Plating Shop Bath Life Extension for Removing Solids

Paul Brezovec, CEF, and Leanne Debias, Concurrent Technologies Corporation, Johnstown, Pennsylvania

The Air Force and other plating facilities need to extend the bath life of inorganic finishing solutions, which generate significant amounts of byproduct sludge, increasing disposal waste amounts. Two phases of a project were completed for the Air Force Research Laboratory, AFRL/MLSC/WPAFB, which screened and tested technologies to address this need for the Air Force. Studies of aluminum chemical milling bath life extension have identified an automatic backwash filter for demonstration and validation with support at Warner-Robins Air Logistics Center (WR-ALC). The alternatives considered are applicable to other concentrated inorganic finishing solutions used by plating shops, such as those used to etch aluminum and aluminum alloys, and to strip chromium plating.

For more information, contact:
Paul Brezovec, CEF
Senior Process Engineer
Concurrent Technologies Corporation
100 CTC Drive
Johnstown, PA 15904
Phone – (814) 269-2844
Fax – (814) 269-6847
E-mail: brezovec@ctc.com

Introduction

The U.S. Air Force Air Logistics Centers (ALCs) presently use concentrated sodium hydroxide (NaOH) solutions to remove chromium plating and to chemically mill and etch aluminum and aluminum alloys as part of their inorganic finishing and maintenance operations. While the use of NaOH solutions is acceptable based on performance needs, the solutions become less efficient over time and with continued use. An operational inefficiency point is reached at which time the ALC decides to dispose of the caustic solution and residue sludge from the process tank, and refill the tank with fresh caustic solution. The NaOH concentration of the used solution results in a pH well above 12.5, making the bath hazardous due to its corrosivity. Also, the wastewater treated sludge from the chromium stripping process is listed as a "F006" sludge, per U.S. Environmental Protection Agency (EPA) regulations (Code of Federal Regulations, 40 CFR 261.31), making draining and replacing the used solution costly and time consuming. Likewise, workers are exposed to a caustic solution that poses safety and health issues (such as deep chemical burns to the skin, and severe eye damage including blindness). Therefore, there is a need within the Air Force to investigate processes that could economically extend the bath life of the NaOH solutions while reducing or eliminating present environmental, health, and safety (EHS) concerns that are associated with the present process.

To address this need, the Air Force Research Laboratory (AFRL) tasked a contractor to investigate the recovery of concentrated sodium hydroxide solutions for inorganic finishing processes. The AFRL solicited the ALCs associated needs, which, at the time of this project, was to focus on aluminum chemical milling wastes, with a secondary need for reducing chromium plating stripping wastes. This paper describes the following activities of this project: (1) Analyze Requirements, (2) Identify Alternatives, (3) Down-Select Options for Testing, (4) Conduct Testing, (5) Report Results, (6) Estimate Costs/Benefits, and (7) Summarize Findings.

Analyze Requirements

This section presents the data gathered to support this need. Data gathering activities included brief visits to the Warner-Robins ALC (WR-ALC) plating shop, WR-ALC analytical laboratory and its industrial wastewater treatment plant (IWTP). At that time, WR-ALC personnel supplied data about their specific chemical milling production and maintenance operations.

Operating Parameters

Sodium hydroxide solution is used to chemically mill a wide variety of aluminum alloy parts for aircraft. Components requiring chemical milling are first cleaned and then masked with wax. The wax is then trimmed from the areas of the part to be milled. Next, the components are immersed into sodium hydroxide solution for chemical milling. The reaction byproduct particles that eventually precipitate out of solution accumulate in the tank as sludge, and can affect the chemically milled product quality. After chemical milling, the part is spray rinsed, deoxidized (which also helps to neutralize any remaining sodium hydroxide), again rinsed, dried, and then the maskant is removed from the part.

The chemistry of chemically milling aluminum has been described in textbooks[1]. Commercial companies customize chemical formulations to mill the surface of aluminum and its alloys in a way that is steady, controlled, and uniform. The Air Force prefers chemical milling instead of mechanical milling for aircraft parts that would be adversely affected by the undesirable stresses that mechanical milling induces into the worked part. After mixing ingredients according to the chemical supplier's instructions, the virgin solution composition is as follows:

a. 100 g/L NaOH
b. 20-30 g/L aluminum, and
c. 7.7 g/L sulfide compounds as sodium sulfide

The solution is monitored almost daily and regenerated as required with make-up of NaOH in order to maintain a ratio of sodium hydroxide to dissolved aluminum between 3.5 to 1 and 2.5 to 1. This ratio range is maintained until the dissolved aluminum content reaches concentrations above the control boundary, at which point the chemical milling production rate declines. This "window" of control varies depending upon the aluminum alloy being chemically milled. For 1000 series aluminum, the limit for dissolved aluminum is 75-85 g/L. WR-ALC estimates that they partially discard and recharge chemical milling solution two or three times per annual quarter, to control dissolved aluminum concentration, and that they discard and recharge a full-tank each annual quarter, due to solids accumulation. Therefore, not counting solution drag-out, which may be significant, approximately nine tank volumes of the solution are discarded per year:

(2.5 discards/quarter x 4 annual quarters x 50 % tank volumes) +
4 full-tank volumes/year = 9 tank volumes discarded/year.

Neutralization of the pH of this chemical solution requires significant amounts of acid, for not just the sodium hydroxide, but also the aluminate formed. The volume of sludge generated from this process is significant. Typical wet aluminum hydroxide sludge has a dry solids content of only 0.5 %. As a result, 1 kilogram (kg) of aluminum dissolved during chemical milling will produce approximately 600 kg (1,323 pounds) of wet aluminum hydroxide sludge.

Operating Costs

The estimates for chemical material costs to make a fresh bath are shown in Table 1, per chemical supplier unit cost data. Note that new chemical milling solution in Tank No. 501 has a material value of approximately $1,235, or $1.02 per gallon, whereas make-up chemical cost is $0.24.

