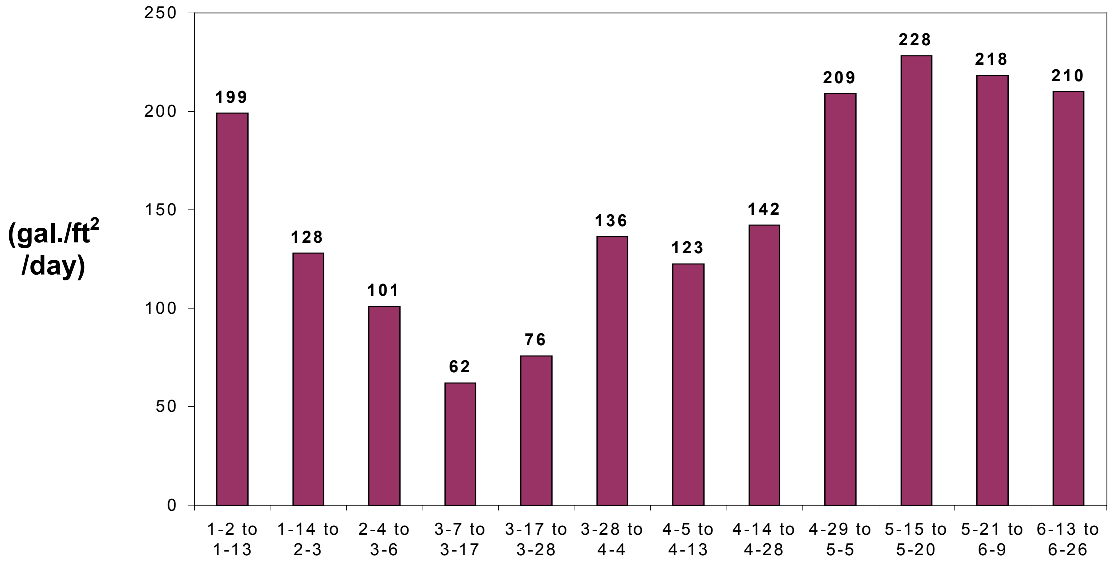
For the first four months of operation, when the permeate flowrate dropped below 100-200 ml/min., Metcam would remove the UF membrane from Stage 1, and batch out (drain) the contents of the retentate process tank to a 55-gallon drum. The drummed oily wastewater would then be transported to the evaporator for volume reduction. The dirty membranes were initially being shipped to the UF equipment supplier for cleaning and performance restoration, but at the end of March 2003, Metcam decided to begin cleaning the membranes in-house.

Figure 6 on the following page exhibits the average flux rate of the UF system from January 2003 through June 2003. It illustrates the permeate flux rates within each cleaning and process tank batch out timeframe. As shown, the average permeate flux rate started at an average of 199 gallons per square foot of membrane per day. Due to a number of variables, the average flux rate achieved by the membrane dropped considerably over the next two months. In addition, 800 ml/min. was not achieved again as a permeate flowrate starting point (after cleaning and restoring the membrane) until April 29, 2003.

First, and most importantly, the low permeate flux rates realized from mid-January though mid-March 2003 can be at least partially if not fully attributed to the overall condition of the Stage 1 cleaner bath. The UF system was tasked with processing a six month old soiled cleaner bath, which led to premature fouling of the membrane and reduced permeate production.

Second, Stage 1 temperatures were found to be below the desired 135 °F for much of the first three months. Permeate flux has been found to be enhanced by increases in solution temperature (Bhattacharyya, et al. 1979) and therefore the lower bath temperature may have played a role in reducing flux rates.

Figure 7. Average Permeate Flux Rate



In actuality, analyzing membrane fouling behavior and determining an effective membrane cleaning regimen is a trail and error process. For the first two months of the technology evaluation, Metcam was relying on the equipment supplier's membrane cleaning program. Metcam would ship the dirty membrane back to the UF supplier for cleaning and flux restoration, and simply connect up their clean standby membrane to keep the UF system running. The cleaning regimen used by the equipment supplier during the first three months, which comprised of a 2-3% caustic solution followed by a citric acid solution, was not completely effective in restoring the membrane's performance. However, due to the condition of the cleaner bath at the start of the project, the equipment supplier did state that it may take some time to evaluate several cleaning methods before the optimal cleaning regimen is found.

On March 28, 2003 Metcam began cleaning the membrane on-site, using a slightly stronger caustic solution (% volume), and they immediately saw an improvement in restoring the flux rate. Metcam injects 300 ml of the caustic solution into the membrane using a syringe, and then the membrane is placed in the Stage 1 cleaner tank to soak. A second hole was bored in the cover of the Stage 1 tank so that the dirty membrane would not interfere with the clean membrane in use. As shown in Figure 6, after the change in the cleaning regimen the average permeate flux increased from 76 to 136 gal./ft^2/day.

This improvement trend for permeate flux continued through the months of May and June 2003 with an average permeate flux of 216 gal/ft^2/day. In addition to a more consistent, higher permeate flux rate during this timeframe, the length of time between membrane cleanings increased to 3.25 weeks even though Metcam was now batching out and cleaning the UF membrane at a higher permeate flux rate (350-300 ml/min.).

Table 17 exhibits the total annual operating cost for the UF system. At $4,264 per year, the operation and maintenance costs are really not considered to be significant when compared to the annual cost savings of $33,287, which is detailed in Section 7.0.

Of note, the equipment supplier's cleaning program is shown in the table but is not a part of the annual operating costs since Metcam is now handling the cleaning activity on-site. It takes approximately one hour to batch out the process tank and one hour to clean the membrane.

Table 17. Ultrafiltration System Operating Costs

Source	Quantity/Year	Units	Unit Cost	$/Year
UF Operation Labor (w/o Batch Out & Cleaning)	65	hours	$20.00	$1,300
UF Maintenance Labor	20	hours	$20.00	$400
UF Energy Use (Motor)	18,492	kW-hrs	$0.07	$1,294
Membrane Cleaning Costs Arbortech Charge	16	cleanings	$55.00	$880
On-Site Membrane Cleaning Chemical Use	300	mililiters	$9.86	Negligible
Batch Out and Cleaning Labor	32	hours	$20.00	$640
Batchout Wastewater	1105	gal.	$0.31	$340
Stage 1 Surfactant Package	7.94	gal.	$36.43	$289
			Total Annual Operating Cost	**$4,264**

At a 3.25-week interval between each batch out and membrane cleaning, the labor time was estimated to be 32 hours per year. Metcam estimated that roughly 10-15 gallons of water is added to the process tank to rinse out solids following each retentate batch out, which makes the total wastewater volume per batch out 65 gallons.

