U.S. Environmental Protection Agency
Environmental Technology Verification Program
For Metal Finishing Pollution Prevention Technologies
Verification Test Plan

for the

Evaluation of the Hadwaco MVR Evaporator for the Metal Finishing Industry

Revision 0

September 20, 2001

Concurrent Technologies Corporation is the Verification Partner for the EPA ETV Metal Finishing Pollution Prevention Technologies Center under EPA Cooperative Agreement No. CR826492-01-0.

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Environmental Technology Verification Program For Metal Finishing Pollution Prevention Technologies Verification Test Plan for the Evaluation of the Hadwaco MVR Evaporator for the Metal Finishing Industry.

PREPARED BY:

Peter Gallerani ETV-MF Project Manager	09/10/2001 Date
Scott W. Maurer *CTC* Project Manager	9/11/01 Date

APPROVED BY:

Clinton E. Twilley *CTC* QA Manager	9/17/01 Date
Donn W. Brown *CTC* ETV-MF Program Manager	9/18/01 Date
Alva E. Daniels EPA ETV Center Manager	9/18/2001 Date
David Thomas Hadwaco General Manager	09/19/01 Date
Host Facility **General Manager** Process Manager, NEXANS.	01/09/19 **Date**

Signature denotes acceptance of this test plan as written regarding experimental design, quality assurance, test and analysis methods, operational procedures, equipment configuration, project management and current Hadwaco Mechanical Vapor Recompression Evaporator operating effectiveness prior to testing.

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ACRONYMS & ABBREVIATIONS

Avg	Average
C	Centigrade
COC	Chain-of-Custody
CTC	Concurrent Technologies Corporation
Cu	Copper
DQO	Data Quality Objectives
ES&H	Environmental Safety and Health
EPA	U.S. Environmental Protection Agency
ETV-MF	Environmental Technology Verification for Metal Finishing Technologies
F	Fahrenheit
FF	Falling Film
gal	Gallon
gpd	Gallon per Day
HDPE	High Density Polyethylene
ICP-AES	Inductively Coupled Plasma – Atomic Emission Spectroscopy
ID	Identification
IDL	Instrument Detection Limit
in	Inch
JTA	Job Training Analysis
K	Heat transfer coefficient
kWh	Kilowatt Hours
L	Liter
L/day	Liter per Day
L/min	Liter per Minute
LM	Laboratory Manager
m^3	Cubic Meter
MDL	Method Detection Limit
ME	Multi-Effect
mg/L	Milligram per Liter
mL	Milliliter
mm	Millimeter
MP&M	Metal Products and Machinery
MRL	Method Reporting Limit
MSDS	Material Safety Data Sheet
MVR	Mechanical Vapor Recompression
µ	Micron
µS	Micro Siemens
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory
O&M	Operation and Maintenance
P	Percent Recovery
PA	Polyamide
PARCCS	Precision, Accuracy, Representativeness, Comparability, Completeness, and Sensitivity

Pb	Lead
PE	Polyethylene
pH	Value used to express acidity or alkalinity
PP	Polypropylene
PPE	Personal Protective Equipment
ppm	Parts per Million
psi	Pounds per Square Inch
PVC	Polyvinyl Chloride
QA	Quality Assurance
QC	Quality Control
QMP	Quality Management Plan
R	Radius
Ref.	Reference
RPD	Relative Percent Difference
SOP	Standard Operating Procedure
SR	Sample Result
SS 316	Stainless Steel grade 316
SSR	Spiked Sample Result
T	Total
t/d	Tons per Day
TDS	Total Dissolved Solids
TS	Total Solids
TSA	Technical Systems Audit
TSS	Total Suspended Solids
TVR	Thermal Vapor Recompression
TWA	Time Weighted Average
U.S.	United States
WG	Water Gauge

1.0 INTRODUCTION

The purpose of this test plan is to document the objectives, procedures, equipment, and other aspects of testing that will be utilized during verification testing of the Hadwaco Mechanical Vapor Recompression (MVR) Evaporator. This test plan has been prepared in conjunction with the U.S. Environmental Protection Agency's (EPA's) Environmental Technology Verification for Metal Finishing Pollution Prevention Technologies (ETV-MF) Program. The objective of this program is to identify promising and innovative pollution prevention technologies through EPA-supported performance verifications. The results of the verification test will be documented in a verification report that will provide objective performance data to metal finishers, environmental permitting agencies, and industry consultants. A verification statement, which is an executive summary of the verification report will be prepared and will be signed by the EPA National Risk Management Research Laboratory (NRMRL) Director.

The Hadwaco MVR Evaporator system is designed to process wastewaters containing dissolved metals. The focus of testing will be determining the quality and quantity of the condensate produced by the Hadwaco MVR Evaporator system at a preset feed rate, evaporator efficiencies, the energy usage of the system, the characteristics of recovered concentrate, the cost of operation, and the environmental benefit.

Testing of the Hadwaco MVR Evaporator system will be conducted at a facility that has requested anonymity. The host facility is a major global manufacturer of copper product. The industrial operations that generate wastewater at this location include copper pickling.

This test plan has been structured based on a format developed for ETV-MF projects. This document describes the intended approach and explains testing plans with respect to areas such as test methodology, procedures, parameters, and instrumentation. Also included are quality assurance/quality control (QA/QC) requirements of this task that will ensure the accuracy of data, data interpretation procedures, and worker health and safety considerations.

1.1 Data Quality Objectives (DQO)

The data quality objective process (Steps 1–7) identified in "Guidance for the Data Quality Objectives Process" (EPA QA/G-4, August 2000) was utilized during preparation of this verification test plan. The project team, composed of representatives from Concurrent Technologies Corporation (*CTC*), the testing organization, the technology vendor, the host site, analytical laboratory, EPA, who assisted in preparing this test plan, jointly developed the test objectives; critical and non-critical measurements; test matrix; sample quantity, type, and frequency; analytical methods; and QA objectives to arrive at an optimized test designed to verify the performance of the technology.

2.0 TECHNOLOGY DESCRIPTION

2.1 Theory of Operation

The unique evaporation technology developed for treatment of various industrial effluents by Hadwaco Ltd. Oy of Helsinki, Finland, has been commercialized and continually upgraded since its introduction in 1993. The technology applies proven Mechanical Vapor Recompression (MVR) and Falling Film (FF) principles, with the key innovation being the construction material of the heat transfer surface elements: corrosion resistant and elastic polymers. The specific cost of the heat transfer surface is low, allowing for the use of large surface areas and resulting in very low energy use per unit of condensate workload. The basic system is designed to use electrical energy; as a result of the large areas, the power use is low, typically 9–13 kWh/m^3 (35–50 kWh/1000 gal) of recovered water. The concept can also be applied as Multi-Effect (ME) in areas where low-pressure waste steam and cooling water are available.

2.2 Background

Evaporation has long been associated with high-energy use; however, improvements in evaporation systems have been made to increase their energy efficiencies. The most significant progress in energy savings has been achieved through the use of ME evaporators and other efficient methods of utilizing energy from the generated vapor. An example of this latter method is Thermal Vapor Recompression (TVR) evaporators, in which the inertia of steam is used for recycling part of the vapors through ejectors.

Another effective way to reuse and recover energy is with MVR evaporators. MVR evaporators recycle all vapors as heating steam by adding energy via vapor compression with high-pressure fans or compressors. In many applications, MVR evaporators may be the superior choice because they do not need additional steam or cooling water for operation. Their operation is simple and the operating temperature can be optimally chosen. In the past, complex and delicate compressors have been the major drawback for MVR evaporators; however, new fan designs have become available for vapor recompression, thus eliminating this drawback.

From a technological point of view, evaporation is an ideal method for purification of industrial effluent aqueous streams for the following reasons:

- Water recovered from aqueous streams can be extraordinarily clean, and therefore suitable for reuse in industrial processes or for discharge to surface water under National Pollutant Discharge Elimination System (NPDES) permits
- All non-volatile substances can be completely separated from the “distillate” stream
- Solids can be recovered for appropriate reuse or disposal

Evaporation can effectively separate non-process substances from aqueous streams, thus making it possible to build effluent-free processes while minimizing fresh makeup water requirements. However, conventional evaporators have several prohibitive properties. Among them are:

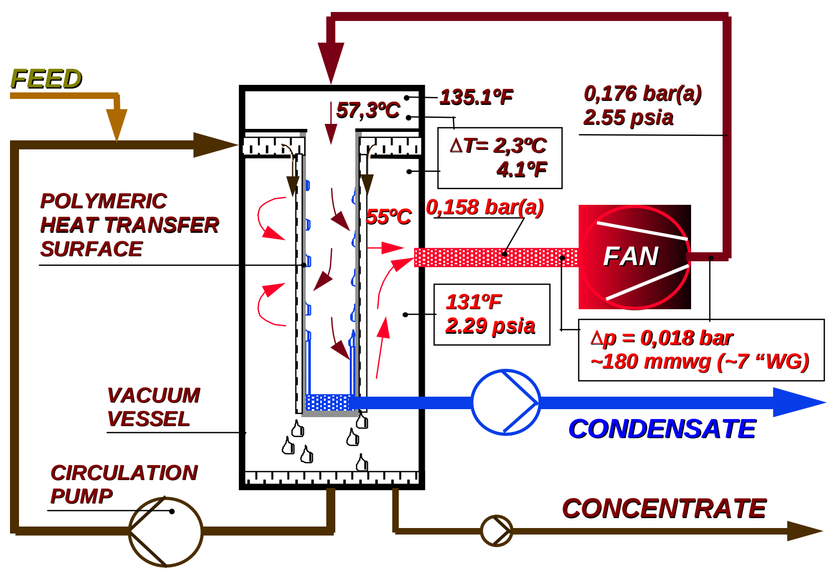
- High operating and maintenance costs
- High capital costs due to the need for corrosion resistant metallic heat transfer surface materials
- Problems with scaling and fouling, especially with varying effluent quality and composition
- Steam and cooling water availability for thermal evaporative systems

The target in the development work of the Hadwaco evaporative technology has been to solve or minimize the above challenges and make the evaporative process competitive for most effluent treatment applications.