Table 1. Chemical Costs for New and Partial (50%) Chemical Milling Bath (1,210 Gallons)

Ingredient	Unit Cost	Quantity	Cost
Alkaline Etchant	$ 0.213/pound	1,162 pounds	$ 247.51
Alkaline Etchant Inhibitor	$ 1.343/pound	726 pounds	$ 975.02
Etchant Additive	$ 7.067/gallon	1.7 gallons	$ 12.01
Total			**$1,234.54**
New Bath Per Gallon Cost (including water @$2.50/1,000 gallons)			**$1.02**
Partial (50%) Recharge Per Gallon Cost (Etchant plus Additive)			**$0.24**

Table 2 shows additional operating cost data for use in estimating the costs and savings.

Table 2. Cost Estimate Bases

Cost Item	Estimated Cost
Labor[1] Engineering Technician @ $22.80/hour Maintenance Electrician @ $19.95/hour Maintenance Pipefitter @ $19.05/hour	(115% burdened for overhead) $49.02/hour $42.89/hour $40.98/hour
Utilities Electricity Water (potable process) Steam Compressed Air	 $0.0573 per kWh $1.82 per 1,000 gallons plus $845/year[2] $22 per MBTU $0.75 per kft^3
Floor space	$30/$ft^2$
Annual repair allowance	3.5% of the new installed capital
On-site industrial wastewater treat/disposal	Range[3] between $14.00 per 1,000/gallons and $33.00 per 1,000 gallons; Average of ~$0.25/gallon
Hazardous waste (caustic) sludge disposal[2]	$0.286 per pound[4]
Chromate (1.5 mg/L) treatment chemicals	$0.06 per 1,000 gallons
Hazardous waste F006 sludge disposal	$0.283 per pound
Waste disposal container	$50/55-gallon drum

1. Hourly wage, including fringe benefits were obtained from "Service Contract Act (SCA) Wage Determination – Robins AFB," http://herbb.hanscom.af.mil/tbbs/R273/Atch4Rob.doc, Dated 31 May 2001, from internet WEB on 25 June, 2003. The 115% overhead rate was estimated based upon operations with similar financial structures.
2. Cost was not available from Warner Robins ALC. Instead, because the source water is the same as that for the City of Warner Robins, the prevailing City of Warner Robins water rates (effective July 1, 2002) were used. For commercial/industrial clients, the monthly base rate of $7.04 was multiplied by the "Equivalent Residential Correction (ERC) Factor" of 10 ($7.04/month x 10 x 12 months/year = $845)
3. The IWTP #2 costs are being estimated currently by WR-ALC. The current estimates range between $420,000 per year and $1,000,000 per year. The cost per thousand gallons in this table

was calculated using that range for the annual estimated cost divided by the 30,000,000 gallons annual discharge.

4. The unit cost was estimated by WR-ALC based upon aluminum etch sludge (WP 0017 17A) weighing 4,523 pounds and costing $1,291.73 in 2001 for the waste company to dispose it.

To baseline the performance data that were generated, Table 3 lists the acceptance criteria that were outlined and agreed upon by client and project personnel.

Table 3. Performance Testing Acceptance Criteria

Criteria	Target
Solids Removal	90% or greater
Reuse of Aluminum Chemical Milling Solution	Better than 1 time and economical
Product Quality	Not degraded
Reduce worker exposure	Same or fewer hazards
Estimated Cost	Lower than current treatment costs

Identification of Alternatives

With the requirements established, alternatives that can meet the current requirements were identified. The following alternatives were investigated for extending the life of concentrated NaOH baths:

1. A rejuvenation technology that can remove the unwanted metals from the caustic solution
2. A particulate separation technology that can remove the sludge from the tanks
3. Consideration of alternatives to the existing chromium plate stripping and aluminum chemical milling processes. However, none that met Air Force requirements were found.

Rejuvenation Technology Alternatives

Project personnel first reviewed how to reduce wastes by separating the dissolved contaminants from the chemical milling solution, and thus continually reuse it. A number of dissolved solids separation processes were discounted for extending the life of this sodium hydroxide milling solution due to costs. For example, ion exchange methods (alkaline sorption, diffusion dialysis, liquid ion exchange, and ion transfer) are not suited for the high pH sodium hydroxide solution. Also, dissolved air flotation, electro-flotation, and electro-flocculation were discounted because they introduce excess air into the sodium hydroxide solution, which will deplete sodium hydroxide to produce sodium carbonate and generate excess caustic aerosols. Further, separation processes that introduced new chemicals into the sodium hydroxide milling solution were avoided, because their effect on this process was considered detrimental to product quality. Two commercial processes were reviewed more closely:

1. Evaporate and filter, and
2. Refrigerate and filter.

Of these, the "evaporate and filter" methods were determined to give the best processing because they do not rely on a solution whose dissolved solids are at the saturation point. However, the economics for adopting either of these processes rely on a continuous operation, unlike that of an ALC's small-scale refurbishment facility. Because the costs are greater than the savings to the ALC, the venture would provide no financial payback (i.e., annual operating costs were $45,000 for an annual savings of $33,000). It appears from financial analyses that the scale of the operation would need to be significantly larger (closer to continuous production scale, which WR-ALC current operations would not attain) for this type of recovery technology to be financially viable. These alternatives are documented in two summary reports[2-3].

Particulate Separation

The alternatives studied focused on the following physical separation processes as options for the "evaporate and filter" application:

1. Microfiltration
2. Automatic backwash filtration
3. Centrifuging
4. Hydrocycloning
5. Inclined plate/gravity separation

Note that these same alternatives are applicable to other concentrated NaOH solutions used by the ALCs, such as those used to etch aluminum and aluminum alloys and strip chromium plating.

Down-Select Options for Testing

WR-ALC process engineering and operations reviewed the potential operations change to consider if it would: (a) pose potential chemical or physical hazards (e.g., operator contact with solution, or operator physical hazards such as tripping over equipment, piping, etc.) or (b) interfere with routine activities associated with the operation.