Metcam did have problems with the pump originally specified for the UF system. A leaking seal found at the beginning of February eventually led to the failure of the pump. It is thought that the pump seal may have deteriorated from exposure to a high pH environment and O&G within the cleaner solution. As a part of the troubleshooting process, the UF supplier provided Metcam with an in-line heater for the process tank solution, to see if a more consistent temperature would prevent further leaking. It was thought that the seal might shrink slightly in colder solutions. Unfortunately, the heater did not solve the problem. The equipment supplier did finally provide Metcam with a new pump seal (EPDM class), which is supposed to be resistant to high pH oily solutions, and a kit for installation. Therefore, the one major maintenance activity is projected to be twenty hours to service the UF system recirculation pump once a year.

6.3.3 Evaporator System

Weekly monitoring of the liquid volume in the 9,400-gallon evaporator holding tank was an indicator for the quantity of wastewater being generated by the five-stage washer and other sources of non-hazardous wastewaters. Metcam has estimated that before the project began, the evaporator system was operating at 95% of its capacity. While Metcam did not measure the liquid level in the wastewater holding tank prior to the pilot project, it was tracked during the evaluation. For the two most important timeframes, before and after the rinse counterflow system was installed, the average liquid level in the wastewater holding tank was 6,814 gallons and 4,092 respectively. Therefore, since both the UF system and the rinse counterflow system were implemented through July 15, 2003, Metcam has not observed the wastewater storage tank go above 50% of its holding capacity.

Reduction estimates for evaporator sludge cleanout labor were based on the empirical data provided by Metcam in determining a cost baseline (1330 gallons of wastewater evaporated per cycle). An evaporator cleanout occurs after each cycle, and Metcam spends roughly three hours completing this task. Therefore, with an annual reduction in wastewater projected to be 76,200 gallons, Metcam should eliminate 57 evaporator cycles per year (76,200 gallons x (1 cycle/1,330 gallons), which equates to 172 hours eliminated and a labor cost savings of $3,438 per year.

Metcam has stated that non-hazardous wastewater generation from the aluminum immersion line has slowly increased since January 2003 due to increases in production and process quality demands for improved rinsing. The increase in evaporation capacity has allowed Metcam to avoid bulk shipment of non-hazardous immersion lines wastewaters, which was the only option for Metcam before reducing wastewater from their five-stage iron phosphate washer. At $0.41 per gallon to send bulk shipments of non-hazardous wastewater off-site for treatment and disposal, Metcam is actually saving an additional $0.10 per gallon by evaporating the non-hazardous immersion line wastewater on-site. Evaporating immersion line wastewater does lower the actual amount of evaporator cycles eliminated; however, to be conservative it was assumed that Metcam would only realize a savings of $0.31/gallon from reducing the number of evaporator cycles required for processing Stage 1 and Stage 2 wastewaters.

6.4 Stage 1 Chemical Use Reduction

Prior to installation of the UF system, over a four-month timeframe from September to December 2002 Metcam was using 1.78 gallons of cleaner per 1000 ft^2 (surface area) of parts pretreated in the five-stage iron phosphate washer. After installing the UF system, from January 2, 2003 to March 10, 2003, the chemical usage rate decreased to 1.46 gallons per 1,000 ft^2. After the rinse counterflow system was added on March 10, 2003 until May 31, 2003, Metcam observed a dramatic reduction in cleaner additions with the chemical usage rate dropping to 0.36 gallons/1,000 $ft^{2.}$.

Table 18 below shows a month-by-month profile of Stage 1 cleaner usage with and without being normalized to production. A graph illustrating the trend shown below for monthly cleaner usage normalized to production can be found in the appendix of this report.

Table 18. Production Normalized Stage 1 Cleaner Usage

Month	Stage 1 Chemical Usage (gal.)	Production (ft^2)	Stage 1 Chemical Usage (gal/1,000 ft^2)
September-02	38	20,735	1.83
October-02	43.0	16,839	2.55
November-02	47.5	27,347	1.74
December-02	35.0	26,996	1.30
January-03	21.3	19,544	1.09
February-03	27.1	22,081	1.23
March-03	31.8	32,991	0.96
April-03	11.9	32,504	0.37
May-03	9.3	35,169	0.26

The cleaner usage reductions observed can be explained by a number of contributing factors. First, since the UF system is removing O&G and other contaminants from Stage 1 continuously while recovering cleaner chemistry, the alkalinity and surfactant package is not being consumed as quickly as it once was and the % solution is being maintained with less cleaner additions. Also, with the rinse counterflow system returning cleaner to Stage 1 that is carried into Stage 2 on the surface of the parts, the need to add new cleaner as makeup for dragout losses is eliminated.

In order to conservatively estimate future savings in cleaner chemical use, the 12-month total provided by Metcam before the project began (July 2001 to June 2002) was used rather than annualizing the four months of data shown in Table 18 above. This approach projects the annual cleaner reduction to be 234 gallons per year, 153 gallons less than what would be calculated by using the data for September through December 2002.

6.5 Environmental Improvement

During the pilot evaluation, Metcam tracked the environmental metrics associated with Stage 1 and Stage 2 of the iron phosphate washer, the UF system, rinse counterflow system, and the evaporator system. The primary environmental metrics tracked include wastewater generation from Stage 1 and Stage 2 and natural gas usage from the evaporator system.

6.5.1 Wastewater Generation Reduction

One of the most rewarding results of Phase I was the dramatic reduction in Stage 2 wastewater generation. Before the project began, it was thought that if the Stage 2 rinse bath life could be extended to four production days from two production days the project would be a success. After installing both the UF and rinse counterflow system, Stage 2 performed very well for three months without needing to be dumped, and therefore without generating any wastewater. For a two-month period before the project started Metcam was generating approximately 200 gallons of wastewater per 1,000 ft of parts processed through Stage 2. During the first two months of the project, with the UF system in place but before installation of the rinse counterflow system, Stage 2 wastewater generation decreased to 90 gallons per 1,000 ft^2. Once the rinse counterflow system was in place, no wastewater was generated from Stage 2 through the remainder of the technology evaluation.