2.3 New Evaporation Technology

2.3.1 Operating Principle

The MVR operating principle with typical operating data is illustrated in **Figure 1**.



Note: European notation; comma serves as decimal point

Figure 1. MVR Operating Principle

2.3.2 The Innovation

The key innovation of the technology is the new, patented heat exchanger concept, in which the heat transfer surface is manufactured of high-tech polymeric film. The heat exchanger "cartridge" has several patents related to surface treatment, surface/edge welding, assembly methods of the film itself, distributor design, and condensate collection system. The distributor, condensate collector, and heat transfer surface are also fabricated of polymeric materials, typically based on HDPE.

The polymeric heat transfer surface element has a "bag-like" structure. The solution to be concentrated is circulated to the top of the element and distributed on the outer surface of the "bag." As the solution reaches its saturation state, it begins to evaporate when heated. The vapor generated flows into a fan, which adds energy by increasing the pressure and temperature of the vapor. After the fan, the compressed vapor is introduced inside the heat transfer element (the "bag"). Here the vapor condenses; latent heat is released and transferred through the polymeric surface, causing the solution on the exterior surface to release more water vapor. The condensed vapor, the product of the process, is then discharged from inside the element as clean condensate. The concentrated solution is discharged from the bottom of the vessel for disposal.

Polymeric materials can be used as the basic component in the cartridge because of the designed low operating temperature of the system. Additionally, the designed operating temperature enables the system to function with a small pressure differential over the heat transfer surface. The pressure differential, as a function of boiling temperature with a typical temperature difference of 2.3ºC (4.1ºF), is shown in **Figure 2**.

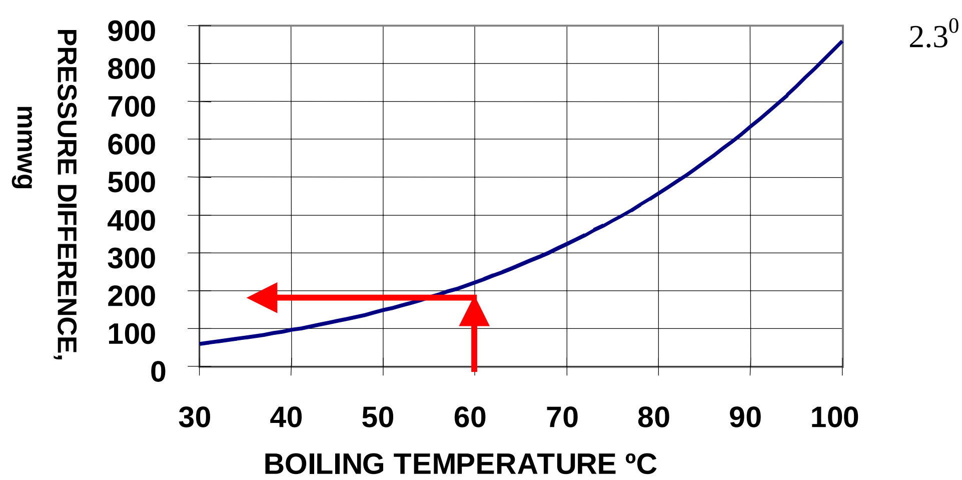


Figure 2. Pressure Differential as a Function of Boiling Point

At the designed operating pressure, the pressure difference over the heat transfer surface is equal to approximately 180 millimeters (mm) 7 in water gauge (wg). This enables the use of thin, flexible films for the heat transfer surfaces.

Due to the relatively poor thermal conductivity properties of polymeric materials, the use of thin walls is essential. To illustrate, the wall thickness of metallic heat transfer surfaces is typically between 0.5–1.5 mm ($^{1}/_{32}$–$^{1}/_{16}$ in), whereas the Hadwaco heat transfer surfaces have a wall thickness between 0.02–0.04 mm ($^{1}/_{1200}$–$^{1}/_{600}$ in). Using such thickness, the thermal conductance in the Hadwaco design is similar to the metallic surfaces used in conventional evaporators. The influence of the wall thickness to the overall heat transfer coefficient (U or K-value) with different polymeric materials and stainless steel is shown in **Figure 3**.

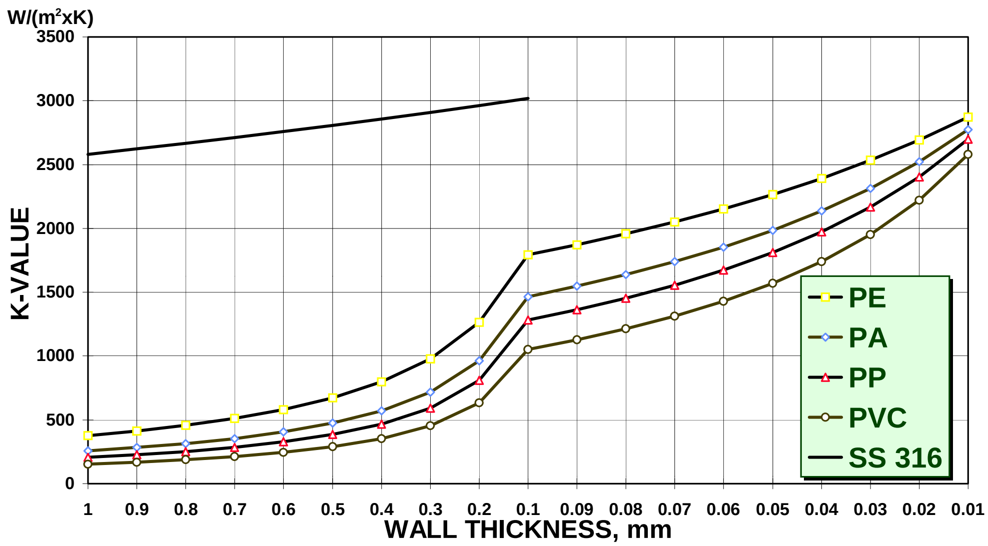


Figure 3. Heat Transfer Coefficient vs. Wall Thickness

The standard polymeric material used for the heat exchanger cartridge is suitable for a wide range of aggressive process streams. This advantage allows Hadwaco to utilize large surface areas even in extremely hostile environments. The direct benefit of the ability to use large surface areas is the reduction of both power consumption and capital cost. Additionally, the larger surface area and reduced pressure ratio make it possible to use a simple low-speed fan instead of a complex compressor, which further reduces the capital, operational, and maintenance costs.

Table 1 contains three basic equations important in the design of evaporators. As indicated in Equation 1, an increase in the surface area means that the effective temperature difference may be correspondingly reduced. A corresponding reduction in the power consumption of the compressor is illustrated in Equation 2. Note that power reduction is directly proportional to the effective temperature differential.

Q	=	$U \times A \times \Delta T_{eff}$	Equation 1
P	=	$C \times MF \times \Delta T$	Equation 2
ΔT_{eff}	=	$\Delta T - \Delta T_{BPE}$	Equation 3

Nomenclature:

Q	=	Heat Flow
U	=	Overall Heat Transfer Coefficient
A	=	Heat Transfer Surface Area
ΔT_{eff}	=	Effective Temperature Difference
P	=	Compressor Power Consumption
C	=	Compressor Coefficient
MF	=	Vapor Mass Flow = Evaporation Workload
ΔT	=	Total Temperature Difference Over the Heat Transfer Surface
ΔT_{BPE}	=	Boiling Point Elevation

Table 1. Basic Equations in Evaporation

2.4 Hadwaco's Modular Concept

2.4.1 Modular Heat Exchangers

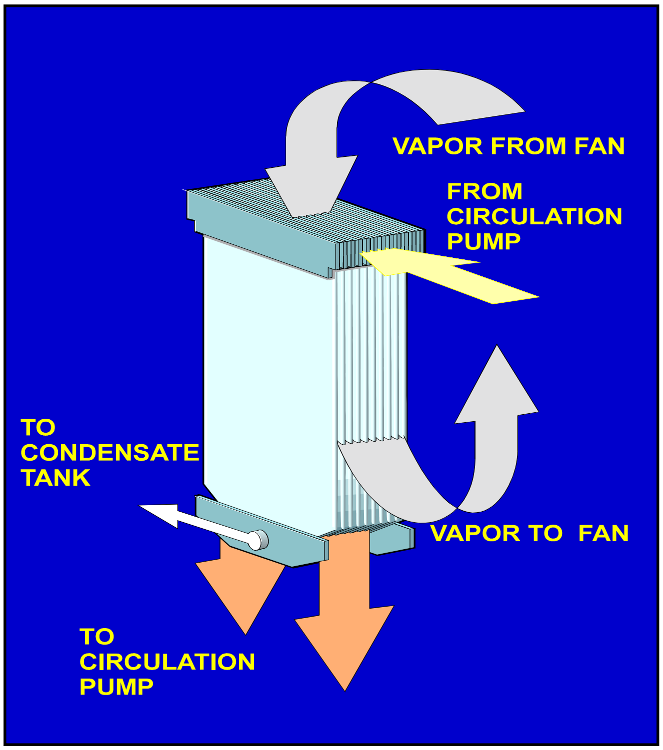


Figure 4. Hadwaco MVR Evaporator System

Forty-six individual heat transfer surface elements are combined to form a single, modular heat transfer surface cartridge. Identical cartridges are added to each system until the designed workload is reached. Since identical cartridges are used within each system, spare part inventories are kept to a minimum. Additionally, the heat transfer cartridges, unlike their metallic counterparts in conventional evaporators, are relatively easy to handle and replace.