Process engineering and operations personnel at WR-ALC thought that the most important feature would be to minimize the potential for a person's contact with hot caustic solution (i.e., avoiding chemical hazards). The conceptual draft engineering drawings and plans for three options were developed. They were reviewed with the WR-ALC personnel, which revealed that WR-ALC preferred the option to recirculate the solution back to the process tank through a filter (Tank 501 in Figure 1). WR-ALC did not prefer the second option to automatically transfer the decanted sodium hydroxide solution to a temporary holding tank (e.g., Tank 502 in Figure 1) through a filter, and then back to the process tank, because it would result in a tank with residual concentrated caustic that would have to be cleaned. The WR-ALC original point of contact (POC) suggested proceeding with testing both options to further prove whether the options have overall positive technical and economic benefits. The third of the three options considered, an off-line filter cleaning procedure, was rejected by WR-ALC because it required an operator to manually schedule the cleaning as well as physically handle the dirty filter.

PROPOSED FILTER

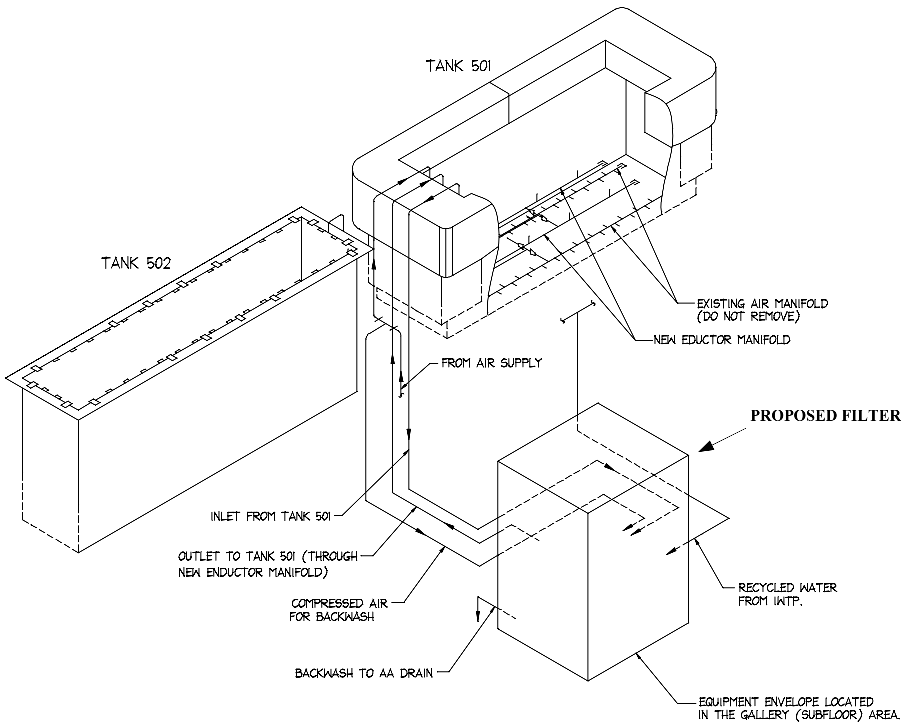


Figure 1. Concept Layout Selected from Operational Safety Review

Test Plan

Testing involved alternative methods to separate particle solids from the NaOH solution. The alternatives remove particulate contaminants via either gravity separation or particle filtration. First, tests were performed to determine if gravity decanting, the simplest approach, could satisfactorily separate the solids from the caustic solution, so that the caustic solution could be reused. If the gravity decanting tests separated a minimum of 90%, by weight, of the particles from the caustic solution, then the testing activities would be considered satisfactory (i.e., complete). If, however, the separation via decanting was unsatisfactory (i.e., less than 90 weight percent of the particles separated from the homogeneous solution), then the performance of filter schemes would be investigated.

In summary, the alternatives were first screened to determine if additional tests would benefit WR-ALC. Investigations would stop if the respective screening test results indicated that further tests would be of no additional benefit, using the criteria described above.

Test Solution Preparation

Laboratory personnel analyzed the chemical milling solution from WR-ALC, using the titration method described by the product vendor. The composition of the spent aluminum chemical milling solution from WR-ALC was within the bounds of a spent solution, which was described by the product vendor as follows:

a. 75-100 g/L available NaOH
b. 57-72 g/L dissolved aluminum
c. 5-7.5 g/L sulfide compounds as sodium sulfide
d. 0.5-15.0% hydrated solids of alumina.

Screening Test Activities and Results

The objective of screening testing was to determine if gravity decanting would satisfactorily separate the solids from the NaOH solution used for chemical milling of aluminum so that the NaOH solution could be reused. To test the solids removal efficiency by decanting, the following procedure was conducted in duplicate.

1. 2,500 ml of the chemical milling solution was thoroughly mixed at room temperature (approximately 21ºC), and then the homogeneous mixture was sampled and analyzed for total suspended solids (TSS) and for settleable solids (per EPA Test Method 160.2 and EPA Test Method 160.5, respectively).
2. 2,000 ml of the chemical milling solution was mixed and heated to its processing temperature (88ºC ±3ºC), using a temperature-controlled hotplate with a magnetic stirrer.
3. Mixing the chemical milling solution was stopped, and the solids were allowed to settle for fifteen minutes at the processing temperature.
4. While still at the processing temperature, the supernatant was decanted by gently siphoning the top 75% of the solution volume into another container. This became the new working chemical milling solution.
5. The new working chemical milling solution was mixed at room temperature (approximately 21ºC), and then the homogeneous mixture was sampled and analyzed for total suspended solids (TSS) and for settleable solids.

The samples were analyzed in duplicate immediately; i.e., while the samples were at the test condition temperature (shown in Table 4).