Before the project began, Metcam would gage the need to dump Stage 2 by measuring the percent of oil found in the rinsewater through an oil split test. Metcam has established an upper limit for oil in Stage 2 of 10ml oil/100ml rinse. With the UF system installed, Stage 2 bath life was extended to six production days before reaching 10ml oil/100ml rinse. After the rinse counterflow system was installed, it was thought that the Stage 2 bath life could be extended almost indefinitely because oil levels were simply not approaching 10ml oil/100ml rinse.

Since it appeared that O&G would no longer be the limiting factor for Stage 2 bath life, the focus switched to monitoring dissolved solids buildup through conductivity measurements. To establish a baseline, conductivity was measured in Stage 2 in the month of December 2002. Over two production days, which was the bath life at the time, conductivity levels in the rinse tank would rise from 0.0 mSiemens to 2.35 mSiemens. After installing the UF system, conductivity levels in Stage 2 rose more gradually, and once the rinse counterflow system was in place, conductivity levels in Stage 2 never exceeded 1.0 mSiemens. Monthly conductivity readings for Stage 2 are included in the appendix of this report.

Even though rinsing quality was not being compromised, Metcam made a decision to dump the 750-gallon rinse after three months, to check for solids buildup at the bottom of tank. It was found that solids did not buildup at the bottom of the tank. At the time of writing the final report, Metcam was considering whether or not to wait six months instead of three months before dumping Stage 2 again.

In summary, as of July 1, 2003, the 1,250-gallon Stage 1 alkaline cleaner bath was extended out from six months to twelve months; a 100% increase in bath life. Stage 1 is expected to last another year before needing to be dumped. This equates to 4,200 gallons eliminated per year.

A 25% reduction was achieved for Stage 2 from the UF system alone; however, after adding on the counterflow, a 96% reduction was realized. With 76,200 gallons of wastewater reduced per year, 4,698 gallons of evaporator sludge will also be eliminated. A graph illustrating the wastewater reduction achievements of the pilot project can be found in the appendix.

6.5.2 Water Conservation and Rinsing Improvements

The amount of water conserved for the UF and rinse counterflow system is equal to the amount of wastewater eliminated (76,200 gallons/year). Metcam began tracking the quantity of water flowing through Stage 2 into Stage 1 once the rinse counterflow system was in place. This was accomplished by installing a water meter on the incoming city water pipe that feeds both tanks. Metcam is now turning over the 750-gallon rinse tank approximately once every 1.5 to 2.0 production days without discharging any wastewater since the water is transported to Stage 1. With the O&G carryover rate from Stage 1 to Stage 2 much lower, Metcam has also improved rinsing quality considerably.

6.5.3 Natural Gas Usage Reduction

The reduction estimates for natural gas usage were based on an average natural gas efficiency for the evaporator system of 170 ccf. per 1330-gallon cycle. By reducing 76,200 gallons of wastewater per year, Metcam can eliminate 57 evaporator cycles, which equates to 9,740 ccf. of natural gas conserved annually. As explained in Section 6.3.3, the net reduction in natural gas usage for the entire facility will be slightly lower due to an increase in non-hazardous wastewater generated from other operations at Metcam that are being sent to the evaporators.

7.0 Project Economic Analysis

A detailed economic analysis was performed for the pilot project. Three of the most widely accepted tools for assessing the cost effectiveness of a project were used: simple payback period, net present value, and internal rate of return.

Table 19 illustrates how cost savings for the project was determined.

Table 19. Project Cost Savings Summary

Source	Quantity/Year	Units	Unit Cost	$/Year
Stage 1 Wastewater Reduction	4,200	gallons	0.31	$1,294
Stage 1 Chemical Additions Reduction	168	gallons	$13.26	$2,230
Stage 1 Dump Labor Reduction	1.50	dumps	$380.00	$570
Stage 1 Tank Cleanout Chemical Reduction	117	gallons	$17.68	$2,072
Stage 1 Chemical Recharge Reduction	66	gallons	$13.26	$870
Stage 2 Wastewater Reduction	72,000	gallons	$0.31	$22,183
Stage 2 Dump Labor	96	dumps	$40.00	$3,840
Stage 1 & Stage 2 Water Conservation	76,200	gallons	$0.003	$229
Evaporator Natural Gas Reduction	9,740	cubic feet	$0.56	$5,454
Evaporator Cleanout Labor Reduction	172	hours	$20.00	$3,438
			Annual Cost Savings	**$33,287**

The total cost savings per year was estimated to be $33,287. The largest contributor to the cost savings was elimination of the need to evaporate 72,000 gallons of Stage 2 rinse wastewater.

With 96% of the Stage 2 rinse wastewater eliminated Metcam will be saving $22,183 in operational costs for the evaporator system and $3,840 in tank dump labor. For informational purposes only, the $8,892 in savings from reductions in natural gas use and evaporator labor was broken out at the bottom of the table. The savings represented by both sources is actually built into the $0.31/gallon unit cost for running the evaporators. The labor rate of $20/hour is considered an average hourly rate for operators.

Table 20 below provides a summary of the economic analysis performed for the technology evaluation project. The equipment and installation costs for the UF system and the counterflow system were separated to show the contribution of each to the total cost. The UF system cost was $8,160, which included two 0.75 ft^2 stainless steel membranes, a 55-gallon process tank, and a 1.5 horsepower recirculation pump.

In addition, Metcam chose to purchase an in-line heater system for $1,660 to keep the cleaner solution in the process tank close to the temperature of Stage 1 (135 °F). The installation cost for the UF system is mainly associated with the labor required.

Table 20. Economic Analysis Summary

Source	Equipment Cost	Installation Cost	Total Cost	Net Cost Savings/Year
Ultrafiltration System	$9,820	$1,919	$11,739	**$29,023**
Counterflow System	$2,280	$6,000	$8,280	
Total Cost	**$12,100**	**$7,919**	**$20,019**	

Simple Payback Before Taxes - No Inflation (Years)	Simple Payback After Taxes - Inflation (Years)	Internal Rate of Return (After Taxes)	Net Present Value (After Taxes)
0.69	**0.97**	**105%**	**$303,895**

Metcam designed and built the automated rinse counterflow system in-house. Therefore, the installation cost actually includes labor to design, fabricate, assemble, and install the counterflow system. Metcam was able to use a transfer pump they had in inventory for the rinse counterflow system. When taking the difference between the operating costs associated with both P2 technologies and the cost savings shown above in Table 20, a net cost savings of $29,023 is realized.