2.5 Description of Hadwaco MVR Evaporator System Design Parameters

In addition to utilizing modular heat transfer cartridges, the complete evaporator systems are also modular. Standard modules are manufactured in sizes with capacities ranging from 12 tons per day (t/d) to 900 t/d or 3,000 gallons per day (gpd) to 225,000 gpd. The evaporator being tested has a capacity of 92,500 gpd. Should the desired workload for an installation exceed these figures, additional units can be installed in series. This modular concept also allows stepwise enlargement of the installation, which can grow as the needs of the user grow. The units can be delivered fully assembled with only external connections to the user's outer systems being completed on-site. The units are designed for outdoor operation, thus requiring no additional building.

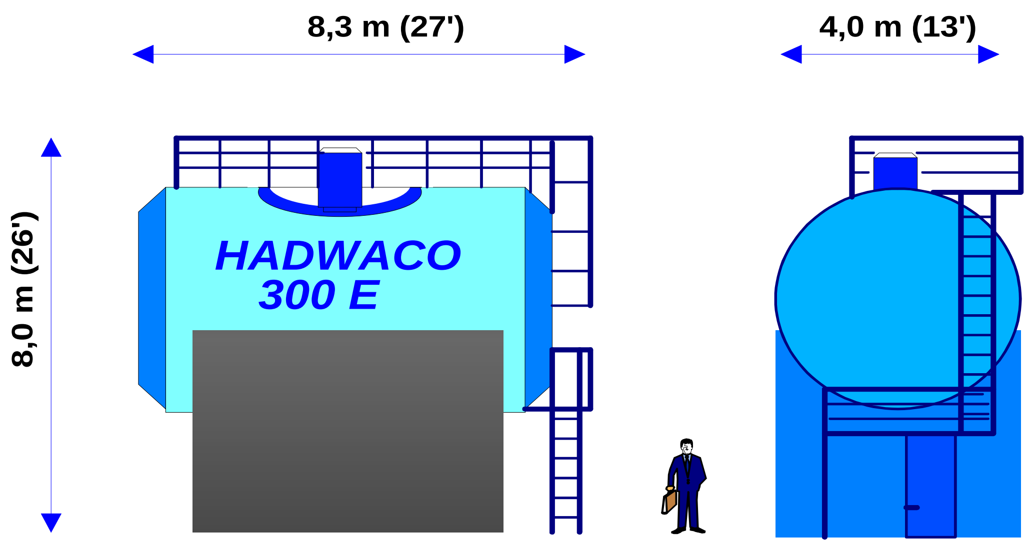


Figure 5. General Dimensions (300e) Module

2.6 Successful Application Parameters

In order to take full advantage of the Hadwaco concept, it is important to understand that the technology is best applied in dilute aqueous streams where recovery of high quality water and/or reduction in volume of a concentrated waste stream are the goals. These incoming streams should be as clear of suspended materials as possible and not be close to saturation of dissolved solids.

2.6.1 Minimized Pretreatment Requirements

Due to basic theory of design, which minimizes heat exchanger scaling and fouling, the Hadwaco technology's pretreatment requirements are minimized. To ensure efficient operation, suspended solids should be removed prior to entry into the evaporator unit, especially when higher concentration ratios are required. Pretreatment options include such traditional methods as sedimentation, flotation, chemical addition, and/or mechanical filtration. The evaporator being tested is equipped with mechanical filtration.

2.6.2 Minimized Effects of Scaling, Fouling, and Precipitation

Because of its characteristics, Hadwaco claims the polymeric heat transfer surface offers superior resistance to the effects of scaling, fouling, and precipitation when applied to dilute streams. The resulting benefits include extended performance life, longer intervals between cleaning, and less downtime for maintenance.

2.6.3 Maximized Volume Reduction with Low Power Consumption

Due to the designed low temperature difference across the heat transfer surface, the technology is best suited for streams having a relatively low concentration of total dissolved solids (TDS) with a correspondingly low boiling point elevation.

As illustrated in **Figure 6**, high recovery rates of purified water can be expected from dilute streams. For example, starting with 0.5 percent TDS, 95 percent of the total liquid volume is removed when the TDS reaches 10 percent. This means that the major part of the evaporation, and corresponding work, takes place at very low TDS levels. It is in these dilute streams where the designed low power consumption of the Hadwaco concept is best utilized.

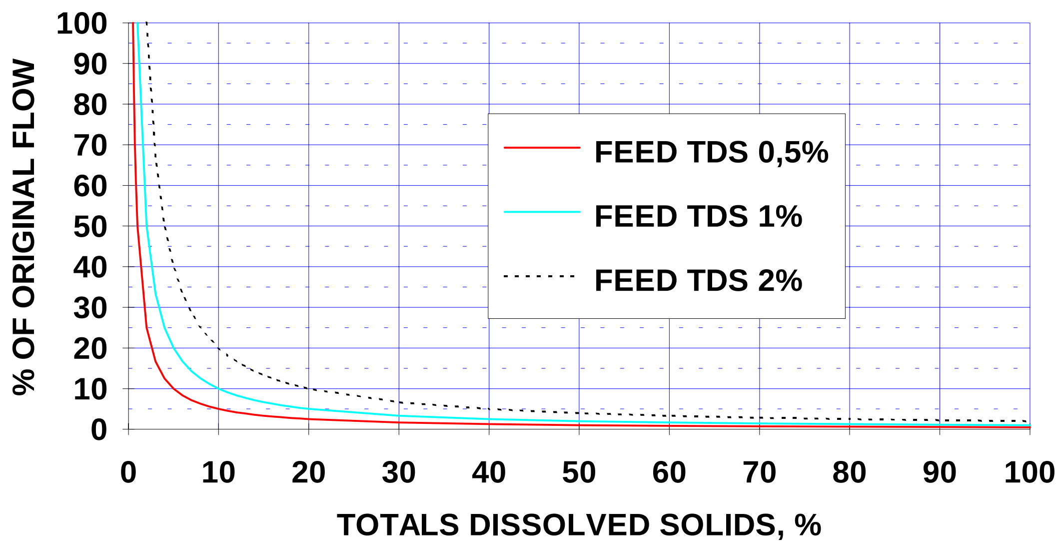


Figure 6. Water Reduction Rates

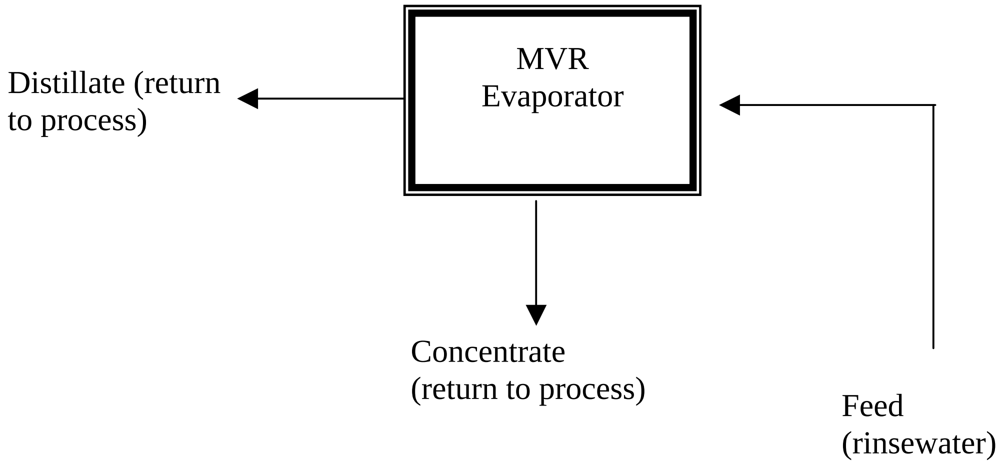


Figure 7. Simplified Flow Diagram

2.7 Commercial Status

The Hadwaco evaporator is a commercial product. Hadwaco has sold 17 systems in total with three units installed on surface finishing processes in Finland, Canada, and the United States.

2.8 Environmental Significance

Wastewater containing heavy metals is often inadequately treated by conventional hydroxide precipitation systems, and advanced precipitation systems can be very difficult and expensive to operate. The newly proposed Metal Products & Machinery (MP&M) effluent limitations for metals will be very difficult to meet for many metal finishers.

The Hadwaco evaporator system is designed to recycle metal-bearing wastewater and, for segregated wastestreams, recover valuable metals and other solution constituents for process reuse or off-site recycle. The copper pickling wastestream will be operated as a closed-loop process. Rinsewater is processed by the Hadwaco evaporator, and the evaporator condensate is recycled as rinsewater makeup. The evaporator concentrate is collected for secondary processing in an electrowinning unit. The copper is sold as scrap metal, and the recovered sulfuric acid is reused in the pickling process.

2.9 Local Installation

The Hadwaco evaporator system is installed at a manufacturing site that has requested anonymity. This facility manufactures copper product. The copper product is pickled in sulfuric acid to remove heat scale. The facility generates up to 400 m^3 or 105,680 gallons of rinse water for recycle per day. According to the vendor, Hadwaco US, Inc., the equipment serves to process a wastewater feed stream presently characterized by data represented in **Table 2**. Due to the characteristics and acidity of the wastestream TSS is expected to be very low.

Parameter	Average Concentration	Maximum Concentration
Copper	850 ppm	1500 ppm
Sulfuric Acid	0.1%	0.5%
TDS	1500 mg/L	3000 mg/L
TSS	<10 mg/L	<30 mg/L
pH	<2	<1

Note: Based on information provided by Hadwaco.

Table 2. Raw Wastewater (Feed) Data

3.0 EXPERIMENTAL DESIGN

3.1 Test Goals and Objectives

The overall goal of this ETV-MF project is to evaluate the ability of the Hadwaco evaporator to operate as the main step in a zero-wastewater discharge system in a metal finishing plant. The following is a summary of primary project objectives:

- Conduct verification testing in order to:
  1) Determine the evaporator separation efficiency
  2) Evaluate the evaporator workload
  3) Determine the evaporator energy usage
  4) Determine concentration factor
  5) Determine recovery efficiency

- Determine the cost of operating the Hadwaco evaporator system for the specific conditions encountered during testing:
  1) Identify operating and maintenance (O&M) tasks
  2) Determine the cost of energy consumed by operating the system
  3) Determine the cost savings associated with the recovered copper, sulfuric acid, and water

- Quantify the environmental benefit by determining the amount of copper (Cu), sulfuric acid (H_2SO_4), and water recovered.