Table 4. Screening Decant Test Results

Sample Description	TSS (g/L)	Settleable Solids (%)
Initial chemical milling solution as received	60.7	15
Duplicate sample from initial container	60.7	15
Observe settling after 1 additional hour		5.13
NOTE: Because the settleable solids of the initial solution as received was greater than 5% this screening decant test proceeded per the Test Plan to heat and decant the top 75% of this initial chemical milling solution, without the addition of aluminum. This new, decanted working solution was analyzed.		
New chemical milling working solution	41.2	18
Duplicate sample of new working solution	41.2	18
Observe settling after 1 additional hour		3.7

The samples were retained and stored for seven days in clear plastic bottles in the laboratory sample refrigerator (kept cool at 4°C) following testing=. It was found that the decanting method removed 32% of the TSS [(60.7% - 41.2%)/60.7% = 32%], which is less than the acceptance criteria of greater than 90% of the TSS (see Section 2.2). The screening test to decant the aluminum chemical milling solution supported WR-ALC's reluctance to adopt the decanting method for its use. Also, laboratory personnel observed during testing that approximately two to three days were required to appreciably settle the solids from this aluminum chemical milling solution and that the alumina solids re-suspended easily with gentle agitation above the sludge blanket surface.

Therefore, because the TSS of the new working chemical milling solution was greater than 10% of the initial working chemical milling solution TSS, the client approved filtration testing to remove the suspended particles from the NaOH solution.

Performance Testing Activities

The objective of the performance testing effort was to select the proper type and size of filter to remove the particles from WR-ALC's NaOH baths.

Two filter types were tested: (1) automatic backwash particle screening filter and (2) vibratory membrane filter. Both vendors market filter equipment to the surface finishing industry. The following parameters were measured:

- Flux (filtrate volume per unit area of the filter per unit time)
- Solution feed pressure (trended if variable during a backwash)
- Solution feed temperature
- Backwash volume generated
- Solids concentration in backwash
- Percent recovery of solution

- Composition of the filtered solution compared to the solution's initial composition.

Performance Testing Results

Performance tests were conducted at nearly full-scale for WR-ALC needs, using the commercial equipment* that was available. First, the particle size distribution of the aluminum chemical milling solution from WR-ALC production was characterized. The two filter equipment vendors used these data for determining the type and pore size of filters they would use with their equipment. This section reports the results of the particle size distribution and testing results of system equipment.

Figure 2 shows the particle size distribution of the aluminum chemical milling solution using a Horiba LA-920 analyzer. The spent aluminum chemical milling solution, which was generated from WR-ALC operations, had a very wide particle range.

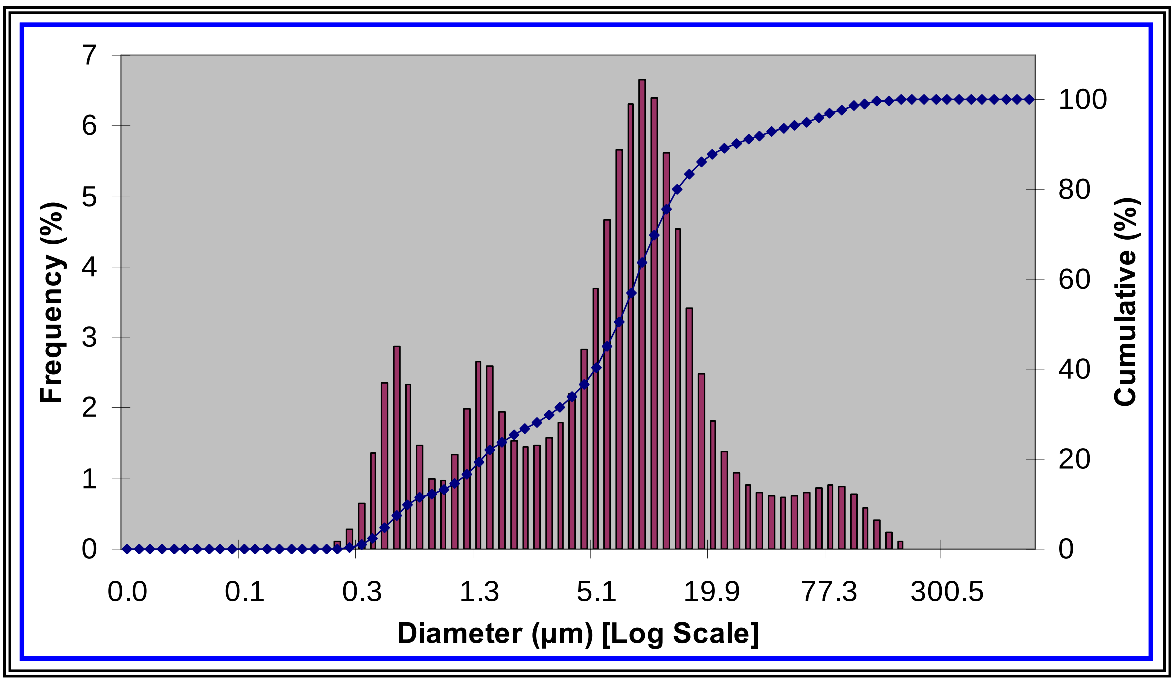
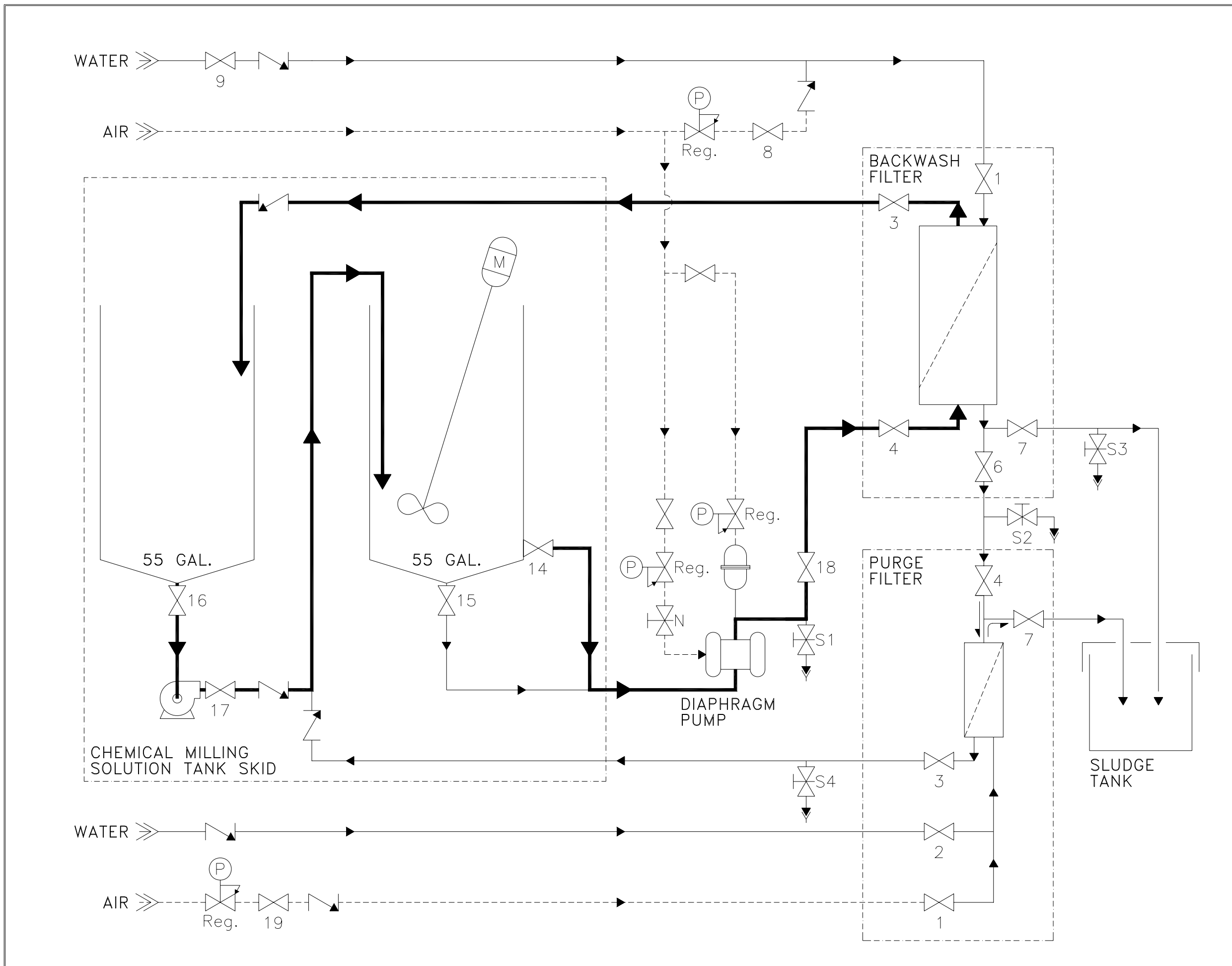