Without considering taxes or inflation, the simple payback turns out to be 0.69 years. Using a 34% income tax rate and 2.12% inflation rate, the simple payback is calculated to be just below 1 year. At 105%, the internal rate of return demonstrates that implementing the P2 technologies evaluated will add a considerable amount of value to the five-stage washer operation. Using a 20-year equipment life without any salvage value, and an interest rate of 4%, the net present value for the project turned out to be $303,895. Overall, the economic analysis shows that Metcam now has a more cost efficient, leaner paint pretreatment system. A spreadsheet that details the calculations used to determine the internal rate of return and net present value is available in the Appendix.

8.0 Conclusion

The UF system and rinse counterflow system, as a single P2 practice, proved to be successful at removing O&G from Stage 1 in order to extend the life of Stage 2, while recovering a majority of the Stage 1 cleaner chemistry. In addition, the UF system demonstrated its ability to clean up and rejuvenate a six month old alkaline cleaner bath. Metcam realized cost savings and labor savings from the implementation of the combined UF and rinse counterflow system. Metcam also reduced wastewater generation from Stage 1 and Stage 2 of the five-stage washer, which helped the company to exceed their internal waste reduction goals. Lastly, the number of washer-related rejects normalized to production dropped considerably after implementing the P2 practice, when compared to an equivalent number of months before the project began.

While Metcam and P^2AD do not feel there are any long-term disadvantages in the use of the ultrafiltration and rinse counterflow P2 practice there were a few challenges to be overcome, and lessons learned to be learned from the technology evaluation project.

From an equipment standpoint, it is important to make sure that the pump specified by the equipment supplier for the UF system is made of the correct materials to withstand the chemicals and oils found in an alkaline cleaner. Specifically, ensure that the UF system is built with EPDM class pump seals.

Cleaning the UF membranes in-house worked better for Metcam than sending the membranes to the equipment supplier for cleaning, in terms of restoring permeate flux. However, it is thought that if the UF system was installed on a fresh alkaline cleaner bath, the equipment supplier's cleaning regimen would have worked more effectively. P^2AD and Metcam also believe that if the UF membrane system had not been tasked with rejuvenating a spent cleaner, the nonionic surfactant recovery efficiency would have been higher than what was realized during the project. Therefore, due primarily to the difficulties encountered with restoring permeate flux and cleaning the membranes early on in the project, Metcam recommends starting with a new cleaner bath when implementing a UF membrane system.

A lesson learned in terms of planning for the technology evaluation relates to the fact that only a single grab sample was pulled from the spent alkaline cleaner bath to establish a baseline. In future efforts, it is recommended to collect a set of multiple samples over at least a 30-day period prior to start up. Ideally, a more accurate O&G profile can be developed by collecting and analyzing samples over one or more complete bath life cycles.

Lastly, Metcam and P^2AD believe that metal finishers could gain the most benefit with the shortest payback period by implementing the UF membrane system and rinse counterflow system at the same time.

Based on the findings of the technology evaluation, Metcam recommends the use of a combined UF and rinse counterflow system for other companies that rely on alkaline cleaning before liquid or powder coating metal substrates.

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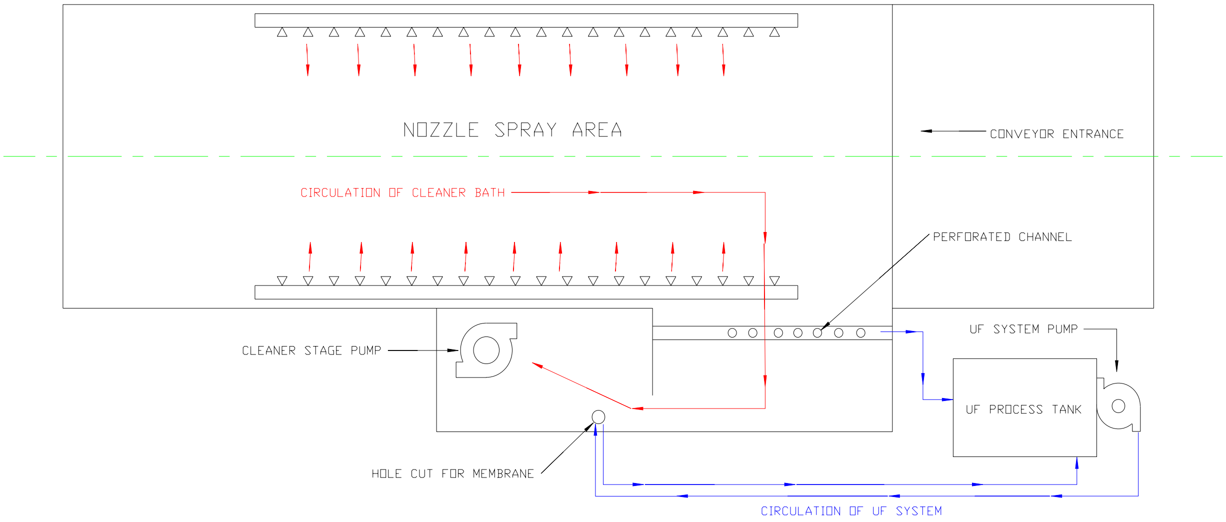
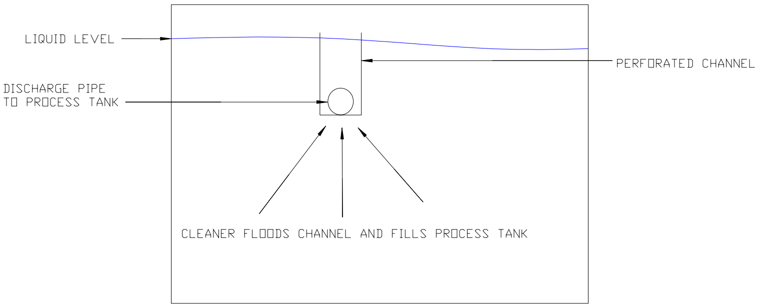
Appendix

Stage 1 Alkaline Cleaner & Ultrafiltration System



SIDE VIEW OF CHANNEL



Rinse Counterflow System Conceptual Design

DAVID SANDERS COMPANY

PROCESS FLOW CHART

CUSTOMER:

METCAM INCORPORATED

PROJECT:

5-STAGE WASHER STAGE 1 & 2 WATER MAKE-UP

DATE:

2/15/03

SCOPE:

Design a system to make-up lost water due to evaporation and carry over in tanks 1 & 2

REQUIREMENTS:

1. Make up water for Stage 1 to be supplied from Stage 2.
2. Stage 2 make-up water to be supplied from City water.
3. System to be fully automated and operate independently of washer control system.
4. System must be able to operate with washer control panel off.
5. Control voltage to be 120 VAC.

