VR-P2MF-01-02
August 2003

Environmental Technology Verification Report

Evaluation of Davis Technologies International Corp. Industrial Wastewater Treatment Plant

Prepared by

Concurrent Technologies Corporation

Under a Cooperative Agreement with

U.S. Environmental Protection Agency

NOTICE

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FOREWORD

The Environmental Technology Verification (ETV) Program has been established by the U.S. Environmental Protection Agency (EPA) to evaluate the performance characteristics of innovative environmental technologies for any media and to report this objective information to the states, local governments, buyers, and users of environmental technology. EPA's Office of Research and Development (ORD) has established a five-year pilot program to evaluate alternative operating parameters and to determine the overall feasibility of a technology verification program. ETV began in October 1995 and will be evaluated through September 2000, at which time EPA will prepare a report to Congress containing results of the pilot program and recommendations for its future operation.

EPA's ETV Program, through the National Risk Management Research Laboratory (NRMRL), has partnered with *CTC* under the Environmental Technology Verification Program Pollution Prevention Metal Finishing Technologies (ETV-MF) Center. The ETV-MF Center, in association with the EPA's Metal Finishing Strategic Goals Program, was initiated to identify promising and innovative metal finishing pollution prevention technologies through EPA-supported performance verifications. The following report describes the verification of the performance of Davis Technologies International Corp.'s Industrial Wastewater Treatment Plant as applied at a metal finishing facility.

ACRONYM and ABBREVIATION LIST

amp	Ampere
COC	Chain of Custody
CTC	Concurrent Technologies Corporation
DAF	Dissolved Air Flotation
DOT	Department of Transportation
DTIC	Davis Technologies International Corp.
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
ETV-MF	Environmental Technology Verification Program P2 Metal Finishing Technologies
ft^2	Square Foot
gal	Gallon
gpd	Gallon per Day
gpm	Gallon per Minute
HCl	Hydrochloric Acid
HP	Horsepower
ICP-AES	Inductively Coupled Plasma – Atomic Emission Spectrometry
ID	Identification
IDL	Instrument Detection Limit
IWTP	Industrial Wastewater Treatment Plant
kg	Kilogram
kVA	Kilovolt Amp
kW	Kilowatt
kWh	Kilowatt-hour
lb	Pound
L	Liter
L/day	Liter per Day
MDL	Method Detection Limit
mg/L	Milligram per Liter
mg/kg	Milligram per Kilogram
min	Minute
mL	Milliliter
MP&M	Metal Products and Machinery
MRL	Method Reporting Limit
NA	Not Applicable
NC	Not Calculated
ND	No Data
ND	Not Detected
NR	Not Regulated
NRMRL	National Risk Management Research Laboratory
O&G	Oil and Grease
O&G (Freon)	Oil and Grease Using Freon Extraction
O&G (HEM)	Oil and Grease – n-Hexane Extractable Material
O&M	Operating and Maintenance

ACRONYM and ABBREVIATION LIST (continued)

ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
P	Percent Recovery
P2	Pollution Prevention
pH	Value used to express acidity or alkalinity
POTW	Publicly Owned Treatment Works
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QMP	Quality Management Plan
RPD	Relative Percent Difference
SR	Spiked Result
SSR	Spiked Sample Result
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
U.S.	United States

ACKNOWLEDGEMENTS

This is to acknowledge Percy Peltzer and Valerie Whitman of *CTC* for their help in preparing this document. *CTC* also acknowledges the support of all those who helped plan and implement the verification activities and prepare this report. In particular, a special thanks to George Moore, EPA ETV Center Manager, and Lauren Drees, EPA Quality Assurance Manager. *CTC* also expresses sincere gratitude to Davis Technologies International Corp., the manufacturer of the Industrial Wastewater Treatment Plant, for their participation in and support of this program. In particular, *CTC* thanks James H. Davis, President and CEO, and Geraldine L. Davis, Corporate Secretary Treasurer, of Davis Technologies International Corp. *CTC* also thanks Federal-Mogul, Inc. of Blacksburg, Virginia, for the use of their facilities and materials, and the extensive contributions of Dr. Robert Stone during the performance of this verification test.

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

Concurrent Technologies Corporation

ETV VERIFICATION STATEMENT

TECHNOLOGY TYPE:	**WASTEWATER TREATMENT**
APPLICATION:	**OILY AND METAL-BEARING WASTEWATER**
TECHNOLOGY NAME:	**DTIC Industrial Wastewater Treatment Plant**
COMPANY:	**Davis Technologies International Corp.**
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The United States Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved, cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups consisting of buyers, vendor organizations, states, and others with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are credible.

The ETV P2 Metal Finishing Technologies (ETV-MF) Program, one of seven technology areas under the ETV Program, is operated by Concurrent Technologies Corporation, in cooperation with EPA's National Risk Management Research Laboratory. The ETV-MF Program has evaluated the performance of a wastewater treatment system for processing oily, and metal bearing wastewater from metal finishing operations. This verification statement provides a summary of the test results for Davis Technologies International Corp.'s Industrial Wastewater Treatment Plant.

VERIFICATION TEST DESCRIPTION

Davis Technologies International Corp. (DTIC) Industrial Wastewater Treatment Plant (IWTP) was tested, under actual production conditions, processing metalworking and metal finishing wastewater, at Federal-Mogul, Inc., in Blacksburg, Virginia. The verification test evaluated the ability of the IWTP system to remove regulated contaminants from the wastewater.

The test plan was designed with three distinct test periods, with a different raw wastewater processed during each test run. The three wastestreams represent wastewaters from three common Metal Finishing/Metal Products and Machinery category manufacturing configurations:

- During the first test period, oily wastewater from metalworking operations (machining, forming, cleaning) was treated.
- During the second test period, metal-bearing wastewater from metal finishing was treated.
- During the third test period, a mixture of oily wastewater from metalworking and metal-bearing wastewater from metal finishing operations was treated.
- The treated effluent from the IWTP system was pumped to a storage tank and fed into the existing Federal-Mogul wastewater treatment system.

Chemical usage, electricity usage, and sludge generation data were collected to perform the cost analysis.

TECHNOLOGY DESCRIPTION

The following technology description was provided by DTIC and was not verified. The IWTP system that was tested is a mobile unit with a flow capacity of 38 to 246 liters/min (approximately 10 to 65 gallons per minute (gpm)). This system is designed to treat various types of industrial wastewaters. When used to process a combined oily and metal-bearing wastewater, the IWTP system consists of two separate processes, oil recovery and metals precipitation, and each process consists of three stages. In the first stage of oil recovery, the hydrocarbon (oil) is cracked via a pH adjustment with hydrochloric acid (HCl). The second stage is flocculation, where a proprietary polymer is added that captures the hydrocarbons in a floc. In the third stage, dissolved air is injected into the wastewater, forcing the flocculated material to the surface, where it is skimmed off and pumped to a collection tank. The metals treatment process is also conducted in three stages. In the first stage, the pH of the wastewater is adjusted using sodium hydroxide. This causes metals to precipitate in a hydroxide form. In the second stage, ferric chloride (acting as a coagulant) and a proprietary polymer are added, which causes precipitated metals to agglomerate in a dense floc. In the third stage, air is injected into the wastewater, forcing the flocculated material to the surface, where it is skimmed off and pumped to a collection tank.

VERIFICATION OF PERFORMANCE

During the first test run (oily wastewater from metalworking operations), an insufficient volume of oily wastewater was available to operate the system at its designed flow rate and this test run was cancelled.

During the second test run (metal finishing wastewater), the IWTP system was evaluated over a four-day period, during which daily composite and grab samples were collected of raw and treated wastewater. Grab samples of the recovered oil and sludge were collected on the final day of testing. The wastewater samples were analyzed for regulated pollutants in order to evaluate the ability of the IWTP system to remove these chemicals. The sludge samples were analyzed to determine their characteristics and for use in mass balance calculations.

During the third test run (metal finishing wastewater and metalworking wastewater combined), the IWTP system was evaluated over a 32-hour period, during which composite samples were collected of raw and treated wastewater at intervals of eight hours, and grab samples of oil & grease (O&G) and sulfide were collected at intervals of four hours. Grab samples of the sludges were also collected. The wastewater samples were analyzed for regulated pollutants in order to evaluate the ability of the IWTP system to remove these chemicals. The sludge samples were analyzed to determine their characteristics and for use in mass balance calculations.

Pollutant Removal Efficiency. The metals found in the raw wastewater at an average concentration of one mg/L or greater include aluminum, copper, lead, tin, and zinc. During Runs 2 and 3, the removal percentages for these five metals ranged from >75 percent to 98.9 percent. During Run 3, when a combined oily and metal-bearing wastewater was treated, the IWTP removed greater than 97.2 percent of O&G (HEM). Pollutant removal efficiency was calculated only for parameters that were found at concentrations above the detection limit in the influent for each daily set of analytical results. Also, four-day average removal efficiencies were calculated for each parameter for the two test runs. When the concentration in the treated sample was below the detection limit, the detection limit value was used as the value for determining the removal efficiency and a "greater than" sign was used in front of the removal efficiency value. The four-day average removal efficiency could not be calculated if one or more of the daily removal efficiencies could not be calculated.