Figure 2. Particle Size Distribution of WR-ALC Tank 501 Sample

* The commercial equipment chosen for this testing by both vendors were their manually controlled models, in order to have more hands-on adjustability to their process. However, both vendors have automatically controlled models for applications that would benefit their clients.

Backwash Filter Testing

Based on their series of solids characterization testing, a commercial backwash filter using a nominal 5-µm filter sleeves were selected for testing. This filtration system uses a patented multi-step process (filter, air-purge, and backwash) that could be automated (Figure 3).



The bold lines are the primary flow. The air purge flows (air only) from "backwash filter" valve numbers "1" to "6"; to "purge filter" valve numbers "4" to "3." The backwash flows (air and water) from "backwash filter" valve numbers "1" to "7." The purge filter cleans from "purge filter" valve numbers "1" (air) and "2" (water) to "7." These functions would be automatically sequenced on an automatically controlled unit. The "S" prefix on the valves so-labeled were the sampling valves

Figure 3. Backwash+Purge Filter Process Flow Diagram

The processing data (Table 5) shows that during the filtration step, the 5-µm nominal filter removed approximately 91% of suspended and settleable solids.

Table 5. Backwash Filter Processing Data

Parameter	Units	Run 1	Run 2	Run 3	Run 4	Average
Flux	gpm/ft^2	0.27	0.32	0.30	0.26	0.29
Feed pressure	psig	8	7	8	8	8
Solution feed temperature	°C	20	20	20	20	20
Backwash volume	Gallons	21	15	5	5	12
Solids in backwash	g/L	3.3	16.6	16.0	17.2	13.3
Percent Filtered (in-out)	%	**94**	**93**	**88**	**90**	**91**

The solids easily backwashed from the filter; however, they were so easily backwashed that overall filtration efficiency dropped when some of the solids slumped off the filter sidewalls and were carried back to the processing tank during the air purge step (when air purges the volume of processing solution that resides in the filter housing back into the process tank).

To address this process problem, a "Purge Filter" was inserted into the test set-up to capture the solids that are carried back to the processing tank during the air-purge processing step (Figure 4).