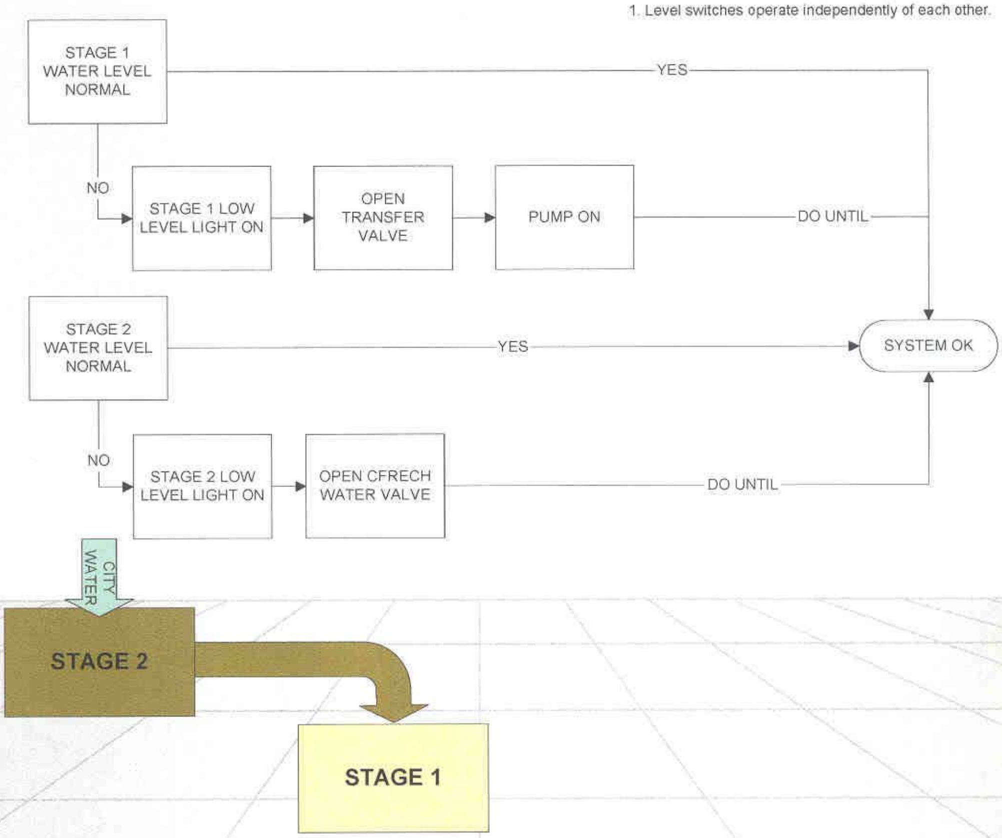
I/O:

1. Stage 1 Float Switch (Discreet)
2. Stage 2 Float Switch (Discreet)

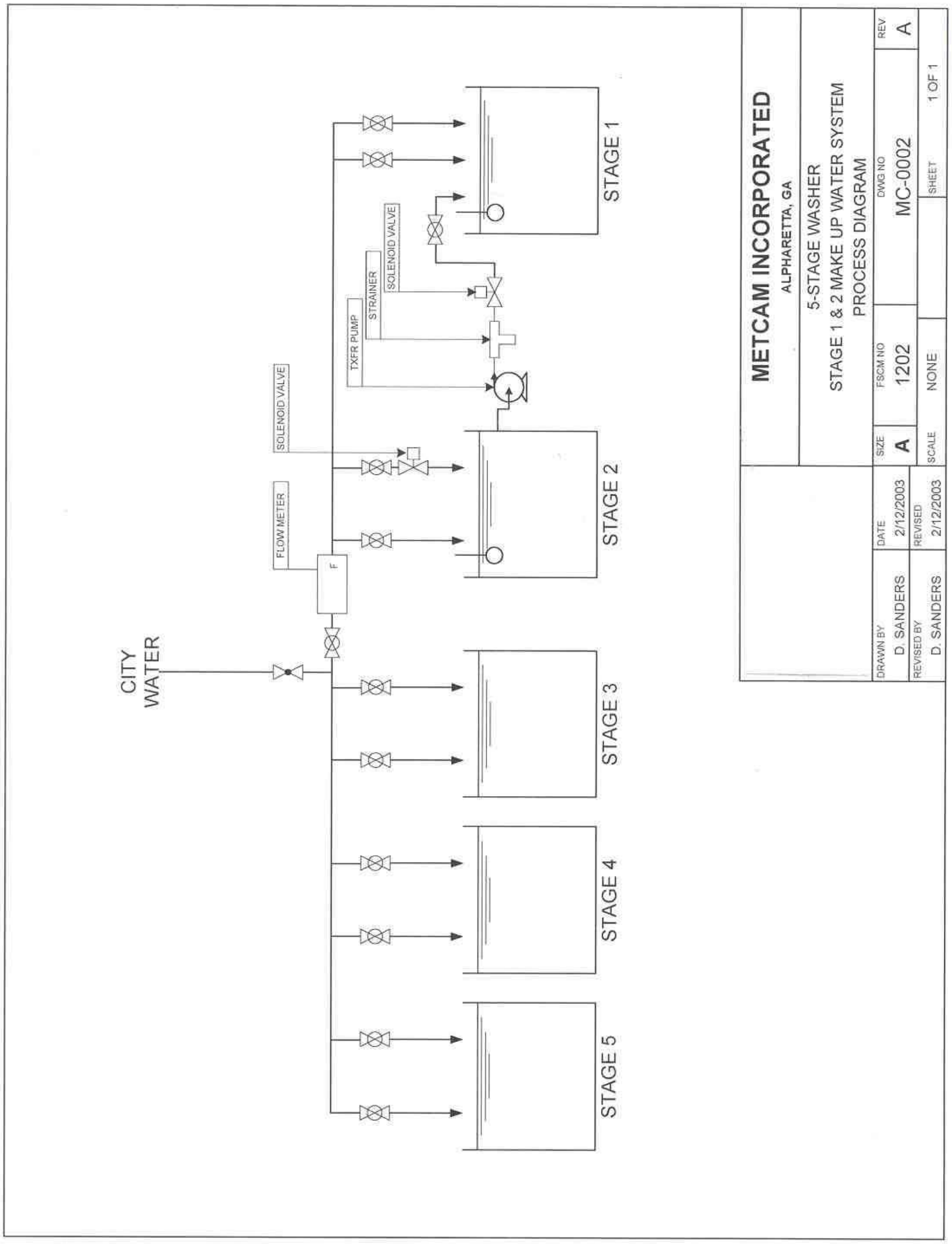
DEVICES:

1. Gems Stainless Float Switch (2)
2. Centrifugal Pump (1)
3. Asco Solenoid Valve (2)

Notes:
1. Level switches operate independently of each other.