Parameter	Run 2 (Metal Finishing Wastewater) Averaged Results			Run 3 (Metal Finishing and Oily Wastewater) Averaged Results		
	Raw Wastewater mg/L	Treated Wastewater mg/L	% Removal	Raw Wastewater mg/L	Treated Wastewater mg/L	% Removal
Sulfide	<1.0	<1.0	NC	<4.0	<1.0	NC
O&G (HEM)	<1.2	<1.0	NC	41.72	<1.0	>97.2
O&G (Freon)	<1.2	<1.1	NC	51.28	<1.0	>98.1
pH*	11.4	7.9	NA	6.3	7.4	NA
TDS	3665	3520	4.0	3135	3463	0.0
TSS	310	25	92.1	61	18	70.1
TOC	5.3	5.5	0.0	11.3	10.6	6.2
Aluminum	ND	ND	ND	4.24	<1.0	>75.5
Cadmium	0.014	<0.006	>49.9	<0.005	<0.005	NC
Chromium	0.070	0.021	69.7	0.073	<0.067	>8.2
Copper	49.65	2.87	94.2	29.70	1.04	96.5
Manganese	0.122	0.150	0.0	0.08	0.16	0.0
Molybdenum	<0.1	< 0.1	NC	<0.10	<0.10	NC
Nickel	0.090	<0.054	>36.7	<0.05	<0.04	NC
Lead	9.85	0.18	98.1	4.15	<0.05	>98.7
Tin	20.85	0.31	98.5	5.14	<0.10	>97.2
Zinc	89.73	17.39	80.6	34.87	8.02	77.0

* pH units
NA = Not Applicable
NC = Not Calculated
ND = No Data
TDS = Total Dissolved Solids
TOC = Total Organic Carbon
TSS = Total Suspended Solids

Table i. Averaged Pollutant Concentrations and Removal Percentages

Raw Wastewater Variability. The characteristics of the wastewater changed significantly between test runs and also within each run. A comparison of average pollutant concentrations for Runs 2 and 3 are shown in **Table ii**. Of particular significance are the differences in TDS, TSS, copper, lead, tin, and zinc. Note that the percent difference between the runs in many cases exceeds 200%.

Parameter	Raw Wastewater, Run 2, 4-Day Avg. (mg/L)	Raw Wastewater, Run 3, 4-Day Avg. (mg/L)	% Difference Run 2/Run 3 x 100%
Sulfide	<1.0	<5.2	NC
O&G (HEM)	<1.2	45.8	NC
O&G (Freon)	<1.2	55.8	NC
TDS	3665	3135	117%
TSS	310	61	508%
TOC	5.3	11.3	46.9%
Cadmium	0.014	<0.005	NC
Chromium	0.071	0.07	101%
Copper	49.2	29.5	167%
Manganese	0.122	0.08	153%
Molybdenum	<0.1	<0.1	NC
Nickel	0.090	<0.05	180%
Lead	10.0	4.1	244%
Tin	20.8	5.0	416%
Zinc	90.5	35.1	258%

NC = Not Calculated

Table ii. Comparison of Raw Wastewater From Runs 2 and 3

Ability to Meet Target Effluent Levels. Two levels of effluent quality were selected and agreed upon by all parties as target effluent concentration levels for certain pollutant parameters. The bases of these levels are the Metal Finishing Point Source Effluent Limitations (target level 1) and the proposed Metal Products and Machinery (MP&M) Point Source Effluent Limitations (target level 2). The "ideal" case would be if the treatment system could meet the more stringent target level 2. The analytical results from each day or sampling period were compared to the two target levels to determine if the IWTP achieved these effluent quality target levels. During Run 2, the target level 1 concentrations were met for all parameters except copper (Day 2) and zinc (Days 1, 2, and 4), and the target level 2 concentrations were met for all parameters except copper (Days 1, 2, 3, and 4), manganese (Days 1 and 2), lead (Days 1, 2, 3, and 4), and zinc (Days 1, 2, 3, and 4). During Run 3, the target level 1 concentrations were met for all parameters except zinc (Periods 2, 3, and 4), and the target level 2 concentrations were met for all parameters except copper (Periods 1, 2, 3, and 4), manganese (Periods 3 and 4), lead (Period 2), and zinc (Periods 1, 2, 3, and 4).

Parameter	Target Level 1	Target Level 2	Run 2[1]				Run 3[2]			
			Day 1	Day 2	Day 3	Day 4	Period 1	Period 2	Period 3	Period 4
Sulfide	**NR**	**31**	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
O&G (HEM)	**NR**	**15**	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.7	<1.0
TOC	**NR**	**87**	6	4.5	5.8	5.8	11.8	12	8.7	9.8
Cadmium	**0.69**	**0.14**	<0.005	0.012	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	**2.77**	**0.25**	0.016	0.014	0.021	0.036	0.027	0.22	0.013	<0.01
Copper	**3.38**	**0.55**	1.6	7.9	0.6	1.7	0.84	1.1	1.3	0.98
Manganese	**NR**	**0.13**	0.19	0.32	0.041	0.049	0.036	0.13	0.2	0.32
Molybdenum	**NR**	**0.79**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	**3.98**	**0.5**	0.12	0.045	<0.04	0.012	<0.04	<0.04	<0.04	<0.04
Lead	**0.69**	**0.04**	0.069	0.13	0.14	0.42	<0.05	0.067	<0.05	<0.05
Tin	**NR**	**1.4**	0.13	0.2	0.3	0.66	<0.1	<0.10	<0.1	<0.1
Zinc	**2.61**	**0.38**	36.5	24.1	2.5	3.5	2.3	9	8.6	13.7

NR = Not Regulated.
Note:[1]Run 2 consisted of four 24-hour sampling periods.
[2]Run 3 consisted of four 8-hour sampling periods.

Table iii. Average Pollutant Concentrations, mg/L

Oil Removal Efficiency. To evaluate the effectiveness of the technology, During Run 3, 61 liters (16 gal) of oil were metered into the raw wastewater to evaluate the effectiveness of the IWTP with regard to oil removal/recovery. The analytical results indicate that the IWTP removed the oil to near or below detection limits (1.0 mg/L) for all sampling periods. Oil is removed by the first process step of the IWTP. Prior to testing it was expected that the oil would be removed in a recoverable form as "free oil." However, during testing, the solid material collected from the first process step more closely resembled an oily sludge than free oil. The usability of this material as recovered oil was not verified during the test.

Energy Use. The power consumption of the IWTP is 23.55 kW under full load at maximum throughput capacity.

Cost of Operation. The following parameters were considered in the cost analysis: chemical reagents, other materials, electricity, sludge management, and oil recovery. The cost of treatment was $0.88/1000 L for Run 2 and $2.21/1000 L for Run 3. The cost is based on total volumes treated during Runs 2 and 3, which were 443,663 L and 188,163 L respectively.

SUMMARY

The raw wastewater treated during this verification contained a number of pollutants whose concentrations varied unexpectedly and suddenly during the test periods. The wastewater variability was a difficult challenge for the technology and may have impacted pollutant removal rates. Many of the pollutant concentrations in the influent to the IWTP varied by more than 200 percent between Runs 2 and 3, with the most significant differences found with TSS, lead, tin, and zinc. The polymer and ferric chloride treatment reagents were added at constant rates previously determined from bench scale testing. The changing characteristics of the raw wastewater may have resulted in non-optimal dosages being applied. The test results show that the Davis Technologies International Corp. Industrial Wastewater Treatment Plant was able to effectively remove oil from metal finishing wastewaters to near or below detection limits and meet the effluent quality target levels for O&G (HEM). However, the IWTP was not able to meet the effluent quality target levels for certain other parameters. The treated effluent parameters that were most frequently found at concentrations higher than the target levels were copper, lead and zinc. These were also the pollutants whose raw wastewater concentration varied significantly. The performance of the IWTP system may also be related to pH during treatment. For sampling periods when the pH of the IWTP effluent averaged above 9.0, the system effectively met the effluent quality target levels for all parameters, except copper and zinc.

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1.0 INTRODUCTION

The Davis Technologies International Corp. (DTIC) Industrial Wastewater Treatment Plant (IWTP) is a wastewater treatment system that can be used to process wastewaters from various types of industrial operations. The system that was tested is a mobile unit that can be leased and used on a temporary basis. Permanent systems can also be purchased and installed. The IWTP was tested by *CTC* under the U.S. Environmental Protection Agency (EPA) Environmental Technology Verification Program for P2 Metal Finishing Technologies (ETV-MF). The purpose of this report is to present the results of the verification test.

The IWTP was tested to evaluate and characterize the operation of the wastewater treatment system through measurement of various waste parameters. Testing was conducted at Federal-Mogul, Inc., in Blacksburg, Virginia. At this location, Federal-Mogul manufactures engine bearings used in automobiles, trucks, and other vehicles. The industrial operations that generate wastewater at this location include machining, metal forming, cutting, cleaning, electroplating, and other similar processes.

2.0 DESCRIPTION OF THE INDUSTRIAL WASTEWATER TREATMENT PLANT

2.1 Industrial Wastewater Treatment Plant

The IWTP system that was tested is a mobile unit with a flow capacity of 38 to 246 liters/min (approximately 10 to 65 gallons per minute (gpm)). The system is fully contained in a trailer, which can be transported to an industrial site for short- or long-term use. Photographs of the exterior and interior of the mobile system are shown in **Figures 1** and **2**. A diagram showing the layout of tanks is presented in **Figure 3**.

The IWTP system consists of two separate processes, oil recovery and metals precipitation, and each process consists of three stages. In the first stage of oil recovery, the hydrocarbon (oil) is cracked via a pH adjustment with hydrochloric acid (HCl). The second stage is flocculation, where a proprietary polymer is added that captures the hydrocarbons in a floc (small mass). In the third stage, dissolved air is injected into the wastewater, forcing the flocculated material to the surface, where it is skimmed off and pumped to a collection tank.

The metals treatment process is also conducted in three stages. In the first stage, the pH of the wastewater is adjusted using sodium hydroxide. This causes metals to precipitate in a hydroxide form. In the second stage, ferric chloride (acting as a coagulant) and a proprietary polymer are added, which causes precipitated metals to agglomerate in a dense floc. In the third stage, dissolved air is injected into the wastewater, forcing the flocculated material to the surface, where it is skimmed off and pumped to a collection tank.