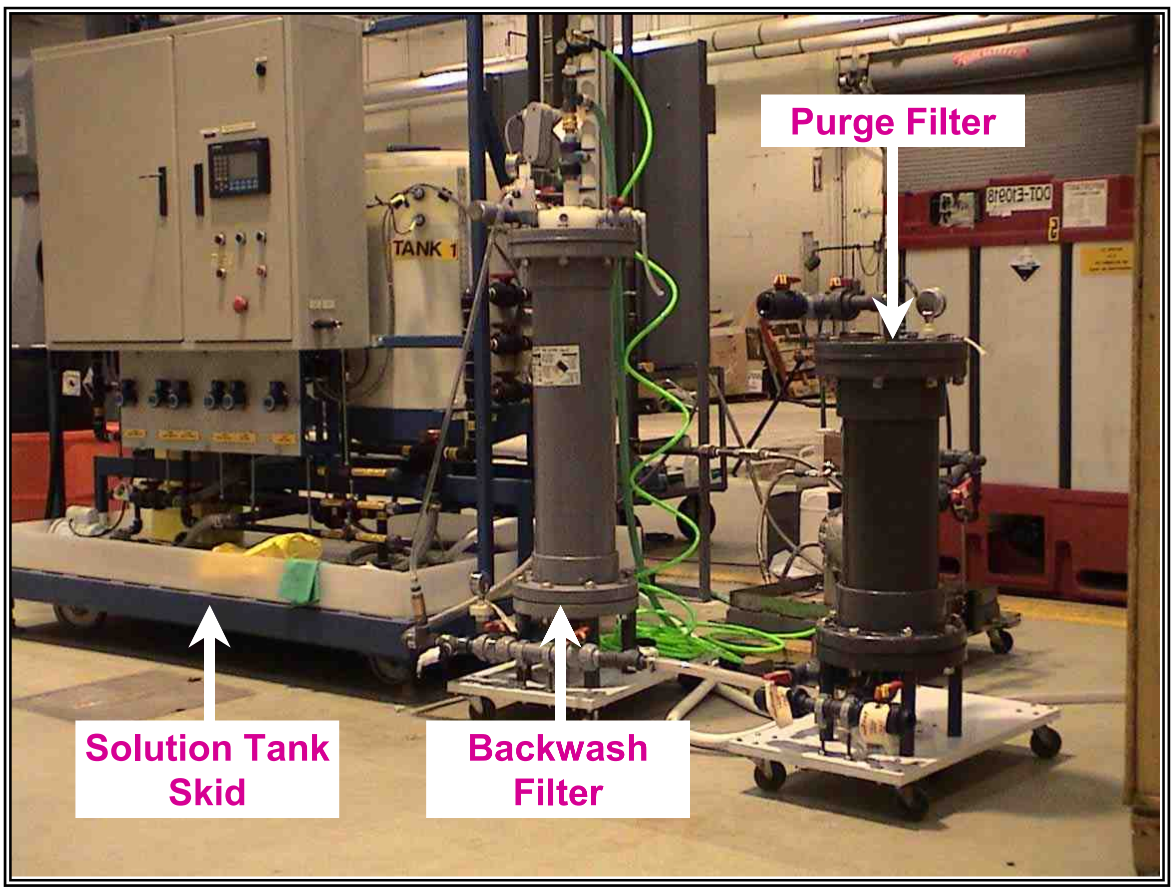


Figure 4. Backwash Filter Application Testing with Purge Filter

The results of the purge filter testing are shown in Table 6. The sample analyses results showed that the purge filter removed 95% of the solids and met the test criteria (recall, acceptance criteria was greater than 90% solids removal). This purge filter corrected the efficiency problem, and assured that operations would reliably avoid the effects of filter cake slumping. The test equipment had no operational problems.

Table 6. Purge Filter Performance Results

Purge Filter Pore Size	Feed Pressure	Flow Rate	Filtrate Solids	% Solids Removal	Notes
1-3 micron	20 psig	2.7 gpm	4.4 g/L	95.2 %	Pass[1]

gpm = gallons per minute
[1] Exceeded criterion of > 90% solids removal.

Vibratory Membrane Filter Testing

A vibratory shear membrane filter system was also tested. This patented technology uses a torsion spring to resonate a cylindrical stack of membranes about its center axis. This creates a shear at the surface of each membrane, which has the effect of minimizing the membrane fouling potential and of maximizing the volumetric output per membrane surface area, referred to as the flux rate.

The equipment manufacturer used the solids slurry characterization that project personnel supplied and selected five (5) membranes for performance testing with their equipment (Table 7).

Table 7. Membranes Selected for Vibratory Membrane Filter Performance Testing

Membrane	Pore Size	Pressure	Max Temp.	Sample Size
PES-5 Tyvec®	7,000 mwco	100 psi	90ºC	16 oz
PES 100H	100,000 mwco	75 psi	90ºC	16 oz
PS 20	200,000 mwco	75 psi	90ºC	16 oz
0.1 micron Teflon®	0.1 µm	75 psi	120ºC	16 oz
0.05 micron Teflon	0.05 µm	75 psi	120ºC	16 oz

PES = Polyether Sulfone
PS = Polysulfone
mwco = molecular weight cut-off
µm = micron

All membranes that were tested passed the % solids removal criteria of >90% (see Table 8). The 0.1-µm Teflon® filter performed the best in terms of flux (flow rate per unit area of membrane) and chemical and thermal resistance.

Table 8. Vibratory Membrane Filter Performance Results

Membrane	Pore Size	Feed Pressure	Flux Rate (gpm/ft^2)	Filtrate Solids	% Solids Removal	Notes
PES-5 Tyvec	7,000 mwco	100 psi	0.26	74 mg/L	99.7	
PES 100H	100,000 mwco	75 psi	0.40	65 mg/L	99.7	Color change[1]
PS 20	200,000 mwco	75 psi	0.52	55 mg/L	99.8	Color change[1]
0.1 micron Teflon	0.1 µm	75 psi	0.74	20 mg/L	99.9	Best[2]
0.05 micron Teflon	0.05 µm	75 psi	0.30	58 mg/L	99.8	

PES = Polyether Sulfone
PS = Polysulfone
mwco = molecular weight cut-off
µm = micron

[1] For an as-yet unknown cause, the filtrate from the "PES 100H" and the "PS 20" membranes turned the color of the solution to a distinct blue – a color not attributed to this normally pale-yellow chemical milling solution.

[2] The 0.1-µm Teflon membrane filter performed the best in terms of flux (flow rate per unit area of membrane) and chemical and thermal resistance. Although not listed, a 0.2-µm Teflon filter was also briefly tested, but the flux rate from it (~ 0.41 gpm/ft^2) was lower than that from the 0.1-µm Teflon filter (~ 0.74 gpm/ft^2).

The 0.1-µm Teflon filter was tested to measure its recovery of chemical milling solution (concentration study setup, Figure 5).