Five-Stage Washer & Counterflow Rinse System
Pumping & Instrumentation Diagram



Metcam Grab Sample Work Instruction

METCAM Advanced Metal Working	**WORK INSTRUCTIONS**	Document Number **WI-4.9**	Revision **A**	**Page 1 of 1**

1.0 Purpose:

Provides a written process for collecting grab samples for internal testing or testing to be conducted by an outside lab.

2.0 Scope:

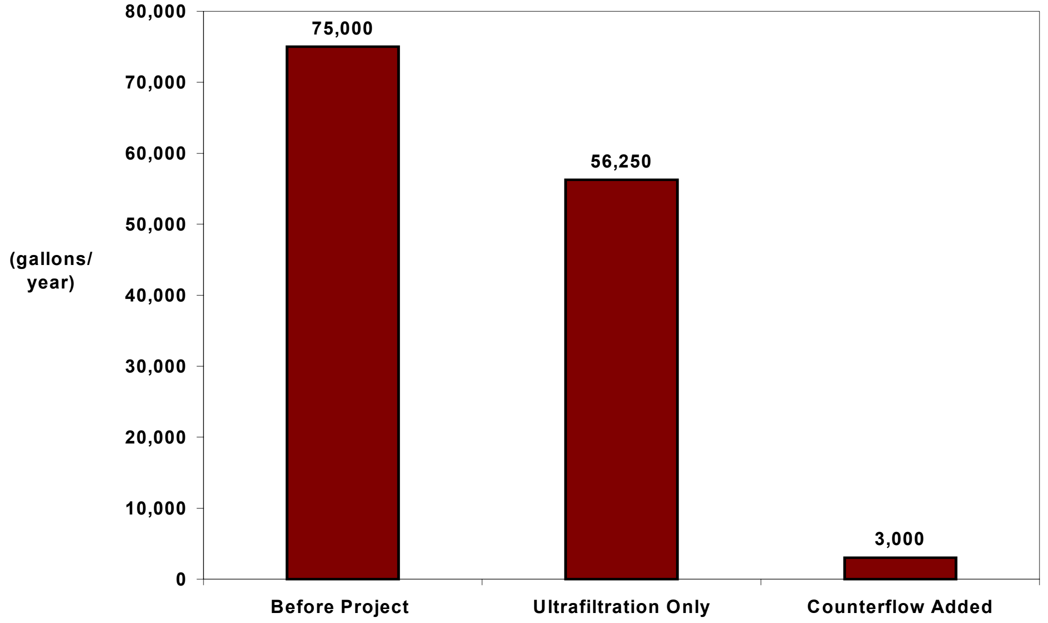
This procedure applies to all samples to be collected from any pretreatment washers.

3.0 Responsibilities:

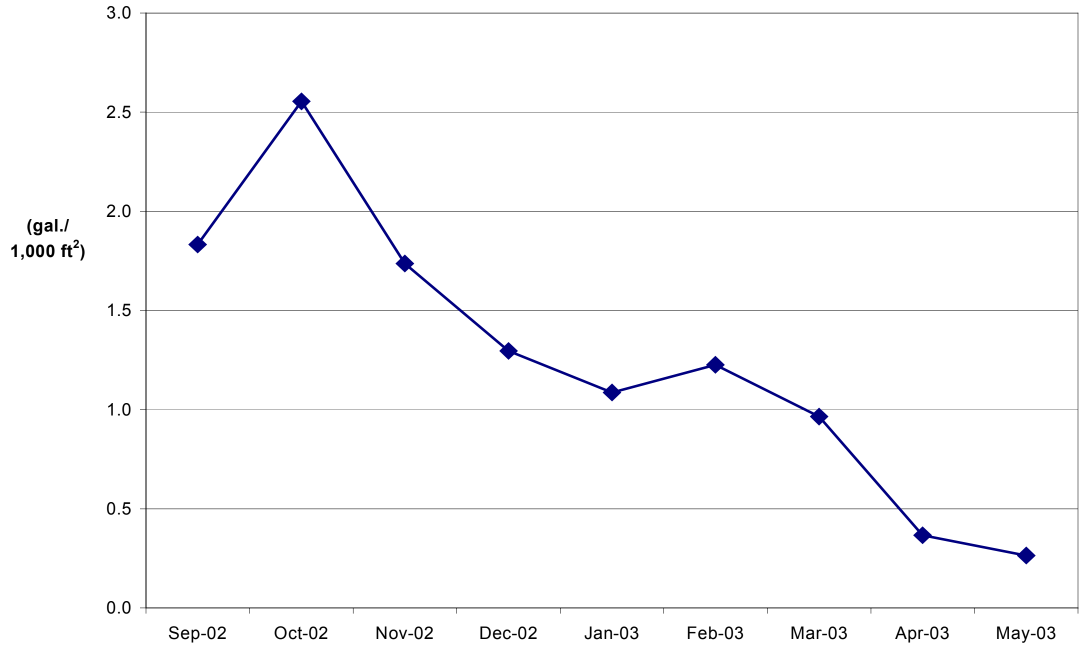
It is the responsibility of the Finishing Manager, Facilities Manager, Chemical Operator or Quality Assurance Technician to assure that they follow this procedure when collecting samples.