Figure 1. Exterior of Mobile DTIC IWTP System Shown at DTIC Headquarters in Harrisonburg, VA

Figure 2. Interior of DTIC IWTP System Shown in Operation at an Industrial Site

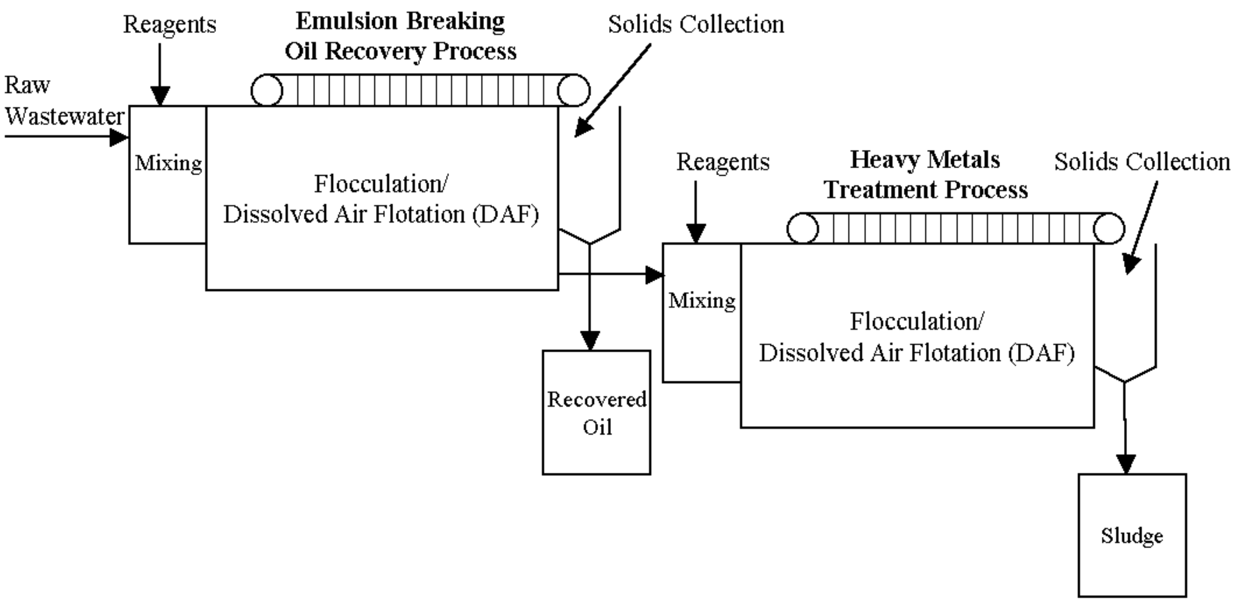

Figure 3. Diagram of DTIC IWTP System

2.2 Test Site Installation

The IWTP was tested at the Federal-Mogul Powertrain Systems plant in Blacksburg, Virginia. This plant is one of nearly 150 manufacturing facilities operated by Federal-Mogul Corporation, which is headquartered in Southfield, Michigan. Federal-Mogul Corporation is an automotive parts manufacturer providing innovative solutions and systems to global customers in the automotive, small engine, heavy-duty, and industrial markets. The company was founded in 1899. The Blacksburg facility manufactures a wide range of engine bearing products, including rod bearings, main bearings, flange bearings, and balance shaft bearings. The plant is part of Federal-Mogul's global Powertrain Systems group, which encompasses design engineering, component manufacturing, and systems delivery to meet the needs of customers worldwide. The facility also provides bimetallic bearing material to other Federal-Mogul manufacturing facilities.

At Federal-Mogul, process wastewater is generated from various manufacturing operations. These operations can be divided into two main types: (1) metal forming/machining/cleaning, and (2) metal finishing. The flow rate of wastewaters from metal forming/machining/cleaning averaged approximately 1,000 L/day (264 gallons per day (gpd)), and it contained oil (free and emulsified), which was a concern during treatment. Metal finishing wastewaters are generated from cleaning, etching, electroplating, and similar processes. The metal coating processes at present include lead electroplating, tin electroplating, copper electroplating, and zincate. The quantity of metal finishing wastewater averages approximately 680,000 L/day (180,000 gpd). It contains dissolved metals, primarily copper, lead, tin, and zinc, and a low concentration of oil.

The wastewater treatment system in use at Federal-Mogul was installed in 1982, and some changes and additions have been made since then. The present system consists of batch treatment of cyanide using chlorine gas and sodium metabisulfite, chromium reduction using sodium metabisulfite, ultrafiltration for oil removal, hydroxide precipitation of metals, clarification, and sand filtration. Wastewaters containing high concentrations of lead are segregated from other streams and are separately processed using an evaporator system. However, lead also is present in the wastestreams processed though the wastewater treatment system. Sludge generated by the treatment system is dewatered on a filter press. Treated effluent is discharged under permit to the Blacksburg sewer system.

3.0 METHODS AND PROCEDURES

3.1 Test Objectives

The overall goals of this ETV-MF project are to (1) evaluate the ability of the IWTP system to remove pollutants from metal finishing wastewater and oily metal machining/forming/cleaning wastewater using effluent quality target concentrations levels, and (2) evaluate the operating characteristics of the system with respect to approximate operating costs, effluent characteristics, oil recovery, and sludge characteristics.

The following is a summary of primary project objectives. For the installation at Federal-Mogul:

- Conduct verification testing in order to:

  1) Determine the ability of the IWTP system to remove specific pollutants from wastestreams and meet the applicable effluent quality target levels daily maximum limitations.
  2) Determine the ability of the IWTP system to recover oil from wastewater.
  3) Determine the quantity and chemical characteristics of the sludge generated by the treatment process.

- Determine the cost of operating the IWTP system for the specific conditions encountered during testing.

  1) Identify operating and maintenance (O&M) tasks.[1]
  2) Determine the quantity and cost of chemical reagents used.
  3) Determine the quantity and cost of energy consumed by operating the system.
  4) Determine the cost of sludge disposal.
  5) Determine the cost savings associated with the recovered oil.

[1] O&M tasks will be observed and documented; however, the associated costs will not be verified during this project since operation of the mobile IWTP system by DTIC staff will not be representative of a permanently installed system operated by plant personnel.

- Quantify the environmental benefit by determining the reduction in metals discharged to the Blacksburg Publicly Owned Treatment Works (POTW) and the percentage of oil recovered.

Test Mode	Test Objectives	Test Measurements
Runs 1, 2, and 3	Determine the ability of the IWTP system to remove specific pollutants from wastestreams and meet the applicable effluent quality target levels	-Source and input volumes of raw wastewater. -Chemical characteristics of the influent and effluent.
Runs 1, 2, and 3	Determine the ability of the IWTP system to recover oil from wastewater.	-Source and input volumes of raw wastewater. -O&G content of the influent and effluent. -Quantity of recovered oil. -Chemical characteristics of recovered oil.
Runs 1, 2, and 3	Determine the quantity and chemical characteristics of the sludge generated by the treatment process.	-Source and input volumes of raw wastewater. -Quantity and chemical characteristics of the sludge.
Runs 1, 2, and 3	Determine the cost of operating the IWTP system for the specific conditions encountered during testing.	-Source and input volumes of raw wastewater. -O&M labor tasks performed. -Energy use for IWTP. -Input quantity and costs of chemical treatment reagents (pounds/test run) and other materials used in treatment. -Cost of sludge disposal. -Cost savings associated with the recovered oil.
Run 3	Quantify the environmental benefit by determining the reduction in metals discharged to the Blacksburg POTW.	-Source and input volumes of raw wastewater. -Chemical characteristics of the effluent. -Historical effluent data.

Table 1. Test Objectives and Related Test Measurements Conducted During the Verification of the IWTP

3.2 Test Procedure

3.2.1 System Set-Up and Initialization Procedure

For the purpose of verification testing, a mobile IWTP was transported to the Federal-Mogul Blacksburg facility and was set up in the area of Federal-Mogul's existing wastewater treatment facilities (see **Figure 4**). This location provided good access to the wastewater sumps, which are located just outside of the building that houses the Federal-Mogul treatment equipment.

The mobile IWTP is a self-contained, fully operational system. The tanks, piping, pumps, and instrumentation are located and operate within the container (trailer). The only utility requirement is electrical service. To provide electrical power to the system, a 100-ampere (amp), 480-volt electrical service line was connected from the Federal-Mogul facility to the IWTP.

The IWTP was operated for a period of 24 hours prior to the start of the first test run. The first test run was initiated after DTIC indicated that the system was operational and stable.

3.2.2 System Operation

During testing, the IWTP was operated by DTIC. Basic procedures for system operation are contained in the test plan [Ref. 1]. DTIC was responsible for all operational aspects of the IWTP, including maintenance, settings (e.g., flow rate and pH), and chemical reagent selection and dosage rates.

During Runs 2 and 3, the IWTP was operated with a flow rate of approximately 20 gpm. During Run 2, the chemical reagents used were polymer in the oily waste recovery stage and polymer and ferric chloride in the metals precipitation stage. During Run 3, hydrochloric acid and polymer were used in the oil recovery stage, and sodium hydroxide, polymer, and ferric chloride were used in the metals precipitation stage.

It was determined after Run 2 had been completed that the raw wastewater contained a negligible quantity of oil. To be certain that a sufficient concentration of oil was present in the raw wastewater for Run 3, the oil concentration of the raw wastewater was increased by metering in a liquid that was equivalent to a spent degreasing bath used at Federal-Mogul. The liquid was prepared by combining 318 L of fresh degreasing solution and 61 L of a common rust preventative oil used at Federal-Mogul to coat parts while they are in temporary storage, waiting further processing. The oil was thoroughly mixed in a container until no floating oil was visible. The emulsified oil waste was then metered into the raw wastewater at a rate of 16 mL/min. During the third sampling period of Run 3, the metering pump was inadvertently switched off for part of that period.