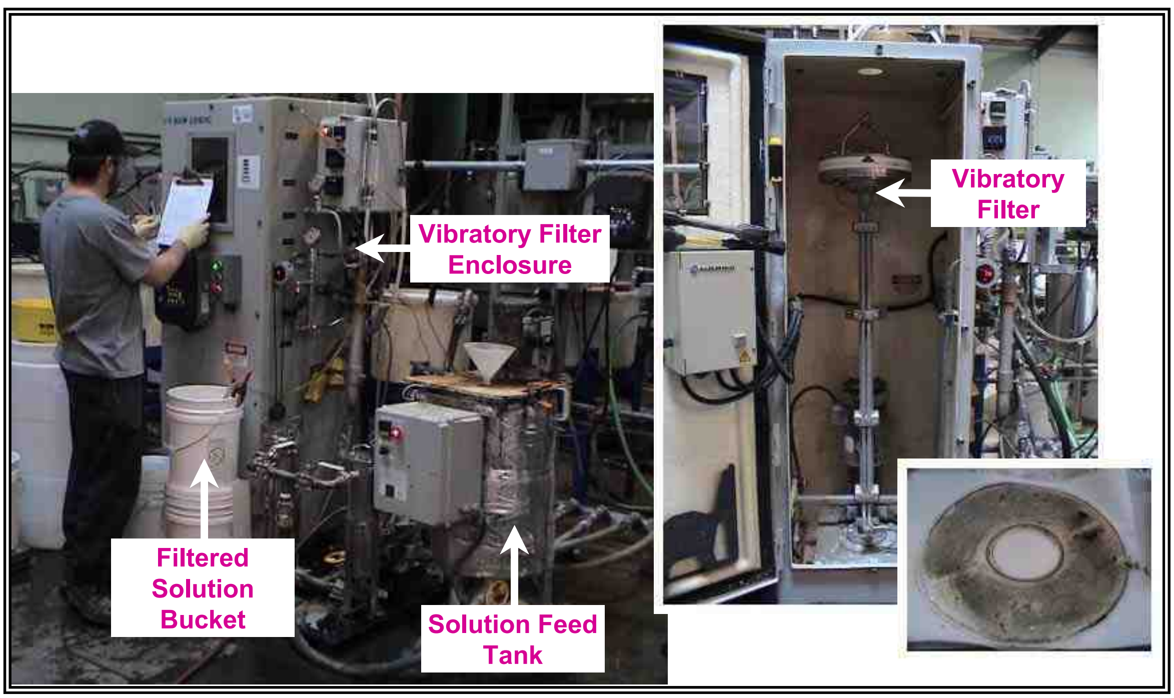


Figure 5. Vibratory Membrane Filter Application Testing at Manufacturer Facilities

The test was completed in batch mode, as the membrane area was only 0.5 square feet. Permeate was continually removed from the system while the concentrated material was returned to the feed tank. These data were used to determine that the recovery was 97.4% of the feed, and that the average flux over the concentration/recovery range was 0.53 gpm/ft^2.

Based on this testing, the equipment with the 0.1-µm Teflon membrane is anticipated to perform satisfactorily for this application to minimize solids accumulation in the aluminum chemical milling solutions used by the ALCs. The equipment will require optimizing per application in order to achieve the maximum recovery of chemical milling solution. Otherwise, the solids rejected may include an excess dilution of chemical milling solution, resulting in an excess loss of chemical milling solution with the discarded solids. Project personnel concurred with the manufacturer's conclusion that the technical aspects of the vibratory membrane filter are attractive. As with all processing systems, it must be adapted to ALC operations.

Cost Estimate

This section reports the costs and benefits associated with implementing a filtration technology at WR-ALC. It evaluates the financial impact of Tank 501 bath life extension via two alternative filtration systems using guidelines of the Environmental Cost Analysis Methodology (ECAM^{SM}). This analysis evaluates the cost impact of implementing alternative processes by identifying and gathering costs for the original baseline process and comparing those to the estimated process costs for the proposed alternative processes. For this analysis, four alternatives were considered:

Backwash Filter
1. Backwash Filter with Purge – Manual Operation
2. Backwash Filter with Purge – Automatic Operation

Vibratory Membrane Filter
3. Vibratory Membrane Filter – Manual Operation
4. Vibratory Membrane Filter – Automatic Operation.

Financial Analysis Criteria

The ECAM includes a financial analysis that was performed using the Pollution Prevention Financial Analysis and Cost Evaluation System (P2/FINANCE) software. The P2/FINANCE software generates financial indicators (net present value [NPV], internal rate of return [IRR], and payback period) that describe the expected performance of a capital investment.

ECAM^{SM} is a service mark of Concurrent Technologies Corporation, Johnstown, Pennsylvania.

- The NPV is the difference between capital investments and the present value of future annual cost benefits associated with the alternatives
- The IRR is the discount rate at which NPV is equal to zero
- The payback period is the time period required to recover all of the capital investment with future dollar-savings.

NPV and IRR indicators account for the time value of money, and discount the future capital investments or annual cost benefits to the current year. For the NPV and IRR calculations, a 3.0% discount rate was used for this financial evaluation, which is consistent with the Office of Management and Budget (OMB) Circular Number A-94 and the ECAM. Guidelines for these performance measures are listed in Table 9.

Table 9. Summary of Investment Criteria*

Criteria	Recommendations/Conclusions
NPV > 0	Investment return acceptable
NPV < 0	Investment return not acceptable
Highest NPV	Maximum value to the facility
IRR > discount rate	Project return acceptable
IRR < discount rate	Project return not acceptable
Shortest payback period	Fastest investment recovery and lowest risk

** Adapted from ECAM Handbook.*

Costs/Benefits Estimates

The ECAM addresses direct and indirect costs associated with the process' operation (i.e., capital costs, operating costs, and environmental costs). Detailed information related to the raw data, assumptions, and calculations are provided in a project Final Report[4].

A summary of the financial evaluation for implementing the technologies that were evaluated during this project is given in Table 10.

Table 10. Results of Financial Evaluation for Filters

Financial Indicator	Backwash Filter System					
	Manual			Automatic		
	5-year	10-year	15-year	5-year	10-year	15-year
Net Present Value	$30,251	$81,560	$125,820	$35,764	$105,000	$164,724
Internal Rate of Return	34.2 %	43.2 %	44.3 %	27.9 %	37.8 %	39.1 %
Discounted Payback	2.4 years			2.7 years		
Financial Criteria	**Vibratory Membrane Filter System**					
	Manual			**Automatic**		
	5-year	**10-year**	**15-year**	**5-year**	**10-year**	**15-year**
Net Present Value	$6,739	$71,779	$127,882	($57,659)	$13,553	$74,982
Internal Rate of Return	6.4 %	20.2 %	22.9 %	-13.1 %	4.8 %	9.6 %
Discounted Payback	4.5 years			9.0 years		

Although the manual backwash filter system resulted in the best IRR and payback period, the automatic backwash filter has the greatest NPV. Of these three financial criteria, the alternative with the best NPV tends to be the optimal capital investment choice. Also, the increased use of manpower for the manual backwash filter system does not align with WR-ALC's lean manufacturing philosophy. Therefore, the automatic backwash system would be the best of these choices for this application.