4.0 Procedure:

4.1 Materials;
  a) One clean (1) quart measuring cup.
  b) Jars (with cooler) from the outside test lab or clean graduated beakers for internal testing
  c) Testing solutions (titration solutions) when conducting internal testing
  d) Titrating solutions, if required
4.2 Turn on the heater to the washer stage being tested and insure it is up to operating temperature before pulling samples.
4.3 Turn on the pump to the washer stage being tested and allow bath to agitate for at least 20 minutes before pulling samples.
4.4 If foam is present on the top of the bath, use the (1) quart measuring cup to swirl the solution to minimize the collection of foam, then, fill the measuring cup.
4.5 For internal testing, follow the instructions for the test to be conducted, in the Chemical Operators Manual.
4.6 For testing to be conducted by an outside lab:
  4.6.1 Fill the bottles/jar provided by the test lab with chemistry from the measuring cup.
  4.6.2 Label bottles/jars per lab instructions.
  4.6.3 Place all covered bottles/jars in the cooler provided.
  4.6.4 When all bottles/jars have been placed in the cooler, open a bag ice an carefully dump over the bottles/jars to keep samples fresh until they are delivered to lab.
  4.6.5 Close cooler securely and affix “chain-of-custody” label.
  4.6.6 Take cooler, with any required paperwork, to shipping/receiving for delivery