3.2 Critical and Non-Critical Measurements

Measurements that will be taken during testing are classified below as either critical or non-critical. Critical measurements are those that are necessary to achieve the primary project objectives. Non-critical measurements are those related to process control or general background readings.

<u>**Critical Measurements:**</u>

- Raw wastewater feed flow rate
- Recovered condensate flow rate

- Recovered concentrate flow rate
- Energy and water use
- Chemical characteristics of feed, condensate, and concentrate streams (mg/L of Cu, Lead (Pb), sulfate, TDS, total suspended solids (TSS)), as well as acidity and conductivity.
- O&M labor tasks

Non-Critical Measurements:

- Temperature
- pH

3.3 Test Matrix

The verification test will be performed in a single test period for duration of four days. During each 24-hour period, two grab samples will be collected from each of the three streams (feed, condensate, and concentrate streams) and analyzed. In total, three sets of eight data points will be generated for each analyte in the test run. The operating conditions for the runs are shown in **Table 3**. The sample quantities and locations are shown in **Table 6.**

Test Run	Duration	Conditions
Test Run 1	Four 24-hr Periods	Feed = 353 m^3/day or 93263 gal/day

Table 3. Test Matrix

The production copper product pickling line generates raw wastewater feed to the Hadwaco evaporator.

Test objectives and measurements are summarized in **Table 4**.

3.4 Testing and Operating Procedures

3.4.1 Set-Up and System Initialization Procedures

The unit to be tested is a full-scale Hadwaco evaporator Model No. E340. Sampling ports have been preinstalled in the feed, condensate, and concentrate piping loops.

Test Objective	Test Measurement
Determine the workload, separation efficiency, energy use, and O&M requirements	-Raw wastewater feed volume -Recovered condensate (distillate) (L/day) -Recovered concentrate (L/day) -Energy use (kWh/L) -Chemical characteristics of feed, condensate, and concentrate streams (mg/L of Cu, Pb, sulfate, TDS, TSS), acidity, pH, and conductivity -Temperature -City water flow volume (L) -O&M labor tasks

Table 4. Test Objectives and Related Test Measurements for Evaluation of the Hadwaco MVR Evaporator System

3.4.2 System Operation

Hadwaco and the host facility will be responsible for operating the Hadwaco evaporator system according to the procedures found in **Appendix A**. The test run will begin once Hadwaco indicates that the system is operational and stable. The unit will be operated for five days during the test run, and samples will be collected during days 2–5.

The Hadwaco MVR Evaporator being tested is a full-scale unit, permanently installed on a full-scale production line. The source of raw wastewater is untreated process wastewater from copper pickling.

3.4.3 Sample Collection and Handling

Grab samples will be collected twice daily from each of the sampling locations (feed, condensate, and concentrate). These samples will be collected into high-density polyethylene (HDPE) containers. Temperature and Flow data will be collected on site from the system instrumentation. Conductivity and pH will be collected using a conductivity and pH meter. The ETV-MF Project Manager will verify the calibration of pH and conductivity instrumentation daily using standards and certified buffers, respectively. Samples will be collected according to the schedule presented in **Table 5** and recorded on the form shown in **Appendix B**. This data is collected to verify equipment operation.

At the time of sampling, each sample container will be labeled with the date, time, test parameter required, and sample identification (ID) number. Samples to be analyzed at an off-site laboratory will be accompanied by a chain-of-custody (COC) form. The COC form will provide the following information: project name, project address, sampler's name, sample numbers, date/time samples were collected, matrix, required analyses, and appropriate COC signatures. All samples will be transported in appropriate sample transport containers (e.g., coolers with packing and blue ice) by common carrier using express service. The transport containers will be secured with tape to ensure sample integrity during the delivery process to the analytical laboratory. The ETV-MF Project Manager or designee will perform sampling and labeling, prepare the COC form, and ensure that samples are properly secured and shipped to the laboratory for analysis.

Sample	Sampling Location	Frequency/Type	Parameters
Feed	Grab samples will draw sample from the evaporator feed	Grab samples will be collected twice/day.	Total metals (Cu, Pb), acidity, sulfate, TDS, TSS
Concentrate	Grab samples will draw sample from the evaporator concentrate return	Grab samples will be collected twice/day.	Total metals (Cu, Pb), acidity, sulfate, TDS, TSS
Condensate	Grab samples will draw sample from the evaporator condensate return	Grab samples will be collected twice/day.	Total metals (Cu, Pb), acidity, sulfate, TDS, TSS

Table 5. Sampling Locations, Frequency, and Parameters

The sample quantities required for analysis of samples, field duplicate, matrix spike and matrix spike duplicates are identified in **Table 6**. Sample container volumes are identified in **Table 7.**

Sample Location	Parameter	Day 1	Day 2	Day 3	Day 4
Feed	Total Metals Cu, Pb	2	3	2	2
	TDS TSS	2	3	2	2
	Acidity	2	3	2	2
	Sulfate	2	3	2	2
Concentrate	Total Metals Cu, Pb	2	3	2	2
	TDS TSS	2	3	2	2
	Acidity	2	3	2	2
	Sulfate	2	3	2	2
Condensate	Total Metals Cu, Pb	2	3	2	2
	TDS TSS	2	3	2	2
	Acidity	2	3	2	2
	Sulfate	2	3	2	2

Table 6. Sample Quantities from Each Location by Parameter

3.4.4 Process Measurements and Information Collection

The process measurements and information collected include the following data: pH, flow, conductivity, temperature, boiling point elevation, energy and water use, cost factors, and O&M activities. The methods that will be used for process measurements and information collection are discussed in this section.

3.4.4.1 Process Streams Flow Rate and Volume Processed

The volume of process streams processed during the test run will be measured using a Rosemount 8712 series flowmeter/totalizer. This instrumentation is presently installed in the Hadwaco evaporator system and is factory calibrated. A factory calibration certificate will be inspected prior to testing. The flow totalizer will be read at the start and end of the test run and three times per day during the test run. The instantaneous flow rate will be read three times per day during the test run. The flowmeter readings and the times those readings are taken will be recorded on the data form in **Appendix B**.

3.4.4.2 Conductivity and pH of Process Streams

Wastewater pH will be measured on-site with a Davis Instruments Model #9214 microprocessor controlled, automatic temperature compensated pH meter. The digital pH meter will be calibrated at the start of each sampling day by the ETV-MF Project Manager. The following calibration information will be collected and recorded in the field notebook: buffer supplier, lot number, expiration date, and date of usage. Wastewater conductivity will be measured with an Oakton Acorn® Series CON 5 microprocessor controlled, automatic temperature compensated conductivity meter. The digital conductivity meter will be calibrated at the start of each sampling day by the ETV-MF Project Manager. The following calibration information will be collected and recorded in the field notebook: buffer pH, meter reading, standard solution supplier, lot number, expiration date, and date of calibration. See **Table 8** for equipment performance details.

3.4.4.3 Temperature of Process Streams

The temperature of the water processed during the test run will be measured using a Rosemount 644 series temperature meter. This instrumentation is presently installed in the Hadwaco evaporator system and is factory calibrated. A factory calibration certificate will be inspected prior to testing. The temperature will be read at the start and end of the test run and three times per day during the test run. The instantaneous temperature will be read three times per day during the test run. The temperature readings and the times those readings are taken will be recorded on the data form in **Appendix B**.

3.4.4.4 Energy and Water Use Data

Energy and water use will be calculated by determining the power requirements and cycle times of pumps and other powered devices associated with the Hadwaco MVR Evaporator or by meter. The energy (kWh) readings, city water flow volume (L) readings and the times those readings are taken will be recorded on the data form in **Appendix B**.

3.4.4.5 System Operation and Maintenance Labor Tasks

The ETV-MF Project Manager will observe operation of the Hadwaco MVR Evaporator system during the verification test. Hadwaco and the host facility operating personnel will report any Hadwaco MVR Evaporator system changes or maintenance activities to the ETV-MF Project Manager. This includes changes to the flow rate, production changes, and maintenance activities. The team leader will record notes pertaining to these activities on the data form in **Appendix B**.

3.4.4.6 Cost Data

Hadwaco and the host facility will provide the cost data for electricity, labor, city water, and recovered chemicals.

3.5 Analytical Procedures

All analytical procedures that will be used during this verification test are EPA methods. A summary of analytical tests is presented in **Table 7**.

Parameter	Test Method	Sample Bottle	Sample Volume Required	Preservation/ Handling	Hold Time
Total copper	EPA 200.7	HDPE	250 mL	HNO_3 pH <2 cool storage (<4^oC)	6 months
Total lead	EPA 200.7	HDPE	250 mL	HNO_3 pH <2 cool storage (<4^oC)	6 months
acidity	EPA Method 305.1	HDPE	250 mL	cool storage (<4^oC)	14 days
sulfate	EPA Method 300.0	HDPE	250 mL	cool storage (<4^oC)	28 days
TDS	EPA Method 160.1	HDPE	250 mL	cool storage (<4^oC)	7 days
TSS	EPA Method 160.2	HDPE	500 mL	cool storage (<4^oC)	7 days

Table 7. Summary of Analytical Tests and Requirements

4.0 QUALITY ASSURANCE/QUALITY CONTROL REQUIREMENTS

Quality Assurance/Quality Control activities will be performed according to the applicable section of the Environmental Technology Verification Program Metal Finishing Technologies Quality Management Plan (ETV-MF QMP) [Ref. 1].