From a technical standpoint, the vibratory membrane filter system resulted in excellent particle removal. If the vibratory membrane system could be used in other plating shop applications when it is in stand-by for this aluminum chemical milling work, then the financial criteria may be revised in favor of the vibratory membrane system.

Lastly, substantial qualitative benefits have been identified, but could not be readily quantified. It is key to note that during the ECAM analyses, costs associated with worker occupational exposures were not included. These costs would need to be further investigated upon a decision to implementation a technology. Improved employee safety, better regulatory relationships, and improved employee morale represent real benefits that enhance the economic benefits already documented.

Findings

Personnel from WR-ALC and Ogden ALC (OO-ALC) plating shops identified a need to remove particulates/sludge from parts processing baths containing NaOH solution, without disposing the entire contents of the bath. This would reduce worker exposure to caustic solutions, and save on the cost of raw materials and waste disposal.

Chemical rejuvenation and recovery technologies that may fit with large manufacturing operations are not necessarily the applicable and economical answer to smaller refurbishment plating shop needs. Some “low-tech” liquid/solids separation alternatives passed the economic hurdles. WR-ALC explained that during their maintenance operation to remove accumulated solids from the bottom of the chemical milling process tank, Tank No. 501, the liquid also is disposed, even though at least 50 % of the solution could be reconstituted and reused. If a “low-tech” liquid/solids separation method could be devised to safely withdraw accumulated solids from the tank without disposing the solution as well, then material cost savings may be realized. These same alternatives also are applicable to the NaOH solution that is used to remove chromium plating at Ogden ALC (OO-ALC). However, the efficiency of the liquid/solid separation techniques for the production solution have to be determined through testing and analysis.

This project tested two technical options to remove particles from the NaOH solution used for aluminum chemical milling at WR-ALC (Tank Number 501):

- Solution decanted slowly from sludge – test failed
- Closed-loop filter systems (both vibratory membrane and backwash) – test successful.

The filters demonstrate positive economic results overall with the greatest benefits occurring with the automatic backwash filter. The ECAM financial analysis indicates that the automatic backwash filter system (Figure 6) has a favorable payback period of less than three years. There are advantages to implementing the automatic backwash filter that are based on cost benefit, as well as advantages from an EHS standpoint.

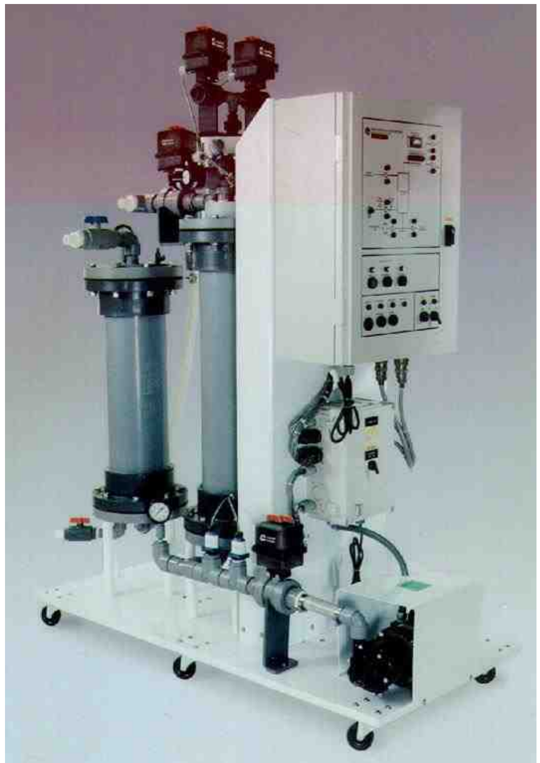


Figure 6. Backwash Filter System for WR-ALC – Automatic Sequence

Based upon WR-ALC data provided, the backwash filter system could conserve raw materials used to make approximately 2,400 gallons of aluminum chemical milling solution annually (Table 11). Also, the backwash filter process would avoid approximately 8,500 pounds of solids in sludge waste because, when aluminum chemical milling solution is treated, it precipitates significant alumina sludge.

Table 11. Performance Testing Acceptance Criteria

Criteria	Target	Estimate
Solids Removal	90% or greater	91%
Reuse of Solution	Better than 1 time and economical	2 times and economical
Product Quality	Not degraded	Better due to fewer solids
Reduce worker exposure	Same or fewer hazards	Lower exposure to hot caustic
Estimated Cost	Lower than current treatment costs	Lower, with 2.7 year payback; 5-year NPV of $36,000

Prior to a final commitment regarding implementation, project personnel visited a manufacturing facility that uses an automatic version of the backwash filter tested. The purpose of the trip was to assess the automatic unit and watch the unit perform in a shop environment, as well as ask the facility personnel about their experiences with the unit (specifically, user installation, operational and maintenance questions). The manufacturing personnel also were lean in staffing. They had used the equipment consistently for the past six years with no significant effort for its installation, start-up, operation, shutdown, and maintenance.

Acknowledgements

The U.S Air Force Research Laboratory, through AFRL/MLSC/WPAFB funded and collaborated in the work described here under GSA Task Order 5TS5702D035G-02 with Concurrent Technologies Corporation. We gratefully acknowledge the participation of Mr. John Speers, Dr. Eric Brooman, Mr. Chris King, Mr. Eddy Rhodes, Mr. Randy Stillwell, and Ms Milissa Pavlik. This publication has not been subjected to U.S. Department of Defense review and, therefore, does not necessarily reflect the views of AFRL and WR-ALC. No official endorsement should be inferred from the results presented. Mention of trade names and commercial products does not constitute endorsement or recommendation for use.

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