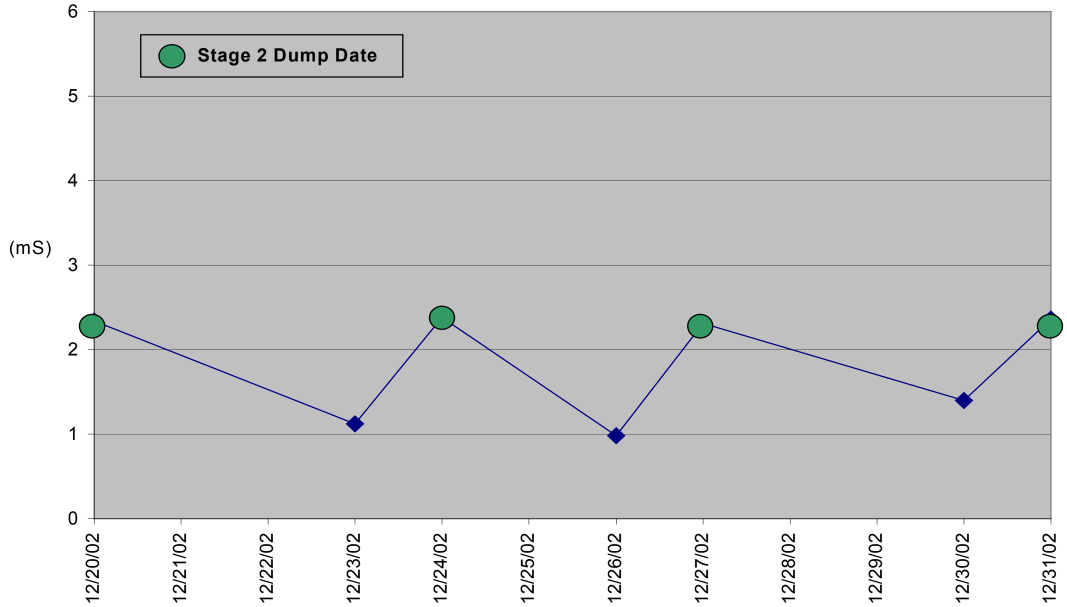


Stage 2 Wastewater Source Reduction

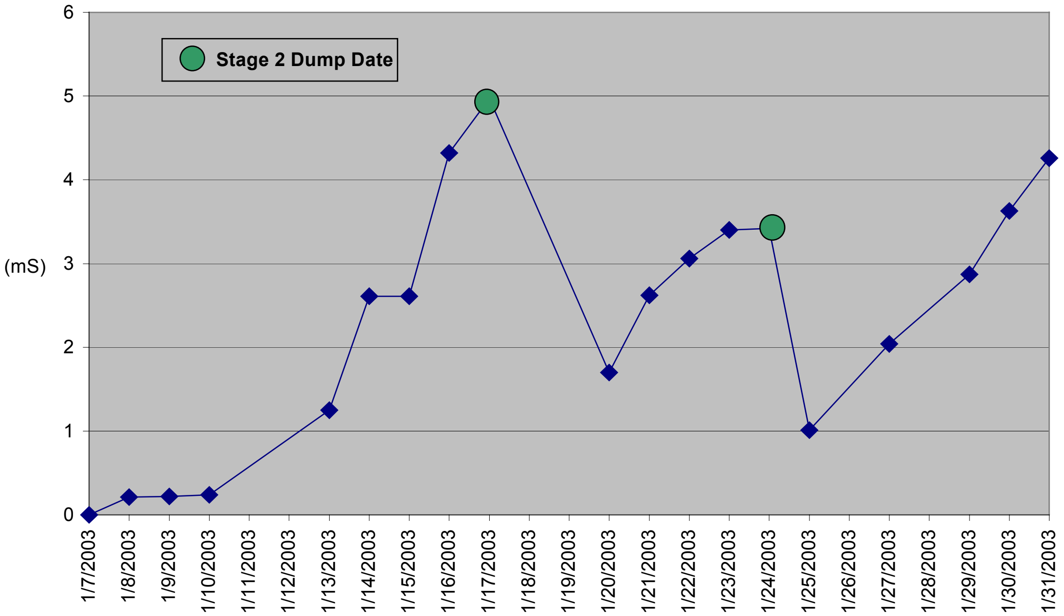


Production Normalized Stage 1 Cleaner Usage

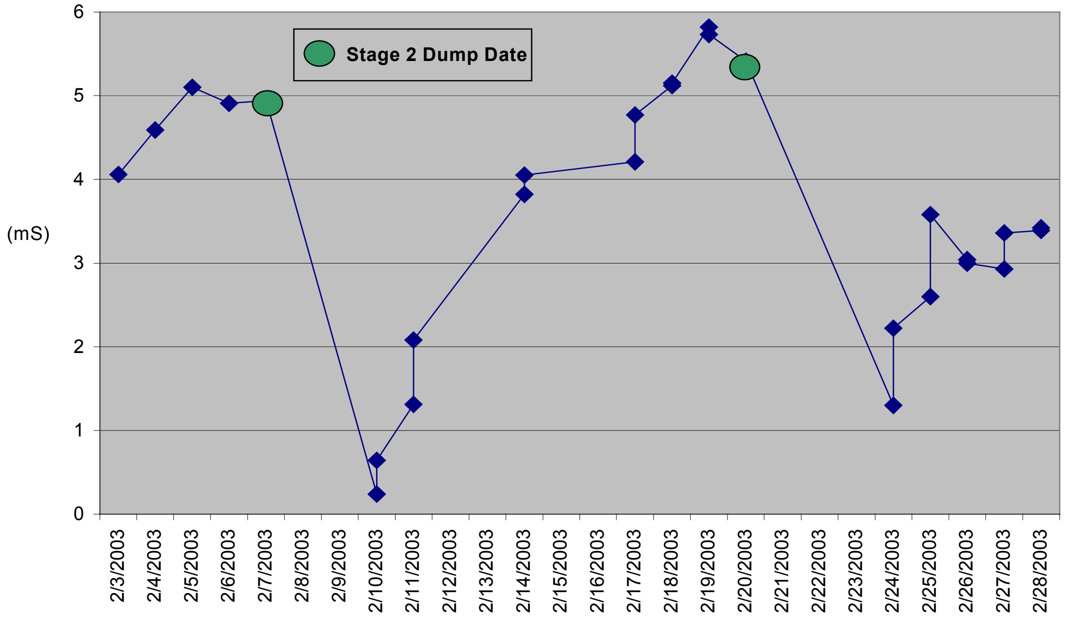
Stage 2 Rinse Conductivity Levels - December 2002



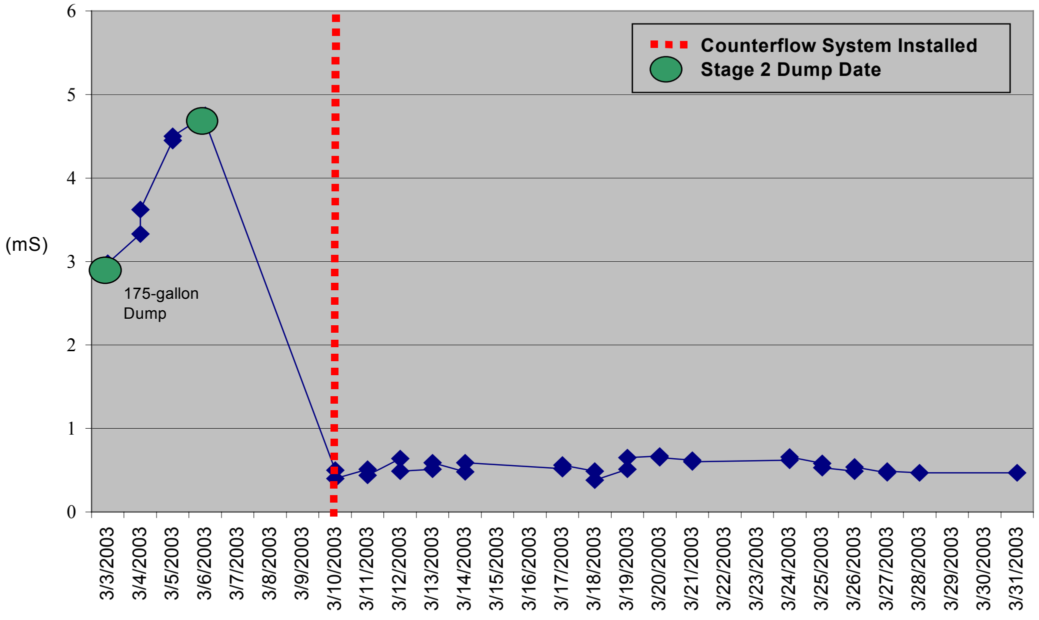
Stage 2 Rinse Conductivity Levels - January 2003



Stage 2 Rinse Conductivity Levels - February 2003



Stage 2 Rinse Conductivity Levels - March 2003



Project Economic Analysis

Year	Annual Savings	Inflation Factor	Actual Dollars	Depr. Affect	Taxable Income	Income Tax	Net Cash Flow	Net Present Value	Internal Rate of Return (NPV @ 104 %)
0	-$20,019						-$20,019	-$20,019	-$20,019
1	$29,023	1.021	$29,639	$2,860	$26,779	$9,105	$20,534	$19,744	$10,038
2	$29,023	1.043	$30,267	$2,860	$27,407	$9,318	$20,948	$19,368	$5,006
3	$29,023	1.065	$30,909	$2,860	$28,049	$9,537	$21,372	$19,000	$2,497
4	$29,023	1.088	$31,564	$2,860	$28,704	$9,759	$21,804	$18,639	$1,245
5	$29,023	1.111	$32,233	$2,860	$29,373	$9,987	$22,246	$18,285	$621
6	$29,023	1.134	$32,916	$2,860	$30,056	$10,219	$22,697	$17,938	$310
7	$29,023	1.158	$33,614	$2,860	$30,754	$10,456	$23,158	$17,598	$155
8	$29,023	1.183	$34,327	$0	$34,327	$11,671	$22,656	$16,554	$74
9	$29,023	1.208	$35,054	$0	$35,054	$11,919	$23,136	$16,255	$37
10	$29,023	1.233	$35,798	$0	$35,798	$12,171	$23,626	$15,961	$18
11	$29,023	1.260	$36,556	$0	$36,556	$12,429	$24,127	$15,673	$9
12	$29,023	1.286	$37,331	$0	$37,331	$12,693	$24,639	$15,389	$5
13	$29,023	1.314	$38,123	$0	$38,123	$12,962	$25,161	$15,111	$2
14	$29,023	1.341	$38,931	$0	$38,931	$13,237	$25,695	$14,838	$1
15	$29,023	1.370	$39,756	$0	$39,756	$13,517	$26,239	$14,570	$1
16	$29,023	1.399	$40,599	$0	$40,599	$13,804	$26,796	$14,306	$0
17	$29,023	1.429	$41,460	$0	$41,460	$14,096	$27,364	$14,048	$0
18	$29,023	1.459	$42,339	$0	$42,339	$14,395	$27,944	$13,794	$0
19	$29,023	1.490	$43,237	$0	$43,237	$14,700	$28,536	$13,544	$0
20	$29,023	1.521	$44,153	$0	$44,153	$15,012	$29,141	$13,300	$0
								$303,895	$0

Item	Factor	Source
Useful Life	20 years	Arbortech Corporation
Inflation Rate	2.12%	US Consumer Price Index (7/8/03)
Income Rate	34%	2003 Income Tax Rate ($335K - $10M)
Discount Rate	4%	WSJ Prime Rate 7/15/03
Depreciation Schedule	7 Years	Straight Line Depreciation