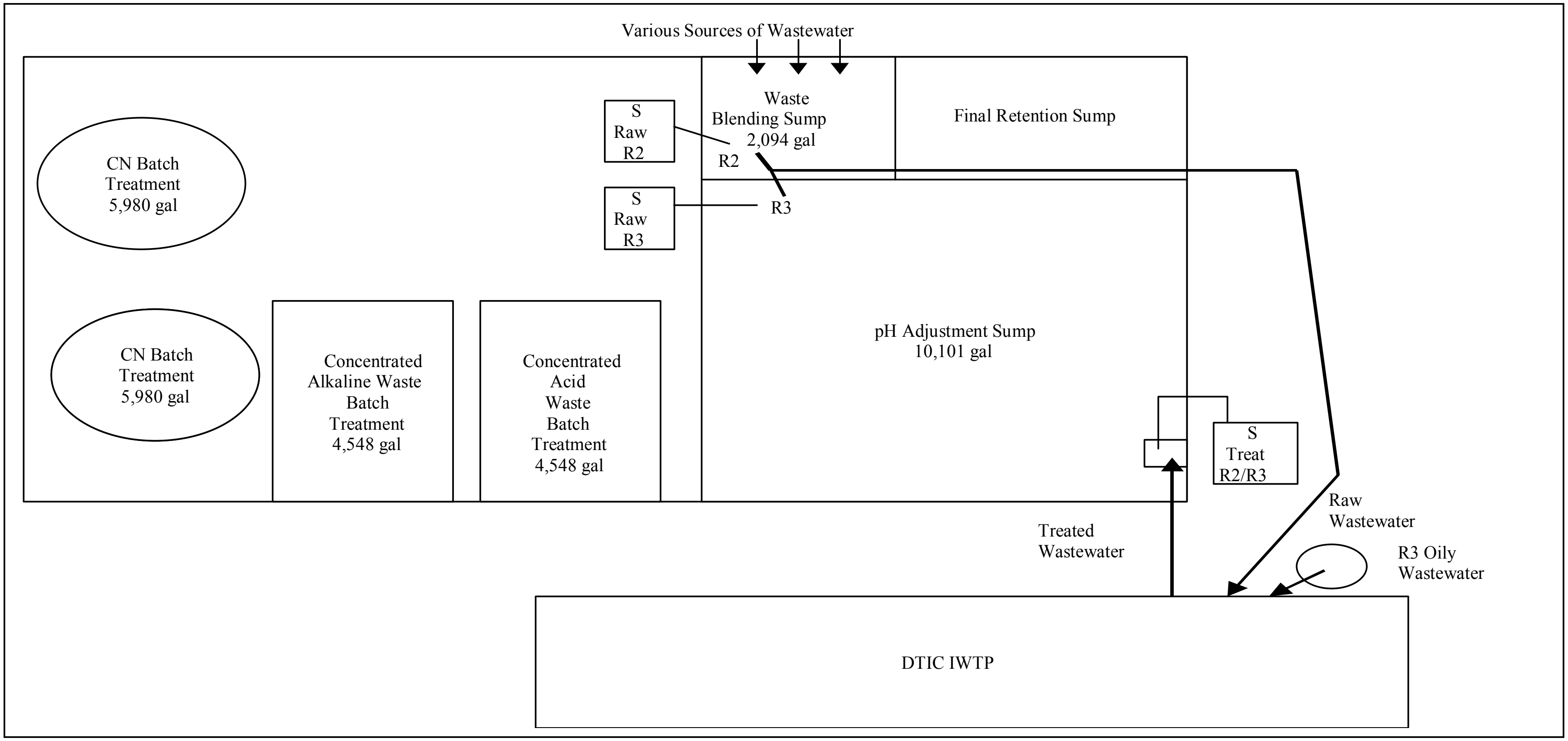

Figure 4. Diagram of DTIC IWTP Test Area

3.2.3 Testing

This verification test was originally designed to include three test runs [Ref. 1]. However, the first test run (treatment of oily wastewater from metalworking operations) was cancelled because there was an insufficient volume of oily wastewater present at the Federal-Mogul facility.

Run 2 was conducted over a period of four consecutive days, without any stoppages. During Run 2, raw wastewater was pumped from the Waste Blending Sump to the IWTP, treated, and discharged to the pH Adjustment Sump (see **Figure 4**). Samples of the raw wastewater were collected using a sampler with its intake located near the intake of the raw wastewater line. The treated wastewater line was directed into a polypropylene bucket, which overflowed into the sump. Samples of the treated wastewater were collected using a sampler with its intake located in the polypropylene bucket.

Run 3 was planned to consist of four consecutive days of testing. However, due to the need to replace a pH sensor between test runs and the infeasibility of rescheduling a full test run, it was necessary to reduce the time of testing to four 8-hr. sampling periods. The setup for Run 3 was identical to that of Run 2, with one exception. During Run 3, raw wastewater was pumped from one side of the pH Adjustment Sump to the IWTP, treated, and discharged to the opposite side of the pH Adjustment Sump. This change was implemented because of the high waste variability experienced during Run 2. Due to the large volume of the pH Adjustment Sump, there was no discernible impact on the verification test caused by this change. Samples of the raw wastewater were collected using a sampler with the intake located near the intake of the raw wastewater line.

3.2.4 Process Measurements and Information Collection

Process measurements and other information were collected to provide the following data: flow, reagent usage, recovered oil quantity, sludge quantity, electricity use, operation and maintenance activities, and historical discharge data. The methods that were used for process measurements and information collection are discussed in this section.

3.2.4.1 Wastewater Volume/Flow Rate

The volume of wastewater processed during each test run was measured using a flowmeter/totalizer (GFI 5500 series), which is installed in the IWTP system. The accuracy of the totalizer was measured during testing using a "stopwatch and bucket" method. The totalizer reading was determined to be 9.7 percent below the actual volume processed. Total flow data were adjusted to reflect this difference. The flow totalizer and instantaneous flowmeter were read at the start and end of each test run and a minimum of three times per day during each test run. The flowmeter readings and the times those readings were taken were recorded on a data collection form.

3.2.4.2 Wastewater Treatment Reagents

The quantities of treatment reagents (hydrochloric acid, ferric chloride, polymer, and sodium hydroxide) used were determined by subtracting the quantity of reagents remaining after each test run from the original quantity prior to the start of the test run.

3.2.4.3 Waste Generation Rates

The IWTP generated two types of sludges during verification testing, which, for this report, are termed oily sludge and metal sludge. The oily sludge was generated from the first stage of treatment and the metal sludge from the second stage of treatment (see **Figure 3**). Prior to testing, it was anticipated that the first stage of treatment would generate recoverable "free" oil. Due to the nature and characteristics of the wastewater treated during this verification test, the solid material from the first stage of treatment contained both oily and metal sludge. The two sludges are further discussed in section 5.5.

The quantity of sludges generated was determined on a daily basis by weighing the collection drums and subtracting from that weight the weight of the empty drums and pallet. The volume of sludge generated was also measured and recorded.

3.2.4.4 Additional Information

Other information collected during the verification test included: historical Federal-Mogul wastewater data, IWTP operational and maintenance tasks, and cost data (e.g., chemical reagents, electricity, and sludge disposal costs).

3.3 Quality Assurance/Quality Control

3.3.1 Data Entry

Sampling events, process measurements, and other data were recorded by the ETV-MF Project Manager on a pre-designed form provided in the verification test plan [Ref 1].

3.3.2 Sample Collection and Handling

Automatic composite samplers (ISCO 6700 Series) were used to collect the influent and effluent samples. The samples were collected in 2.5 gal glass containers. The composite samples were collected on a time-proportioned basis. The automatic samplers were set to collect 80 mL ± 10 mL every 15 minutes. Grab samples of the influent and effluent were collected for O&G (Freon), O&G (HEM), pH, and sulfide (as S) analyses. These grab samples were collected 4 ± 2 hours after the start of a sampling period and 4 ± 2 hours before the end of the sampling period. The automatic sampler was used to accomplish the collection of grab samples. It was used for this purpose between sampling events to avoid interfering with the collection of the composite samples.

An abbreviated sampling run using fresh water was performed to ensure the sampler was programmed to collect the correct amount of sample prior to the first test run. An equipment blank sample was collected prior to each test run. Deionized water was pumped through the automated sampler and tubing to clean the tubing and pump. After the pump and tubing were cleaned, deionized water was pumped through the sampler and was collected and analyzed for O&G (Freon), O&G (HEM), total organic carbon/compound (TOC), metals, and sulfide (as S).

Grab samples of the sludges were collected after first completely mixing the materials. Oil and sludge samples were placed into 250 mL, wide mouth glass jars.

At the time of sampling, each sample container was labeled with the date, time, and sample identification (ID) number. Samples to be analyzed at an off-site laboratory were accompanied by a chain of custody (COC) form; the ETV-MF Project Manager generated the COC form, which provided 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 were transported in coolers with packing and blue ice to the lab by two-day express service. The transport containers were secured with tape to ensure sample integrity during the delivery process to the analytical laboratory. The ETV-MF Project Manager performed sampling and labeling, and ensured that samples were properly secured and shipped per regulations under Department of Transportation (DOT) and Occupational Safety and Health Administration (OSHA) to the laboratory for analysis.

3.3.3 Project Responsibilities/Audits

Verification testing activities and sample analysis were performed according to section 6.0 of the verification test plan [Ref. 1]. There was no verification test audit conducted during the verification period for this technology.

4.0 VERIFICATION DATA

4.1 Analytical Results

A summary of analytical data is presented in **Tables 2** and **3**. Composite samples of the raw and treated wastestreams were collected for each 24-hr. (Run 2) or 8-hr. (Run 3) sampling period and analyzed for total dissolved solids (TDS), total suspended solids (TSS), TOC, pH, aluminum (Run 3 only), cadmium, chromium, copper, manganese, molybdenum, nickel, lead, tin, and zinc. Two grab samples of the raw and treated wastestreams were collected for each sampling period and analyzed for pH, sulfide, O&G (HEM) and O&G (Freon). Grab samples of the oily and metal sludges were collected once for each test run and analyzed for percent solids, percent water (oily sludge only), aluminum (Run 3 only), cadmium, chromium, copper, manganese, molybdenum, nickel, lead, tin, and zinc.

4.2 Calculation of Data Quality Indicators

Data reduction, validation, and reporting were conducted according to the verification test plan [Ref. 1] and the ETV-MF Quality Management Plan (QMP) [Ref. 2]. Calculations of data quality indicators are discussed in the following sections.