4.1 Quality Assurance Objectives

The first QA objective is to ensure that the process operating conditions and test methods are maintained and documented throughout the test and laboratory analysis of samples. The second QA objective is to use standard test methods (where possible) for laboratory analyses. Severn Trent Laboratories will provide all analytical services. The QA objectives and test methods to be used are listed in **Table 7**.

4.2 Data Reduction, Validation, and Reporting

4.2.1 Internal Quality Control Checks

Raw Data Handling. Raw data are generated and collected by analysts at the laboratory. These include original observations, printouts, and readouts from equipment for sample, standard, and reference QC analyses. Data are collected both manually and electronically. At a minimum, the date, time, sample ID, raw signal or processed signal, and/or qualitative observations will be recorded. Comments to document unusual or non-standard observations also will be included in the data package submitted by the laboratory to *CTC*.

The ETV-MF Project Manager will generate COC forms, and these forms will accompany samples when they are shipped off-site.

Raw data will be processed manually by the analyst, automatically by an electronic program, or electronically after being entered into a computer. The analyst will be responsible for scrutinizing the data according to laboratory precision, accuracy, and completeness policies. Raw data bench sheets and calculation or data summary sheets will be kept together for each sample batch. From the standard operating procedure and the raw data bench files, the steps leading to a final result may be traced. The *CTC* ETV-MF Program Manager will maintain process-operating data for use in verification report preparation.

<u>Data Package Validation.</u> The generating analyst will assemble a preliminary data package, which shall be initialed and dated. This package shall contain all QC and raw data results, calculations, electronic printouts, conclusions, and laboratory sample tracking information. A second analyst will review the entire package and check sample and storage logs, standard logs, calibration logs, and other files, as necessary, to ensure that all tracking, sample treatments, and calculations are correct. After the package is reviewed in this manner, a preliminary data report will be prepared, initialed, and dated. The entire package and final report will be submitted to the Laboratory Manager (LM).

The LM shall be ultimately responsible for all final data released from the laboratory. The LM or designee will review the final results for adequacy to task QA objectives. If the LM or designee suspects an anomaly or non-concurrence with expected or historical performance values, or with task objectives for test specimen performance, the raw data will be reviewed, and the generating and reviewing analysts queried. If suspicion about data validity still exists after internal review of laboratory records, the LM will authorize a re-test. If sufficient sample is not available for re-testing, a re-sampling shall occur. If the sampling window has passed, or re-sampling is not possible, the manager will flag the data as suspect. The LM signs and dates the final data package.

<u>Data Reporting.</u> A report signed and dated by the LM will be submitted in duplicate to the ETV-MF Project Manager and *CTC* Project Manager. The ETV-MF Project Manager will decide the appropriateness of the data for the particular application. The final report contains the laboratory sample ID, date reported, date analyzed, the analyst, the method used for each parameter, the process or sampling point identification, the final result, the units, and the quality control sample results. The *CTC* ETV-MF Program Manager shall retain the data packages as required by the ETV-MF QMP [Ref. 1]. Additionally, the *CTC* QA Manager shall review the data packages as called out by the ETV-MF QMP.

4.2.2 Calculation of Data Quality Indicators

Analytical performance requirements are expressed in terms of precision, accuracy, representativeness, comparability, completeness, and sensitivity (PARCCS). Summarized below are definitions and QA objectives for each PARCCS parameter.

4.2.2.1 Duplicates

Duplicate samples collected in the field will be used to quantify sample representativeness associated with the entire sampling and analysis system. Field duplicate samples (submitted as two aliquots) will be submitted once during the test run from the feed, condensate and concentrate. The duplicate samples will be analyzed for all analytical parameters listed in **Table 5**.

4.2.2.2 Matrix Spikes

Matrix spikes and matrix spike duplicates will be prepared in the analytical laboratory. Matrix spike/matrix spike duplicates will be analyzed once during the test period for each applicable parameter. Test parameters that will undergo matrix spike/matrix spike duplicate analyses are copper, lead, and sulfate (TSS, TDS, and total acidity cannot undergo matrix spike/matrix spike duplicate procedures). Sample splitting will occur at the analytical laboratory, which requires additional quantity of the sample to be collected at the time of sampling in order to provide enough samples to perform matrix spike/spike duplicate procedures.

Three streams, each defined as a separate matrix, will be sampled: feed, concentrate, and condensate (distillate). Refer to the referenced EPA test methods for more specific information.

4.2.2.3 Blank Samples

Severn Trent Laboratory will provide trip blanks which will be analyzed for the normal test parameters (TSS, TDS, copper, lead, acidity, and sulfate). These samples will be prepared by the laboratory and will follow the sample collection containers through shipping, sample collection, and analysis processes.

4.2.2.4 Precision

Precision is a measure of the agreement or repeatability of a set of replicate results obtained from duplicate analyses made under identical conditions. Precision is estimated from analytical data and cannot be measured directly. The precision of a duplicate determination can be expressed as the relative percent difference (RPD), and calculated as:

$$\text{RPD} = \left\{ \frac{|X_1 - X_2|}{\frac{(X_1 + X_2)}{2}} \right\} x100\,\%$$

where:

X_1 = larger of the two observed values
X_2 = smaller of the two observed values

Multiple determinations will be performed for the test on the same test specimen. The replicate analyses must be in accord with the RPD limits provided in **Table 7**.

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4.2.2.5 Accuracy

Accuracy is a measure of the agreement between an experimental determination and the true value of the parameter being measured. Accuracy is estimated through the use of known reference materials or matrix spikes. It is calculated from analytical data and is not measured directly. Spiking of reference materials into a sample matrix is the preferred technique because it provides a measure of the matrix effects on analytical accuracy. Accuracy, defined as percent recovery (P), is calculated as:

$$\text{P} = \left[\left(\frac{\text{SSR} - \text{SR}}{\text{SA}} \right) \right] \text{X100\%}$$

Where
:

SSR	=	spiked sample result
SR	=	sample result (native)
SA	=	the concentration added to the spiked sample

Analyses will be performed with periodic calibration checks with traceable standards to verify instrumental accuracy. These checks will be performed according to established procedures in the contracted laboratory(s) that have been acquired for this verification test. Analysis with spiked samples will be performed to determine percent recoveries as a means of checking method accuracy. QA objectives will be satisfied if the *average* recovery is within the goals described in **Table 8**.

Parameters	Test Method	Reporting Units	Method of Determination	MRL	Precision (RPD)	Accuracy (% Recovery)	Completeness
Copper	EPA 200.7	mg/L	ICP-AES	0.02	<20	75–125	90
Lead	EPA 200.7	mg/L	ICP-AES	0.005	<20	75–125	90
Acidity	EPA 305.1	mg/L as $CaCO_3$	Titration	10	<30	80–120	90
Sulfate	EPA 300.0	mg/L	Ion chromatography	0.1	<30	90–110	90
TDS	EPA 160.1	mg/L	Gravimetric	5.0	<25	N/A	90
TSS	EPA 160.2	mg/L	Gravimetric	5.0	<25	N/A	90
Flow	Flow Totalizer	liters/hr	Flowmeter	1.0%	<10	N/A	90
pH	EPA 150.1	pH	Electrometric	0.1	.2	N/A	90
Conductivity	EPA 9050A	μS/cm	Wheatstone Bridge-Type	1.0%	<2	N/A	90
Temperature	Electrometric	°C	Electrometric	1.0%	<10	N/A	90

EPA: EPA Methods and Guidance for Analysis of Water

Table 8. QA Objectives

4.2.2.6 Completeness

Completeness is defined as the percentage of measurements judged to be valid compared to the total number of measurements made for a specific sample matrix and analysis. Completeness is calculated using the following formula:

$$\text{Completeness} = \frac{\text{Valid Measurements}}{\text{Total Measurements}} \times 100\%$$

Experience on similar projects has shown that laboratories typically achieve about 90 percent completeness. QA objectives will be satisfied if the percent completeness is 90 percent or greater as specified in **Table 8**.

4.2.2.7 Comparability

Comparability is another qualitative measure designed to express the confidence with which one data set may be compared to another. Sample collection and handling techniques, sample matrix type, and analytical method all affect comparability. Comparability is limited by the other PARCCS parameters because data sets can be compared with confidence only when precision and accuracy are known. Comparability will be achieved in this technology verification by the use of consistent methods during sampling and analysis and by traceability of standards to a reliable source.

4.2.2.8 Representativeness

Representativeness refers to the degree to which the sample represents the properties of the particular wastestream being sampled. For the purposes of this demonstration, representativeness will be determined by submitting identical samples (field duplicates) to the laboratory for analysis. The samples will be representative if the relative percent difference between the sample and the field duplicate is similar to or less than the precision (laboratory duplicates) calculation of the sample.

4.2.2.9 Sensitivity

Sensitivity is the measure of the concentration at which an analytical method can positively identify and report analytical results. The sensitivity of a given method is commonly referred to as the detection limit. Although there is no single definition of this term, the following terms and definitions of detection will be used for this program.

Instrument Detection Limit (IDL) is the minimum concentration that can be measured from instrument background noise.

Method Detection Limit (MDL) is a statistically determined concentration. It is the minimum concentration of an analyte that can be measured and reported with 99 percent confidence that the analyte concentration is greater than zero as determined in the same or a similar matrix. (Because of the lack of information on analytical precision at this level, sample results greater than the MDL but less than the Method Reporting Limit (MRL) will be laboratory qualified as "estimated.")

MDL is defined as follows for all measurements:

$$MDL = t_{(n-1,1-\alpha = 0.99)} \times s$$

Where:

- MDL = method detection limit
- $T_{(n-1,1-\alpha = 0.99)}$ = students t-value for a one-sided 99 percent confidence level and a standard deviation estimate with n-1 degrees of freedom
- s = standard deviation of the replicate analyses

Method Reporting Limit (MRL) is the concentration of the target analyte that the laboratory has demonstrated the ability to measure within specified limits of precision and accuracy during routine laboratory operating conditions. (This value is variable and highly matrix dependent. It is the minimum concentration that will be reported without qualifications by the laboratory.)