4.2.1 Precision

Precision is a measure of the agreement or repeatability of a set of replicate results obtained from duplicate analyses under identical conditions. Precision is estimated from analytical data and cannot be measured directly. To satisfy the precision objectives, the replicate analyses must agree within defined percent deviation limits, expressed as a percentage.

Relative Percent Difference (RPD) is calculated as follows:

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

where:

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

The analytical laboratories performed a total of 42 precision evaluations on aqueous samples. All of the aqueous results were within the precision limits identified in the verification test plan [Ref. 1]. There were 19 evaluations on sludge samples. On the sludge samples, there were 18 samples or 94.7 percent that were within the limits. The results of the precision calculations are summarized in **Appendix A.**

Parameter	Raw Day 1 mg/L	Treated Day 1 mg/L	Raw Day 2 mg/L	Treated Day 2 mg/L	Raw Day 3 mg/L	Treated Day 3 mg/L	Raw Day 4 mg/L	Treated Day 4 mg/L	Oily Sludge mg/kg	Metal Sludge mg/kg	Equip. Blank mg/L
Sulfide Grab 1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	NA	ND
Sulfide Grab 2	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	NA	ND
O&G (HEM) Grab 1	<1.0	<1.0	<1.0	<1.0	2.2	<1.0	1.5	<1.0	NA	NA	ND
O&G (HEM) Grab 2	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	NA	NA	ND
O&G (Freon) Grab 1	1.3	1.3	<1.0	<1.0	1.4	<1.0	<1.0	<1.0	NA	NA	ND
O&G (Freon) Grab 2	1.9	<1.0	1.5	<1.0	<1.0	<1.0	<1.0	<1.0	NA	NA	ND
pH Composite*	11.4	6.8	11.6	6.6	11.3	9.6	11.4	8.6	NA	NA	4.4
pH Grab 1*	11.6	6.2	11.5	7.7	10.5	9.5	11.7	10.1	NA	NA	ND
pH Grab 2*	11.1	5.5	11.7	6.6	11.7	6.6	11.8	8.3	NA	NA	ND
TDS	3,050	3,320	3,010	2,840	4,020	3,630	4,580	4,290	NA	NA	<10
TSS	340	7	372	14	299	24	227	53	NA	NA	<1.0
% Solids	NA	NA	NA	NA	NA	NA	NA	NA	5.4%	3.5%	ND
% Water	NA	NA	NA	NA	NA	NA	NA	NA	77.0%	ND	ND
TOC	5.4	6	5.1	4.5	5	5.8	5.8	5.8	NA	NA	<1.0
Cadmium	0.006	<0.005	0.037	0.012	0.0053	<0.005	0.0064	<0.005	<44.9	<70.8	<0.005
Chromium	0.063	0.016	0.066	0.014	0.066	0.021	0.089	0.036	141	198	<0.10
Copper	66.7	1.6	62.1	7.9	28.6	0.6	39.2	1.7	111,000	153,000	<0.025
Manganese	0.13	0.19	0.069	0.32	0.089	0.041	0.2	0.049	593	870	<0.015
Molybdenum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<89.8	<142	<0.1
Nickel	0.11	0.12	0.064	0.045	0.067	<0.04	0.12	0.012	369	518	<0.04
Lead	7.5	0.069	9.3	0.13	10.8	0.14	12.3	0.42	42,200	64,000	<0.05
Tin	24.8	0.13	23	0.2	14.5	0.3	20.9	0.66	49,400	72,300	<0.1
Zinc	74.9	36.5	111	24.1	84.4	2.5	91.6	3.5	251,000	370,000	<0.02

*pH units NA = Not Applicable ND = No Data

Table 2. Summary of Analytical Results for Run 2

Parameter	Raw Day 1 mg/L	Treated Day 1 mg/L	Raw Day 2 mg/L	Treated Day 2 mg/L	Raw Day 3 mg/L	Treated Day 3 mg/L	Raw Day 4 mg/L	Treated Day 4 mg/L	Oily Sludge mg/kg	Metal Sludge mg/kg	Equip. Blank mg/L
Sulfide Grab 1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	13.1	< 1.0	NA	NA	ND
Sulfide Grab 2	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	22.2	<1.0	NA	NA	ND
O&G (HEM) Grab 1	33.7	<1.0	<1.0	<1.0	306	<1.0	51.5	< 1.0	NA	NA	ND
O&G (HEM) Grab 2	45.6	<1.0	26.7	<1.0	16.7	2.3	148	<1.0	NA	NA	ND
O&G (Freon) Grab 1	36.7	<1.0	<1.0	<1.0	76	< 1.0	162	< 1.0	NA	NA	ND
O&G (Freon) Grab 2	23.9	<1.0	16.7	<1.0	16.0	<1.0	158	<1.0	NA	NA	ND
pH Composite*	6.3	9.1	6.3	6.9	6.4	6.8	6	6.9	NA	NA	ND
pH Grab 1*	11.1	9.5	9.6	9.8	9.6	6.5	9.6	8.6	NA	NA	ND
pH Grab 2*	9.6	9.5	9.6	6.5	9.6	7.2	9.6	8.5	NA	NA	ND
TDS	4,130	4,360	3,160	3,380	2,060	2,690	3,190	3,420	NA	NA	<10
% Solids	NA	NA	NA	NA	NA	NA	NA	NA	39.0%	1.80%	ND
% Water	NA	NA	NA	NA	NA	NA	NA	NA	62.5%	ND	ND
TSS	98	16	56	30	56	9.0	34	18	NA	NA	<1.0
TOC	14.2	11.8	9.9	12	10.7	8.7	10.5	9.8	NA	NA	1.9
Aluminum	6.9	1.9	6.2	1.4	1.6	0.39	1.7	<0.20	833	11,400	<0.20
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<6.4	<138	<0.005
Chromium	0.097	0.027	0.096	0.220	0.042	0.013	0.050	<0.010	70.4	711	<0.10
Copper	35.8	0.84	20.6	1.1	25.5	1.3	35.9	0.98	34,300	43,800	<0.025
Manganese	0.098	0.036	0.07	0.13	0.071	0.2	0.076	0.32	55.0	989	<0.015
Molybdenum	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<64.1	<1,380	<0.1
Nickel	0.075	<0.04	0.043	<0.04	<0.04	<0.04	<0.04	<0.04	<32.1	<689	<0.04
Lead	5.2	<0.05	6.0	0.067	2.9	<0.05	2.1	<0.05	4,550	4,380	<0.05
Tin	6.9	<0.1	6.7	<0.1	3.0	<0.1	3.4	<0.1	4,390	4,320	<0.1
Zinc	33.4	2.3	26.8	9.0	36.2	8.6	44	13.7	13,800	243,000	0.27

*pH units NA = Not Applicable ND = No Data

Table 3. Summary of Analytical Results for Run 3

4.2.2 Accuracy

Accuracy is a measure of the agreement between an experimental determination and the true value of the parameter being measured. Analyses with spiked samples were performed to determine percent recoveries as a means of checking method accuracy. The percent recovery, expressed as a percentage, is calculated as follows:

$$P = \left[\frac{(SSR - SR)}{SA} \right] x\ 100\%$$

where:

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

Quality Assurance (QA) objectives are satisfied for accuracy if the average recovery is within selected goals. The analytical laboratories performed 98 accuracy evaluations on aqueous samples. All results were within the limits identified in the verification test plan [Ref. 1]. There were 41 accuracy evaluations on sludge samples. On the sludge samples, there were 38 samples or 92.7 percent that were within the limits. The results of the accuracy calculations are summarized in **Appendix B.**

4.2.3 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, expressed as a percentage, is calculated using the following formula:

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

QA objectives are satisfied if the percent completeness is 90 percent or greater. All measurements made during this verification project were determined to be valid, and completeness was greater than 90 percent. Therefore, the completeness objective was satisfied.

4.2.4 Comparability

Comparability is a 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 was achieved during this verification test by the use of consistent methods during sampling and analysis, and traceability of standards to a reliable source.

4.2.5 Representativeness

Representativeness refers to the degree to which the data accurately and precisely represent the conditions or characteristics of the parameter being tested. For this verification project, one field duplicate sample was collected from each sample location and sent to the laboratory for analysis. Representativeness was calculated as an RPD of these field duplicates. There were 48 out of 49 of the liquid samples were within their RPD values. There were 11 out of the 13 oily sludge samples within their RPD values. For the metal sludge samples 5 out of the 12 samples were within their RPD values. The results of these calculations are shown in **Appendix C**.

4.2.6 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 were used for this project.

Instrument Detection Limit (IDL) is the minimum concentration that can be differentiated from instrument background noise; that is, the minimum concentration detectable by the measuring instrument.

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 sample matrix.

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. In other words, this is the lowest concentration that can be reported with confidence. The MRL for the metal sludge sample varies for each individual metal analyte and sludge sample. This is due to the percent moisture in the sludge and is calculated as follows:

Sludge MRL = Standard MRL x (100/ % Solids) x Dilution Factor

The MRLs for this verification project are shown in **Table 4**.

Critical Measurements	Matrix	Method	Reporting Units	Method of Determination	MRL
O&G (Freon)	Water	EPA 413.1	mg/L	gravimetric	1.0
O&G (HEM)	Water	EPA 1664	mg/L	gravimetric	1.0
TSS	Water	EPA 160.2	mg/L	gravimetric	40.0
TDS	Water	EPA 160.1	mg/L	gravimetric	4.0
TOC	Water	EPA 415.1	mg/L	combustion or oxidation	1.0
Metal	Water	SW-846 3005A 6010B	mg/L	ICP-AES	0.1 – 0.005*
Metal	Solid	SW-846 3050B 6010B	mg/kg	ICP-AES	28.3 – 5670*
Sulfide (as S)	Water	EPA 376.1	mg/L	titration	1.0
Sulfide (as S)	Water	EPA 376.1	mg/kg	titration	7080
pH	Water	Digital Meter	pH units	electrometric	0.1 pH unit
% Solid	Solid	EPA 160.3	%	gravimetric	0.1
% Water	Recovered oil	Karl-Fisher	%	titration	0.5

* MRL – depends on the individual metal analyte

Table 4. Laboratory Methodology Information

4.3 Process Measurements

Process measurements and other information were collected to provide the following data: flow, reagent usage, recovered oil quantity, sludge quantity, electricity use, operation and maintenance activities, and historical discharge data. The methods that were used for process measurements and information collection are discussed in section 3.2.3. Certain key process measurements are discussed in the following sections.

4.3.1 Flow Measurements

The volume of wastewater processed during each sampling period was measured using a flowmeter/totalizer. The accuracy of the totalizer was measured and the readings were adjusted accordingly. These results are presented in **Table 5**.

Test Run/Period	Dates	Time		Volume Treated Liters (gal)
		Start	Finish	
Run 2/Day 1	4/3/01 to 4/4/01	1120	1005	123,921 (32,740)
Run 2/Day 2	4/4/01 to 4/5/01	1005	1000	106,022 (28,011)
Run 2/Day 3	4/5/01 to 4/6/01	1000	1000	113,153 (29,895)
Run 2/Day 4	4/6/01 to 4/7/01	1000	0900	100,567 (26,570)
Run 2 Summary	*4/3/01 to 4/7/01*	*1120*	*0900*	*443,663 (117,216)*
Run 3/Period 1	4/26/01 to 4/27/01	1415	0015	55,086 (14,554)
Run 3/Period 2	4/27/01	0015	0815	46,196 (12,205)
Run 3/Period 3	4/27/01	0815	1615	44,186 (11,649)
Run 3/Period 4	4/27/01 to 4/28/01	1615	0015	42,994 (11,334)
Run 3 Summary	*4/26/01 to 4/28/01*	*1415*	*0015*	*188,463 (49,792)*

Table 5. Volumes of Wastewater Treated During Test Runs 2 and 3

4.3.2 Operation and Maintenance Labor

DTIC personnel operated the IWTP during verification testing. The IWTP requires an operator during startup and shutdown. The startup and shutdown procedures are summarized in the test plan [Ref. 1]. During operation, the system is self-regulating; however, for testing purposes, a DTIC operator was on-site at all times while Runs 2 and 3 were being conducted. The operational tasks performed by the DTIC operator during Runs 2 and 3 included:

- Monitoring water levels in tanks and adjusting, if necessary.
- Monitoring sludge skimmer for proper operation and adjusting, if necessary.
- Monitoring pH readings and adjusting chemical dosage, if necessary.
- Checking levels in chemical feed containers and changing feed containers, when necessary.

During Runs 2 and 3, the IWTP system was fully operational and no maintenance tasks were required.

4.3.3 Additional Information

Other key information collected at the time of the verification test is summarized in **Table 6**.

Parameter	Data
Cost of Electricity	$0.034/kWh
Cost of Sludge Disposal	$275/ton
Hydrochloric Acid	$0.27/lb
Sodium Hydroxide	$0.28/lb
Ferric Chloride	$0.24/lb
Polymer	$3.00/lb

Table 6. Additional Information Collected During Verification Test

5.0 EVALUATION OF RESULTS

5.1 Pollutant Removal Efficiency

The pollutant removal efficiency was calculated based on a comparison of influent and effluent concentrations for each pollutant parameter. Pollutant removal efficiency was calculated only for parameters that were found at concentrations above the detection limit in the influent for each daily set of analytical results.[2] Also, four-day average removal efficiencies were calculated for each parameter for the two test runs. When the concentration in the treated sample was below the detection limit, the detection limit value was used as the value for determining the removal efficiency and a "greater than" sign was used in front of the removal efficiency value. The four-day average removal efficiency could not be calculated if one or more of the daily removal efficiencies could not be calculated.

The results of the pollutant removal efficiency analysis for Run 2 are shown in **Table 7**. The average pollutant removal efficiencies are based on a four-day period (24-hour day). Percent removal was not calculated for sulfide, O&G (HEM), O&G (Freon), and molybdenum, due to the low concentration of these pollutants in the raw wastewater. Average metal pollutant removals for the remaining parameters ranged from 0.0 percent (manganese) to 98.5 percent (tin). The exact pollutant removal efficiency of cadmium and nickel are expressed as "greater than" because one or more treated samples had concentration below detection limits for those parameters. When the concentration in the raw wastewater is low, the removal efficiency for that parameter tends to be low or even zero.

The results of the pollutant removal efficiency analysis for Run 3 are shown in **Table 8**. The average pollutant removal efficiencies are based on four eight-hour periods. Percent removal was not calculated for sulfide, cadmium, molybdenum, and nickel, due to the low concentration of these pollutants in the raw wastewater. Average pollutant removals for the remaining parameters ranged from 0.0 (manganese) to 98.9 percent (lead). The exact pollutant removal efficiency of sulfide, O&G (HEM), O&G (Freon), aluminum, lead, and tin are expressed as "greater than" because one or more treated samples had concentrations below detection limits for those parameters. When the concentration in the raw wastewater is low, the removal efficiency for that parameter tends to be low or even zero.

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[2] Two grab samples per day (Run 2) or per sampling period (Run 3) were collected for the following parameters: sulfide, O&G (HEM), and O&G (Freon). The average of the two grab sample results were used to calculate pollutant removal efficiency. For all other parameters, composite samples were used.

On various days, for certain parameters, such as TOC, TDS, Cr, Mn, and Ni, treated wastewater concentrations were higher than in the raw wastewater. This cannot be explained with the available data that passed QA/QC requirements.

Parameter	Raw Day 1 mg/L	Treated Day 1 mg/L	% Removal Day 1	Raw Day 2 mg/L	Treated Day 2 mg/L	% Removal Day 2	Raw Day 3 mg/L	Treated Day 3 mg/L	% Removal Day 3	Raw Day 4 mg/L	Treated Day 4 mg/L	% Removal Day 4	Avg. 4-Day % Removal
Sulfide	<1.0	<1.0	NC	<1.0	<1.0	NC	<1.0	<1.0	NC	<1.0	<1.0	NC	NC
O&G (HEM)	<1.0	<1.0	NC	<1.0	<1.0	NC	1.6	<1.0	>37.5	1.3	<1.0	>23.1	NC
O&G (Freon)	1.6	1.2	25.5	1.3	<1.0	>23.1	1.2	<1.0	>16.7	<1.0	<1.0	NC	NC
TDS[1]	3050	3320	0.0	3010	2840	5.6	4020	3630	9.7	4580	4290	6.3	4.0
TSS	340	7	97.9	372	14	96.2	299	24	92.0	227	53	76.7	92.1
TOC[1]	5.4	6	0.0	5.1	4.5	11.8	5	5.8	0.0	5.8	5.8	0.0	0.0
Cadmium	0.006	<0.005	16.7	0.037	0.012	67.6	0.0053	<0.005	5.7	0.0064	<0.005	21.9	>49.9
Chromium	0.063	0.016	74.6	0.066	0.014	79.8	0.066	0.021	68.2	0.089	0.036	60.0	69.7
Copper	66.7	1.6	97.6	62.1	7.9	87.3	28.6	0.6	97.9	39.2	1.7	95.7	94.2
Manganese[1]	0.13	0.19	0.0	0.069	0.32	0.0	0.089	0.041	53.9	0.2	0.049	75.5	0.0
Molybdenum	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC	NC
Nickel[1]	0.11	0.12	0.0	0.064	0.045	29.7	0.067	<0.04	40.3	0.12	0.012	90.0	>36.7
Lead	7.5	0.069	99.1	9.3	0.13	98.6	10.8	0.14	98.7	12.3	0.42	96.6	98.2
Tin	24.8	0.13	99.5	23	0.2	99.1	14.5	0.3	97.9	20.9	0.66	96.8	98.5
Zinc	74.9	36.5	51.3	111	24.1	78.3	84.4	2.5	97.0	91.6	3.5	96.2	80.6

Sulfide, O&G (HEM), and O&G (Freon) are average values based on analytical results from two grab samples per day. All other values are analytical results from single one-day composite samples.
NC = Not Calculated
NA = Not Applicable
Percent removal was not calculated for the parameter where it was not detected in the raw.
The treated value for the non-detected parameter was assumed to be at detection limit.
The average 4-day percent removal is based on the mass balance [(total 4-day mass in raw minus total 4-day mass in treated) divided by total 4-day mass in raw].
If concentration in treated is greater than in raw, the percent removal is zero.
If concentration in treated is less the detection, the percent removal is greater than the value calculated using detection limit.
[1]Values in treated wastewater are higher than raw wastewater and cannot be explained with available data.