4.2.3 Other Calculations

4.2.3.1 Mass Balance

Mass balance calculations are performed for the metals parameters for all test runs. These results will be used as an indicator of the accuracy of the verification test. The mass balance criterion will be satisfied when the mass balance is within the range of 75 percent to 125 percent. The mass balance equation for calculating each constituent parameter is shown below.

$$\text{mass bal. (\%)} = [(C_E \times V_E) / (C_I \times V_I)] \times 100\%$$

Where:

- C_E = effluent constituent concentration (mg/L)
- V_E = effluent volume processed during the test period (L)
- C_I = influent constituent concentration (mg/L)
- V_I = influent volume processed during the test period (L)

4.2.3.2 Evaporator Workload

The evaporator workload is determined by the volume of condensate recovered per day.

4.2.3.3 Concentration Factor

The concentration factor will be calculated on a daily basis as a qualitative measure of system performance.

Concentration Factor = Feed volume/Concentrate volume

4.2.3.4 Recovery Efficiency

The evaporator recovery efficiency is determined by comparing the volume of water recovered as condensate to the volume of water in the feed. These calculations are performed for each daily set of analytical results. The equation for water recovery calculation is shown below.

$$W_{eff}\,(\%) = [(V_{C/d}) / (V_F)] \times 100\%$$

Where:

W_{eff} = water recovery efficiency
$V_{C/d}$ = volume of condensate recovered per day (L)
V_F = feed volume processed per day (L)

4.2.3.5 Separation Efficiency

The separation efficiency is calculated based on a comparison of feed and condensate concentrations for each pollutant parameter.[1] These calculations are performed for each daily set of analytical results. The removal efficiency rate for each constituent parameter will be separately calculated. These include copper, lead, sulfate, TSS, and TDS.

$$C_{remove}\,(\%) = [((C_I \times V_I) - (C_C \times V_{C/t})) / (C_I \times V_I)] \times 100\%$$

Where:

C_{remove} = constituent removal efficiency
C_I = influent constituent concentration (mg/L)
V_I = influent volume processed during the test period (L)
C_C = condensate constituent concentration (mg/L)
$V_{C/t}$ = condensate volume processed during the test period (L)

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[1] Separation efficiency will only be calculated for parameters that are found at concentrations above reporting limits in the feed.

4.2.3.6 Energy and Water Use

Energy requirements for the Hadwaco MVR Evaporator system will be calculated by summing each component of energy in (kWh) and (L) and dividing by the total volume of condensate recovered (L). This figure is represented in (kWh/L). Water use and reuse will be evaluated in terms of city water consumed (L) and condensate recovered (L).

4.2.3.7 Cost Analysis

This analysis will determine the operating cost of the Hadwaco MVR Evaporator system considering the following cost parameters: materials (e.g., filters), electricity, labor, water use and reuse, and material recovery. Costs will be calculated separately for each cost parameter for the test run and expressed in dollars per thousand liters processed ($/1000 L) by dividing the cost by the total volume of wastewater processed for a given test run. Total costs for the test run will be calculated by summing the individual cost elements. The calculation of treatment cost for test run 1 is shown below. Cost equations for other test runs will be similar.

$$C_{\text{evaporation cost 1}} = (M_1 + MR_1 + E_1 + W_1 + L_1)$$

where:

$C_{\text{evaporation cost 1}}$ = total operating cost for test run ($/1000 L)
M_1 = cost of materials for test run ($/1000 L)
MR_1 = cost of materials recovered for test run ($/1000 L)
E_1 = cost of electricity for test run ($/1000 L)
W_1 = cost of water recovered for test run ($/1000 L)
L_1 = Labor cost for test run ($/1000 L)

4.2.3.8 Environmental Benefit

This analysis will quantify the environmental benefit of the evaporator for test run 2. The environmental benefit of the evaporator will be calculated by extrapolating annual water and material savings from test period data and estimating the kilograms and cost of material that would have been generated without the evaporator.

4.3 Quality Audits

Technical System Audits. An audit will be performed during verification testing by the *CTC* QA Manager according to section 2.9.3 Technical Assessments of the ETV-MF QMP [Ref. 1] to ensure testing and data collection are performed according to the test plan requirements. In addition to the *CTC* Technical System Audit (TSA), the EPA QA Manager may also conduct an audit to assess the quality of the verification test.

Internal Audits. In addition to the internal laboratory quality control checks, internal quality audits will be conducted to ensure compliance with written procedures and standard protocols.

Corrective Action. Corrective action for any deviations to established quality assurance and quality control procedures during verification testing will be performed according to section 2.10 Quality Improvement of the ETV-MF QMP [Ref. 1].

Laboratory Corrective Action. Examples of non-conformances include invalid calibration data, inadvertent failure to perform method-specific QA, process control data outside specified control limits, failed precision and/or accuracy indicators, etc. Such non-conformances will be documented on a standard laboratory form. Corrective action will involve taking all necessary steps to restore a measuring system to proper working order and summarizing the corrective action and results of subsequent system verifications on a standard laboratory form. Some non-conformances are detected while analysis or sample processing is in progress and can be rectified in real time at the bench level. Others may be detected only after a processing trial and/or sample analyses are completed. Typically, these types of non-conformances are detected by the LM. In all cases of non-conformance, sample re-analysis will be considered as one source of corrective action by the LM. If insufficient sample is available, or the holding time has been exceeded, complete re-processing may be ordered to generate new samples if a determination is made by the ETV-MF Project Manager that the non-conformance jeopardizes the integrity of the conclusions to be drawn from the data. In all cases, a non-conformance will be rectified before sample processing and analysis continues.

5.0 PROJECT MANAGEMENT

5.1 Organization/Personnel Responsibilities

The ETV-MF Project Team that is headed by *CTC* will conduct the evaluation of the Hadwaco MVR Evaporator system. The *CTC* ETV-MF Program Manager, Donn Brown, will have ultimate responsibility for all aspects of the technology evaluation. The ETV-MF Project Manager assigned to this evaluation is Peter Gallerani. Mr. Gallerani will be on-site throughout the test period and will conduct or oversee all sampling and related measurements.[2]

David Thomas will head the Hadwaco staff. Hadwaco and the host facility will be responsible for operation of the Hadwaco MVR Evaporator system. They will be on-site or on-call throughout the entire test period.

The ETV-MF Project Manager or staff member will collect samples and record data from process measurements.

[2] The *CTC* ETV-MF Program Manager, Donn Brown, will make a determination as to the qualifications of any staff member assigned to the project. This will occur prior to testing.

The ETV-MF Project Manager and the host facility have the authority to stop work when unsafe or unacceptable quality conditions arise. The *CTC* ETV-MF Program Manager will provide periodic assessments of verification testing to the EPA ETV Center Manager.

Severn Trent Laboratories of Tampa, FL, is responsible for analyzing verification test samples. The Project Manager, Michael Valder, will be the point of contact (813) 885-7427. Severn Trent Laboratories is approved by the State of Florida for the analyses identified in this test plan.

5.2 Test Plan Modification

In the course of verification testing, it may become necessary to modify the test plan due to unforeseen events. These modifications will be documented using a Test Plan Modification Request form (**Appendix C**), which must be submitted to the *CTC* ETV-MF Program Manager for approval. Upon approval, the modification request will be assigned a number, logged, and transmitted to the requestor for implementation.

6.0 EQUIPMENT AND UTILITY REQUIREMENTS

The Hadwaco MVR Evaporator system is a full-scale system installed and operational at the host facility. Utilities include steam, electricity, and city water. The system is fed by 480V electrical, 12-15psi steam, and standard city water.

7.0 ENVIRONMENTAL SAFETY AND HEALTH (ES&H) REQUIREMENTS

This section provides guidelines for recognizing, evaluating, and controlling health and physical hazards during the verification test. More specifically, this section specifies the training, materials, and equipment necessary for assigned personnel to protect themselves from hazards created by acids and any waste generated by the process.

7.1 Hazard Communication

All personnel assigned to the project will be provided with the potential hazards, signs and symptoms of exposure, methods or materials to prevent exposures, and procedures to follow if there is to be potential contact with a hazardous substance. The host facility's Hazard Communication Program and safety requirements will be reviewed during the training session described in **Section 7.8**. The training session will be completed prior to the start of any work and will be practiced throughout the test period. All appropriate Material Data Safety Sheet (MSDS) forms will be available for chemical solutions used during testing.

7.2 Emergency Response Plan

The host facility has a contingency plan (Consolidated Emergency Response Plan) to protect employees, assigned project personnel, and visitors in the event of an emergency at the facility. This plan will be used throughout the project. All assigned personnel will be provided with information about the emergency response plan during the training session described in **Section 7.8**. The plan will be accessible to project personnel for the duration of the test.

7.3 Hazard Controls Including Personal Protective Equipment

All assigned project personnel will be provided with appropriate personal protective equipment (PPE) and any training needed for its proper use, considering their assigned tasks. The use of PPE will be covered during training as indicated in section 9.0.

The following PPE will be required and must be worn at all times while in the host facility: eyeglasses with side splashguards, hardhat, ear plugs, and safety shoes.

The Hadwaco MVR Evaporator system is essentially a closed process and fully contained within an adjoining building. There are no apparent hazards to the surrounding community due to operation or testing of the system.

7.4 Lockout/Tagout Program

The host facility's Lockout/Tagout Program will be reviewed prior to testing, and relevant lockout/tagout provisions of the program will be implemented. No activities requiring Lockout/Tagout are anticipated as part of this project.

7.5 Material Storage

In accordance with the host facility's Hazard Communication Program, any materials used during the project will be kept in proper containers and labeled. Proper storage of the materials will be maintained based on associated hazards. Spill trays or similar devices will be used as needed to prevent material loss to the surrounding area.

7.6 Safe Handling Procedures

All chemicals and wastes or samples will be transported on-site in non-breakable containers used to prevent spills. Spill kits will be strategically located in the project area. These kits contain various sizes and types of sorbents for emergency spill cleanup. Emergency spill cleanup will be performed according to the host facility's consolidated Emergency Response Plan.

7.7 Waste Managment

The Hadwaco MVR Evaporator system will process wastewater generated by manufacturing operations at the host facility. After processing, the condensate and concentrate from the Hadwaco MVR Evaporator system is transferred to the existing host facility process for reuse. Any residuals generated by the Hadwaco MVR Evaporator system will be managed by the host facility.

7.8 Training

Environmental safety and health training will be coordinated with the host facility's staff. All ETV-MF personnel will undergo environmental safety and health training provided by the host facility prior to initiating the verification test.

Also, the ETV-MF Job Training Analysis (JTA) Plan [Ref. 2] will be utilized to identify additional training requirements relating to QC, worker safety and health, and environmental issues. The purpose of this JTA Plan is to outline the overall procedures for identifying the hazards, quality issues, and training needs. This JTA Plan establishes guidelines for creating a work atmosphere that meets the quality, environmental, and safety objectives of the ETV-MF Center. The JTA Plan describes the method for studying ETV-MF project activity and identifying training needs. The ETV-MF Operation Planning Checklist (**Appendix D**) will be used as a guideline for identifying potential hazards, and the JTA Form (**Appendix E**) will be used to identify training requirements. After completion of the form, applicable training will be performed. Training will be documented on the ETV-MF Project Training Attendance Form (**Appendix F**).

8.0 REFERENCES

- 1) Concurrent Technologies Corporation, Environmental Technology Verification Program Metal Finishing Technologies (ETV-MF) Quality Management Plan, Revision 1, March 26, 2001.
- 2) Concurrent Technologies Corporation, Environmental Technology Verification Program Metal Finishing Technologies (ETV-MF) Pollution Prevention Technologies Pilot Job Training Analysis Plan, May 10, 1999.
- 3) EPA, Effluent Limitations Guidelines, Pretreatment Standards, and New Source Performance Standards for the Metal Finishing Point Source Category.

9.0 DISTRIBUTION

Alva Daniels, EPA (3)

David Thomas, Hadwaco

Host Facility

Peter Gallerani, ITI

Donn Brown, *CTC* (2)

Scott Maurer, *CTC*

Percy Peltzer, *CTC*

Clinton Twilley, *CTC*

Michael Valder, Severn Trent Laboratories

APPENDIX A

Hadwaco MVR Evaporator Operation and Maintenance Manual (selected sections)

OPERATION MANUAL

FOR

HADWACO MVR 340 / 24L-1.2

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1. OPERATION

1.1 Process concept

The HADWACO 340 / 24L-1.2 evaporating unit is designed to recover and recycle water purified from rinse water generated in the copper rod production line. The evaporator is a single effect MVR evaporator with one vapor recompressor fan. The rinse water is as follows:

1. Waste Rinse water to be processed is stored in feed buffer tank
2. The stored rinsewater is pumped through heat exchanger HE-301 for heat recovery from the exiting condensate and further through HE-302 for heating/cooling as required and into the evaporator unit at the bottom of Tank T-101. The cooling water is city water. The evaporator can be run either with T-101, T-102 or both.
3. Within the unit, condensate is removed from the feed water via a distillation process, leaving most of the dissolved constituents as concentrate.
4. Concentrate is discharged from the unit with pump P-201 or P-202 into the concentrate tank No 1, No 2 or into the feed tank.
5. Condensate is discharged from the unit with pump P-401 or P-402 into the condensate tank or into the feed tank.

1.2 Evaporator Operating Principles

The Hadwaco Evaporator Unit applies vapor recompression (MVR) and Falling Film (FF) principles. Evaporation takes place under vacuum and at low temperature.

When an aqueous solution at saturated state is heated, it starts to evaporate and generate water vapor. The generated vapor is directed through the vapor compressor, which will increase the pressure and saturation temperature. The compressed vapor is used as heating steam in the same evaporator stage, thus recycling the latent heats

Only a small amount of additional energy, steam, is used, depending on the pressure ratio of the compressor. The Hadwaco evaporator operates on a very small temperature difference.

1.3 Operation

Rinse water is pumped through external plate heat exchangers into the unit. The circulation pump transfers the rinse water to the upper section of the evaporator, where it is distributed on the evaporator heat transfer surface.

On the surface, a part of the circulating water evaporates and the generated vapor is compressed by the fan located on the top of the evaporator vessel. After the fan, the compressed vapor is led to the other side of the primary, internal heat transfer surface and used as heating steam. The condensed vapor (condensate) flows into the condensate tank T-401 and is pumped out with the condensate pump P-401 or P-402.

The concentrate is pumped out from the bottom of the evaporator vessel with the concentrate pump P-201 or P-202.

Vacuum generation and de-aeration during operation is made by the liquid ring vacuum pump P-501 or P-502.

The evaporation unit is equipped with a double pump system. This redundancy will enable the operator to keep the unit on-line should there be a pump related equipment failure.

Duplex pumps are as follows:

Feed pumps	P-301, P-302
Circulation pumps	P-101, P-102
Concentrate pumps	P-201, P-202
Condensate pumps	P-401, P-402
Vacuum pumps	P-501, P-502

1.3.1 Start-up of the unit

The start-up sequence of the MVR unit is automatic and requires minimal supervision by the operator

Following heck-up must be made prior to start-up:

- All manholes to be closed.
- All drain valves to be closed.
- All sample valves to be closed.
- Pipe flanges and connections to be tightened.
- All manual operated valves are in their right positions, open / closed according to P&ID or start-up valve list. All devices, which are operated with sequence, should be put on AUTO-mode. In case there are two pumps parallel, one should be in AUTO-mode and the other in MANUAL-mode.
- Feed water is available in the feed tank, if not: check the additional water line feeding the feed tank.
- Heat exchangers are tightened according to manufacturers' manuals.
- Cooling water system for the pump sealing is in condition and water available.
- Concentrate and condensate tanks are in condition to take the flows.
- Condensate tank T-401 must be filled manually, open valve HS-902, to the level of current set-point, (level control LIC-411)
- Check the water feed for the vacuum pumps.
- All remaining alarms must be acknowledged in the process control system.
- All power switches in the motor cabinet must be turned into position "automatic", which are going to be used in the process operation.
- The water flow is correct to the nozzles for avoiding overheating.

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NOTICE!

Never open the steam valves, PCV-112A or HS-912, before the evaporator has been filled with water in between minimum and maximum levels. Failure to do so will result in the total destruction of the primary heat transfer surfaces.

As soon as the items mentioned above have been checked, the start-up program can be started.

The program will start devices in following order:

1. If this is the initial start-up, make sure that all the automatic on / off-valves are in automatic position.
2. Fan F-101 starts.
   Pressure difference control PDIC-111 is activated.
3. As the pressure difference produced by the fan exceeds 5 mbar, the vacuum pump, P501 (P-502) starts. Cooling water valves HS-901 and SV-904, (SV-905) open.
4. Feed pump P-301, (P-302) starts. Feed control valve FCV-314 opens to recipe set-point value. TIC-31 3 activates the control valve PCV-921 to regulate the feed water temperature.
5. After the liquid level in the evaporator has reached its higher level, HH1, the circulation pump P-101 (P-102) will start. Feed flow is controlled by LIC-1 13.
6. Concentrate pump P-201, (P-202) starts. The concentrate flow is regulated with the control valve FCV-211.
7. If the pressure in the evaporator vessel is less than its set-point (normally 200 mbar), feed temperature control TIC-313 deactivates and the overall pressure control PIC-112 is activated. The pressure control will feed heating steam from pipeline 005-ST to achieve normal operating temperature and pressure.
8. When the temperature of the circulating water meets its saturation point, the evaporation process will start. This can be seen as a sudden drop in the fan pressure differences. The level of the condensate in the condensate tank T-401 starts to rise. When the level has exceeded the higher level H1, the condensate pump P-401, (P-402) will start and the condensate level control LIC-411 activates.
9. Cooling water flows through heat exchanger HE-50-1 and the vacuum pump is adjusted so that convenient effluent temperature is achieved.
10. Normal operation checking includes checking of temperatures, pressures and flows.
11. Check and adjust the water flow for the nozzles, in the rotameters.

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The start-up time is depending on the water temperature.

1.3.2 Shut-down of the unit

Shut-down of the unit is done in the following order:

1. The procedure is started in the operating system.
2. The fan F-101 is stopped.
3. The vacuum pump P-501 (P-502), concentrate pump P-201, (P-202) and feed pump P301 (P-302) are all stopped.
4. The circulation pump P-l01 (P-102) and condensate pump P-401 (P-402) are stopped when the pressure difference across the fan is less than 3 mbar.
5. All actuated valves and the priming water valves are closed.
6. Heating steam valve HS-912 must be closed manually.
7. If the unit is to be closed for a longer period, e.g. for weekend, or maintenance, it is recommended to close the manual valves.
8. The shut-down procedure takes approximately 10 to 20 minutes.
9. If liquid needs to be discharged, it can be pumped out by the concentrate pump.

1.3.3 Cleaning of the evaporator

Cleaning of the evaporator is performed by circulating RO permeate or condensate in the unit, or manually by water hose inside the vessel.

NOTICE!

Before entering the evaporator, it has to be cooled down and ventilated to assure that no hazardous gases remain in the vessel.

2. ACTIVITIES DURING OPERATION

The operation of the evaporator can be adjusted to meet the actual water need of the factory. In this section, basic activities during evaporation are described.

2.1 Changing of evaporator capacity

The capacity of the evaporator depends on the effective temperature difference over the heat surface. This temperature difference, generally called delta T, is most easily changed by altering the pressure difference produced by the fan (PDIC-111). **It is recommended that the pressure difference always changed gradually, not more than two mbar at a time to avoid sudden peaks in pumping rates and fan loading! For a different pressure, a different set-point has to be set**.