Table 7. Results of Pollutant Removal Efficiency Analysis for Run 2

Parameter	Raw Period 1 mg/L	Treated Period 1 mg/L	% Removal Period 1	Raw Period 2 mg/L	Treated Period 2 mg/L	% Removal Period 2	Raw Period 3 mg/L	Treated Period 3 mg/L	% Removal Period 3	Raw Period 4 mg/L	Treated Period 4 mg/L	% Removal Period 4	Avg. 4-Period % Removal
Sulfide	<1.0	<1.0	NC	<1.0	<1.0	NC	<1.0	<1.0	NC	17.7	<1.0	>94.4	NC
O&G (HEM)	39.7	<1.0	>97.5	13.8	<1.0	>92.8	16.7	1.7	89.8	100	<1.0	>99.0	>97.2
O&G (Freon)	30.3	<1.0	>96.7	8.9	<1.0	>88.8	16	<1.0	>93.8	160	<1.0	>99.4	>98.1
TDS[1]	4130	4360	0.0	3160	3380	0.0	2060	2690	0.0	3190	3420	0.0	0.0
TSS	98	16	83.7	56	30	46.4	56	9	83.9	34	18	47.1	70.1
TOC	14.2	11.8	16.9	9.9	12	0.0	10.7	8.7	18.7	10.5	9.8	6.7	6.2
Aluminum	6.9	1.9	72.5	6.2	1.4	77.4	1.6	0.39	75.6	1.7	<0.20	>85.7	>75.5
Cadmium	<0.005	<0.005	NC	<0.005	<0.005	NC	<0.005	<0.005	NC	<0.005	<0.005	NC	NC
Chromium[1]	0.097	0.027	72.2	0.096	0.22	0.0	0.042	0.013	69.0	0.05	<0.01	>85.7	>8.2
Copper	35.8	0.84	97.7	20.6	1.1	94.7	25.5	1.3	94.9	35.9	0.98	97.3	96.5
Manganese[1]	0.098	0.036	63.3	0.07	0.13	0.0	0.071	0.2	0.0	0.076	0.32	0.0	0.0
Molybdenum	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC	NC
Nickel	0.075	<0.04	>46.7	0.043	<0.04	>7.0	<0.04	<0.04	NC	<0.04	<0.04	NC	NC
Lead	5.2	<0.05	>99.0	6	0.067	98.9	2.9	<0.05	>98.3	2.1	<0.05	>97.6	>98.7
Tin	6.9	<0.1	>98.6	6.7	<0.10	>98.5	3	<0.1	>96.7	3.4	<0.1	>97.0	>97.2
Zinc	33.4	2.3	93.1	26.8	9	66.4	36.2	8.6	76.2	44	13.7	68.9	77.0

Sulfide, O&G (HEM), and O&G (Freon) are average values based on analytical results from two grab samples per day. All other values are analytical results from single one-day composite samples.
NC = Not Calculated
NA = Not Applicable
Percent removal was not calculated for the parameter where it was not detected in the raw.
The treated value for the non-detected parameter was assumed to be at detection limit.
The average 4-day percent removal is based on the mass balance [(total 4-day mass in raw minus total 4-day mass in treated) divided by total 4-day mass in raw].
If concentration in treated is greater than in raw, the percent removal is zero.
If concentration in treated is less the detection, the percent removal is greater than the value calculated using detection limit.
[1]Values in treated wastewater are higher than raw wastewater and cannot be explained with available data.

Table 8. Results of Pollutant Removal Efficiency Analysis for Run 3

5.2 Ability to Meet Effluent Quality Target Levels

The results from each daily set of analytical data were compared to the applicable effluent quality target levels. To meet an effluent quality target level, the analytical result must be equal to or below the corresponding daily maximum limit. The comparisons were made on a parameter-by-parameter basis for each daily (or sampling period) analysis of the effluent. The daily analyses shown for sulfide, O&G (HEM) and O&G (Freon) are average values for two grab samples.

The results of the comparison for Run 2 are shown in **Table 9**. The target level 1 limitations were met for all parameters except copper (Day 2) and zinc (Days 1, 2, and 4). The target level 2 comparison shows that limitations were not met for copper (Days 1, 2, 3, and 4), manganese (Days 1 and 2), lead (Days 1, 2, 3, and 4), and zinc (Days 1, 2, 3, and 4).

The results of the comparison for Run 3 are shown in **Table 10**. The target level 1 limitations were met for all parameters except for zinc (Periods 2, 3, and 4). The target level 2 comparison shows that limitations were not met for copper (Periods 1, 2, 3, and 4), manganese (Periods 3 and 4), lead (Period 2), and zinc (Periods 1, 2, 3, and 4).

Parameter	Target Level 1	Target Level 2	Raw Day 1 mg/L	Treated Day 1 mg/L	Target Level 1 Yes/No	Target Level 2 Yes/No	Raw Day 2 mg/L	Treated Day 2 mg/L	Target Level 1 Yes/No	Target Level 2 Yes/No	Raw Day 3 mg/L	Treated Day 3 mg/L	Target Level 1 Yes/No	Target Level 2 Yes/No	Raw Day 4 mg/L	Treated Day 4 mg/L	Target Level 1 Yes/No	Target Level 2 Yes/No
Sulfide	**NR**	**31**	<1.0	<1.0	NR	Yes	<1.0	<1.0	NR	Yes	<1.0	<1.0	NR	Yes	<1.0	<1.0	NR	Yes
O&G (HEM)	**NR**	**15**	<1.0	<1.0	NR	Yes	<1.0	<1.0	NR	Yes	<1.6	<1.0	NR	Yes	<1.3	<1.0	NR	Yes
TOC	**NR**	**87**	5.4	6	NR	Yes	5.1	4.5	NR	Yes	5	5.8	NR	Yes	5.8	5.8	NR	Yes
Cadmium	**0.69**	**0.14**	0.006	<0.005	Yes	Yes	0.037	0.012	Yes	Yes	0.005	<0.005	Yes	Yes	0.006	<0.005	Yes	Yes
Chromium	**2.77**	**0.25**	0.063	0.016	Yes	Yes	0.066	0.014	Yes	Yes	0.066	0.021	Yes	Yes	0.089	0.036	Yes	Yes
Copper	**3.38**	**0.55**	66.7	1.6	Yes	No	62.1	7.9	No	No	28.6	0.6	Yes	No	39.2	1.7	Yes	No
Manganese	**NR**	**0.13**	0.13	0.19	NR	No	0.069	0.32	NR	No	0.089	0.041	NR	Yes	0.2	0.049	NR	Yes
Molybdenum	**NR**	**0.79**	<0.1	<0.1	NR	Yes	<0.1	<0.1	NR	Yes	<0.1	<0.1	NR	Yes	<0.1	<0.1	NR	Yes
Nickel	**3.98**	**0.5**	0.11	0.12	Yes	Yes	0.064	0.045	Yes	Yes	0.067	<0.04	Yes	Yes	0.12	0.012	Yes	Yes
Lead	**0.69**	**0.04**	7.5	0.069	Yes	No	9.3	0.13	Yes	No	10.8	0.14	Yes	No	12.3	0.42	Yes	No
Tin	**NR**	**1.4**	24.8	0.13	NR	Yes	23	0.2	NR	Yes	14.5	0.3	NR	Yes	20.9	0.66	NR	Yes
Zinc	**2.61**	**0.38**	74.9	36.5	No	No	111	24.1	No	No	84.4	2.5	Yes	No	91.6	3.5	No	No

Sulfide and O&G (HEM) are average values based on analytical results from two grab samples per day. All other values are analytical results from single one-day composite samples.

NR = Not Regulated

Table 9. Target Level Comparison Analysis for Run 2

Parameter	Target Level 1	Target Level 2	Raw Period 1 mg/L	Treated Period 1 mg/L	Target Level 1 Yes/No	Target Level 2 Yes/No	Raw Period 2 mg/L	Treated Period 2 mg/L	Target Level 1 Yes/No	Target Level 2 Yes/No	Raw Period 3 mg/L	Treated Period 3 mg/L	Target Level 1 Yes/No	Target Level 2 Yes/No	Raw Period 4 mg/L	Treated Period 4 mg/L	Target Level 1 Yes/No	Target Level 2 Yes/No
Sulfide	**NR**	**31**	<1.0	<1.0	NR	Yes	<1.0	<1.0	NR	Yes	<1.0	<1.0	NR	Yes	17.7	<1.0	NR	Yes
O& G (HEM)	**NR**	**15**	39.7	<1.0	NR	Yes	13.8	<1.0	NR	Yes	16.7	<1.7	NR	Yes	100	<1.0	NR	Yes
TOC	**NR**	**87**	14.2	11.8	NR	Yes	9.9	12	NR	Yes	10.7	8.7	NR	Yes	10.5	9.8	NR	Yes
Cadmium	**0.69**	**0.14**	<0.005	<0.005	Yes	Yes	<0.005	<0.005	Yes	Yes	<0.005	<0.005	Yes	Yes	<0.005	<0.005	Yes	Yes
Chromium	**2.77**	**0.25**	0.097	0.027	Yes	Yes	0.096	0.22	Yes	Yes	0.042	0.013	Yes	Yes	0.05	<0.01	Yes	Yes
Copper	**3.38**	**0.55**	35.8	0.84	Yes	No	20.6	1.1	Yes	No	25.5	1.3	Yes	No	35.9	0.98	Yes	No
Manganese	**NR**	**0.13**	0.098	0.036	NR	Yes	0.07	0.13	NR	Yes	0.071	0.2	NR	No	0.076	0.32	NR	No
Molybdenum	**NR**	**0.79**	<0.1	<0.1	NR	Yes	<0.1	<0.1	NR	Yes	<0.1	<0.1	NR	Yes	<0.1	<0.1	NR	Yes
Nickel	**3.98**	**0.5**	0.075	<0.04	Yes	Yes	0.043	<0.04	Yes	Yes	<0.04	<0.04	Yes	Yes	<0.04	<0.04	Yes	Yes
Lead	**0.69**	**0.04**	5.2	<0.05	Yes	Yes	6	0.067	Yes	No	2.9	<0.05	Yes	Yes	2.1	<0.05	Yes	Yes
Tin	**NR**	**1.4**	6.9	<0.1	NR	Yes	6.7	<0.10	NR	Yes	3	<0.1	NR	Yes	3.4	<0.1	NR	Yes
Zinc	**2.61**	**0.38**	33.4	2.3	Yes	No	26.8	9	No	No	36.2	8.6	No	No	44	13.7	No	No

Sulfide and O&G (HEM) are average values based on analytical results from two grab samples per 8-hr. sampling period. All other values are analytical results from single 8-hr. composite samples.
NR = Not Regulated

Table 10. Target Level Comparison Analysis for Run 3

The residual concentrations of copper and zinc in the treated wastewater appear to be related to pH during treatment. **Figure 5** shows that the relationship of pH and metal hydroxides solubilities in water. These figures indicate that the optimal pH for copper and zinc removal is greater than 9.0. **Table 2**, shows only one treated composite sample from Run 2 (Day 3) and in **Table 3** one composite treated sample from Run 3 (Period 1) had a pH of greater than 9.0. On those two days the treated wastewater came the closest to meeting target level 1 and target level 2 as shown in **Table 9** and **Table 10**.