In addition to change the pressure difference, there are two alternative ways to alter the capacity: changing of concentration ratio and operational pressure.

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- Decreasing concentration ratio (increasing concentrate flow) leads to smaller boiling point elevation and to greater effective delta T.
- Increasing of operational pressure and temperature leads to a higher density of the vapor and to a higher capacity of the fan.

NOTICE!

The operation pressure may not be higher than 230 mbar to avoid damage in the heat surface.

2.2 Altering of concentration ratio

The concentration ratio can be altered by changing the ratio in the concentrate flow control FIC-211. The concentrate flow normally follows the alteration of feed flow. This keeps the concentration ratio constant and is not dependent on alteration in feed flow. The concentration ratio may not exceed in weekdays operation and in week-end operation. The highest allowed TDS (total dry solids) content of the concentrate will be determined during the commissioning.

2.3 Regular check-ups during normal operation

During normal operation, the equipment operates automatically and warns for malfunctions and abnormalities of process conditions. However, regular visual inspections should be made to assure safe operation. Equipment and functions that must be checked regularly are listed below. This check-up will take approximately 10 to 15 minutes and must be carried out at least four times a day.

1. No leakage in the system, visible or audible, (if any leakage, a proper vacuum level can not be reached). There may not be abnormal vibrations or sounds in the unit, which could indicate damage on the fan.
2. Sealing water is running through the pumps P-101, P-102, P-201, P-202, P-501, P-502.
3. Cooling water temperature must be at tolerable level, max 20 degree Celsius.
4. The overall temperature of the evaporator T-101, T-102 is at tolerable level, 50-60 degree Celsius.
5. Every pump must produce a normal pressure.
6. Sufficient water must be fed for superheating prevention for the fan. Water flow through Fl-461 and FI-462 must be appr. 2 l/min.
7. If anything exceptional is occurring in the process or in the feed water composition, the operator must take appropriate corrective action to assure safe operation of the unit.
8. The operator should make daily written reports and follow-ups in the log-book of the process run, and keep appropriate and accurate records to facilitate safe and efficient operation as well as document warranty issues.

9. It is generally recommended to keep record of the main process parameters such as fan current, fan pressure differences, evaporator pressure, feed flow, condensate flow and the concentrate flow. Specific power consumption numbers (kWh/m3 condensate produced) is also a useful figure.

NOTE!

Maintenance of heat transfer surfaces (cartridges) is prohibited without Hadwaco's permission or instructions during the two (2) year warranty period (see the Agreement paragraph 5).

APPENDIX B

Data Collection Form for Hadwaco MVR Evaporator System Verification Test

Data Collection Form for Hadwaco MVR Evaporator System Verification Test

Test Run/Day: ________________________
ETV-MF Project Manager: ________________________
Hadwaco Operator: ________________________

Parameter/Date/Time	Reading	Observations/Comments
Energy kW Hours		
Start		
Stop		
City Water Flow Totalizer		
Start (L)		
Stop (L)		
Feed Flow Totalizer		
Start (L):		
Reading (L):		
Reading (L):		
Stop (L):		
Feed Flow Instantaneous		
Start (L/min):		
Reading (L/min):		
Reading (L/min):		
Stop (L/min):		
Condensate Flow Totalizer		
Start (L):		
Reading (L):		
Reading (L):		
Stop (L):		
Condensate Flow Instantaneous		
Start (L/min):		
Reading (L/min):		
Reading (L/min):		
Stop (L/min):		
Concentrate Flow Totalizer		
Start (L):		
Reading (L):		
Reading (L):		
Stop (L):		
Concentrate Flow Instantaneous		
Start (L/min):		
Reading (L/min):		
Reading (L/min):		
Stop (L/min):		

Test Run/Day: ______________________
ETV-MF Project Manager: ______________________
Hadwaco Operator: ______________________

Parameter/Date/Time	Reading	Observations/Comments
Feed Conductivity Instantaneous		
Start µS/cm		
Reading µS/cm		
Reading µS/cm		
Stop µS/cm:		
Condensate Conductivity Instantaneous		
Start µS/cm:		
Reading µS/cm:		
Reading µS/cm:		
Stop µS/cm:		
Concentrate Conductivity Instantaneous		
Start µS/cm:		
Reading µS/cm:		
Reading µS/cm:		
Stop µS/cm:		
Feed Temperature Instantaneous		
Start °C:		
Reading °C:		
Reading °C:		
Stop °C:		
Condensate Temperature Instantaneous		
Start °C:		
Reading °C:		
Reading °C:		
Stop °C:		
Concentrate Temperature Instantaneous		
Start °C:		
Reading °C:		
Reading °C:		
Stop °C:		
Feed pH Instantaneous		
Start		
Reading		
Reading		
Stop		

Additional Notes:

____
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APPENDIX C

Test Plan Modification

Test Plan Modification

In the course of verification testing, it may become necessary to modify the test plan due to unforeseen events. The purpose of this procedure is to provide a vehicle whereby the necessary modifications are documented and approved.

The Test Plan Modification Request form is the document to be used for recording these changes. The following paragraphs provide guidance for filling out the form to ensure a complete record of the changes made to the original test plan.

The person requesting the change should record the date and project name in the form's heading. Program management will provide the request number.

Under Original Test Plan Requirement, reference the appropriate sections of the original test plan, and insert the proposed modifications in the section titled Proposed Modification. In the Reason section, document why the modification is necessary; this is where the change is justified. Under Impact, give the impact of not making the change, as well as the consequences of making the proposed modification. Among other things, the impact should address any changes to cost estimates and project schedules.

The requestor should then sign the form and obtain the signature of the project manager. The form should then be transmitted to the *CTC* ETV-MF Program Manager, who will either approve the modification or request clarification. Upon approval, the modification request will be assigned a number, logged, and transmitted to the requestor for implementation.

TEST PLAN MODIFICATION REQUEST

Date:___________ Number:___________ Project:___________________________

Original Test Plan Requirement:____
____
____
____
____

Proposed Modification:____
____
____
____
____

Reason: ____
____
____
____
____

Impact:____
____
____
____
____

Approvals:

Requestor:______________________________

Project Manager:_________________________

Program Manager:________________________

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APPENDIX D

ETV-MF Operation Planning Checklist

ETV-MF Operation Planning Checklist

The ETV-MF Project Manager prior to initiation of verification testing must complete this form. If a "yes" is checked for any items below, an action must be specified to resolve the concern on the Job Training Analysis Form.

Project Name: ______________________________ Expected Start Date:
ETV-MF Project Manager: ______________________________ ________________

Will the operation or activity involve the following:	Yes	No	Initials & Date Completed
Equipment requiring specific, multiple steps for controlled shutdown? (e.g. in case of emergency, does equipment require more than simply pressing a "Stop" button to shut off power?) *Special Procedures for emergency shut-down must be documented in Test Plan.*			
Equipment requiring special fire prevention precautions? (e.g. Class D fire extinguishers)			
Modifications to or impairment of building fire alarms, smoke detectors, sprinklers or other fire protection or suppression systems?			
Equipment lockout/tagout or potential for dangerous energy release? *Lockout/tagout requirements must be documented in Test Plan.*			
Working in or near confined spaces (e.g., tanks, floor pits) or in cramped quarters?			
Personal protection from heat, cold, chemical splashes, abrasions, etc.? *Use Personal Protective Equipment Program specified in Test Plan.*			
Airborne dusts, mists, vapors and/or fumes? *Air monitoring, respiratory protection, and /or medical surveillance may be needed.*			
Noise levels greater than 80 decibels? *Noise surveys are required. Hearing protection and associated medical surveillance may be necessary.*			
X-rays or radiation sources? *Notification to the state and exposure monitoring may be necessary.*			
Welding, arc/torch cutting, or other operations that generate flames and/or sparks outside of designated weld areas? *Follow Hot Work Permit Procedures identified in Test Plan.*			
The use of hazardous chemicals? *Follow Hazard Communication Program, MSDS Review for Products Containing Hazardous Chemicals. Special training on handling hazardous chemicals and spill clean-up may be needed. Spill containment or local ventilation may be necessary.*			
Working at a height of six feet or greater?			

ETV-MF OPERATION PLANNING CHECKLIST

The ETV-MF Project Manager prior to initiation of verification testing must complete this form. If a "yes" is checked for any items below, an action must be specified to resolve the concern on the Job Training Analysis Form.

Project Name: ____
ETV-MF Project Manager: ______________________________________

Will the operation or activity involve the following:	Yes	No	Initials & Date Completed
Processing or recycling of hazardous wastes? *Special permitting may be required.*			
Generation or handling of waste?			
Work to be conducted before 7:00 a.m., after 6:00 p.m. and/or on weekends? *Two people must always be in the work area together.*			
Contractors working in *CTC* facilities? *Follow Hazard Communication Program.*			
Potential discharge of wastewater pollutants?			
EHS aspects/impacts and legal and other requirements identified?			
Contaminants exhausted either to the environment or into buildings? *Special permitting or air pollution control devices may be necessary.*			
Any other hazards not identified above? (e.g. lasers, robots, syringes) *Please indicate with an attached list.*			

The undersigned responsible party certifies that all applicable concerns have been indicated in the "yes" column, necessary procedures will be developed, and applicable personnel will receive required training. As each concern is addressed, the ETV-MF Project Manager will initial and date the "initials & date completed" column above.

ETV-MF Project Manager:______________________ ______________________ ______________
(Name) (Signature) (Date)

APPENDIX E

Job Training Analysis Form

Job Training Analysis Form

ETV-MF Project Name: ____

Basic Job Step	Potential EHS Issues	Potential Quality Issues	Training

ETV-MF Project Manager:____

Name Signature

____

Date

APPENDIX F

ETV-MF Project Training Attendance Form

Project Training Attendance Form

ETV-MF Project:___________________________________

Date Training Completed	Employee Name Last First	Training Topic	Test Score (If applic.)

ETV-MF Project Manager: _____________________________________