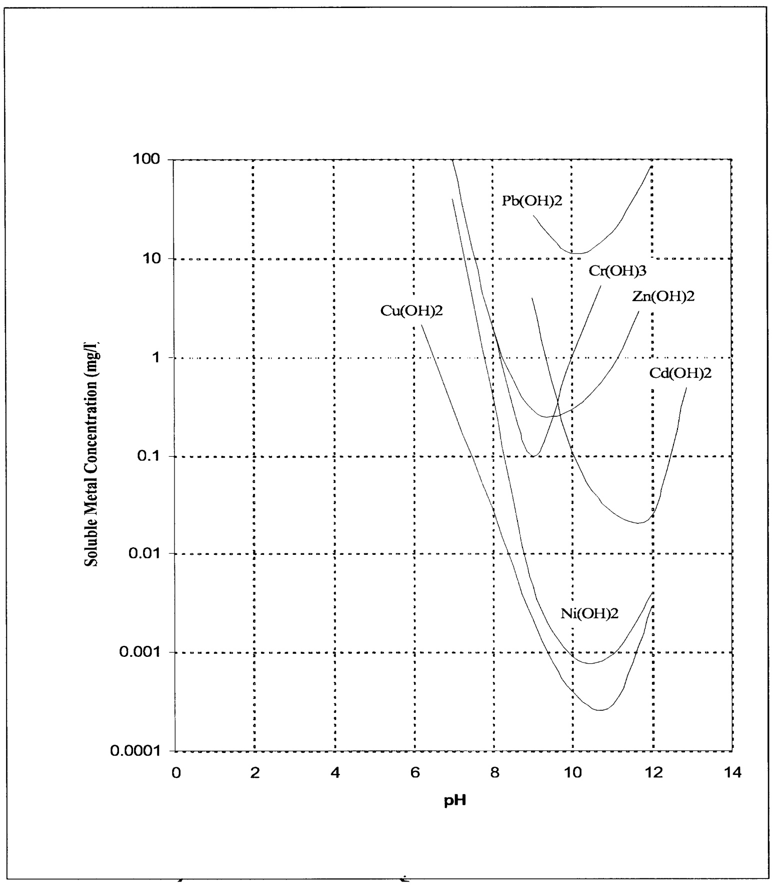

Figure 5. Effect of pH on Metal Hydroxide Concentration in Water

5.3 Mass Balance

Mass balance calculations were performed for the metals parameters for Runs 2 and 3. These results are used as an indicator of the accuracy of the verification test. The mass balance criterion is satisfied when the mass balance is within the range of 75 percent to 125 percent. The equation for the zinc mass balance is shown below. Other mass balance equations are similar.

$$\text{Mass Balance (\%)} = \left[\sum_{i=1}^{4}\left(Z_{i,E}V_i\right) + Z_O V_O + Z_M V_M\right] X100\% / \left[\sum_{i=1}^{4}\left(Z_{i,I}V_i\right)\right]$$

where:

Z_E = avg. effluent zinc concentration for day run (mg/L)
V_i = influent volume processed during the day run (liters)
Z_0 = oily sludge zinc concentration (mg/kg)
V_0 = oily sludge quantity processed during the test run (kg)
Z_M = metal sludge zinc concentration (mg/kg)
V_M = Metal sludge quantity processed during the list runs (kg)
Z_I = avg. influent zinc concentration for day run (mg/L)

The results of the mass balance calculations for Run 2 are shown in **Table 11**. The mass balance results for the four metals found at average concentrations above 1.0 mg/L in the raw wastewater are:

- Copper: 104.6 percent
- Lead: 202.5 percent
- Tin: 110.1 percent
- Zinc: 148.2 percent

Two of these metals (copper and tin) are within the range of the mass balance criteria (75 percent to 125 percent) and two metals (lead and zinc) are outside of that range. The overall mass balance calculation for the nine metals parameters is 134.0 percent. Mass balance percentages outside of the mass balance criteria range could be indicative of difficulty obtaining representative sludge samples. The oily and metal sludge samples were collected during only one day (Day 4). Therefore, the sludge samples may not be representative of the sludge generated over the four-day sampling period. A large amount of sludge was generated by high metal loading in the incoming wastestream, making it difficult to obtain a representative sample. This could explain the poor representativeness results from the sludge sample as shown in **Appendix C**. The accuracy of the mass balance calculation is dependent on the percent solids analytical measurement. For example, the percent solids content of the metal sludge sample was measured to be 3.5 percent. If the percent solids content of the metal sludge was 3.0 percent, the mass balance result would be 125 percent, which is within the criteria (75 percent to 125 percent). Since the metal sludge had a high percentage of water, it separated into solid and liquid phases immediately after it was generated which also made it difficult to collect a representative sample.

The results of the mass balance calculations for Run 3 are shown in **Table 12**. The mass balance results for the five metals found at average concentrations above 1.0 mg/L in the raw wastewater are:

- Aluminum: 52.4 percent
- Copper: 65.7 percent
- Lead: 57.8 percent
- Tin: 46.1 percent
- Zinc: 90.0 percent

The mass balance results for all five of these metals are below 100 percent. One of these metals (zinc) is within the range of the mass balance criteria (75 percent to 125 percent) and four metals (aluminum, copper, tin, and lead) are outside of that range. Mass balance percentages outside of the mass balance criteria range could be indicative of difficulty obtaining representative sludge samples. The overall mass balance calculation for the ten metals parameters is 75.1 percent. This value is within the range of the mass balance criteria (75 percent to 125 percent).

Parameter	Raw, g	Treated, g	Oily Sludge, g	Metal Sludge, g	Sludges Plus Treated, g	Mass Bal, %
Cadmium	5.91	2.96	ND	2.01	4.97	84.1
Chromium	31.22	9.46	10.93	17.03	37.42	119.9
Copper	22027.9	1,274.7	8607.4	13,156.2	23,038.3	104.6
Manganese	53.61	67.0	46.0	2.4	115.5	215.4
Molybdenum	ND	ND	ND	ND	NC	NC
Nickel	40.07	25.37	28.61	44.54	98.5	245.9
Lead	4,374.4	80.4	3,272.4	5,503.2	8,856	202.5
Tin	9,254.3	137.6	3,830.7	6,216.9	10,185.2	110.1
Zinc	39,812.1	7,713.1	19463.5	31,815.6	58992.2	148.2
All Metals (9)	75,599.6	9,310.7	35259.5	56,757.9	101328.1	134.0

ND = Not Detected NC = Not Calculated

[1]Mass balance percentages outside of the criteria range (75-125%) indicated difficulty obtaining representative sludge samples

Table 11. Results of Mass Balance Analysis for Run 2

Parameter	Raw, g	Treated, g	Oily Sludge, g	Metal Sludge, g	Sludges Plus Treated, g	Mass Bal, %[1]
Aluminum	797.1	195.1	70.2	151.6	4016.9	52.36
Cadmium	ND	ND	ND	ND	NC	NC
Chromium	13.8	12.7	5.9	9.5	28.0	203.6
Copper	5,588.2	196.4	2,890.2	582.6	3,669.2	65.7
Manganese	15.0	30.5	4.6	13.2	48.3	321.6
Molybdenum	ND	ND	ND	ND	NC	NC
Nickel	6.1	ND	1.6	3.5	5.8	84.7
Lead	781.6	10.2	383.4	58.3	451.9	57.8
Tin	967.7	18.8	369.9	57.5	446.2	46.1
Zinc	6,561.6	1,508.6	1,162.8	3,232.4	5,903.8	90.0
All Metals (10)	14,731.2	1976.3	4,888.7	4,110.1	11,063.2	75.1

ND = Not Detected NC = Not Calculated

[1]Mass balance percentages outside of the criteria range (75-125%) indicated difficulty obtaining representative sludge samples

Table 12. Results of Mass Balance Analysis for Run 3

5.4 Raw Wastewater Variability

The characteristics of the wastewater changed significantly between test runs and also within each run. The wastewater processed during Run 2 was a combination of wastewater generated by the normal operation of the manufacturing facility, plus wastewater that was pumped from a temporary storage tank. The stored wastewater apparently contained a significantly higher level of TDS, TSS, and certain metals than the wastewater generated by the normal manufacturing processes. The wastewater processed during Run 3 was a mixture of oily wastewater from metalworking and metal bearing wastewater from metal finishing operations. A comparison of average pollutant concentrations for Runs 2 and 3 are shown in **Table 13**. Of particular significance are the differences in TDS, TSS, copper, lead, tin, and zinc. Note that the percent difference between the runs in many cases exceeds 200%. The appearance of O&G in Run 3 was caused by the addition of an oil-bearing solution as described in section 3.2.2.

Parameter	Raw Wastewater, Run 2, 4-Day Avg. (mg/L)	Raw Wastewater, Run 3, 4-Day Avg. (mg/L)	% Difference Run 2/Run 3 x 100%
Sulfide	<1.0	<5.2	NC
O&G (HEM)	<1.2	45.8	NC
O&G (Freon)	<1.2	55.8	NC
TDS	3665	3135	117%
TSS	310	61	508%
TOC	5.3	11.3	46.9%
Cadmium	0.014	<0.005	NC
Chromium	0.071	0.07	101%
Copper	49.2	29.5	167%
Manganese	0.122	0.08	153%
Molybdenum	<0.1	<0.1	NC
Nickel	0.090	<0.05	180%
Lead	10.0	4.1	244%
Tin	20.8	5.0	416%
Zinc	90.5	35.1	258%

NC = Not Calculated

Table 13. Comparison of Raw Wastewater from Runs 2 and 3

Wastewater variability was also examined during Run 3 by collecting four grab samples of the raw wastewater one to two hours apart during the third sampling period. The analytical results are presented in **Table 14**. The most significant variability occurs with copper and zinc. Over a five-hour period, the copper concentration ranged from 3.8 mg/L to 48.1 mg/L and the zinc concentration ranged from 25.2 mg/L to 47.2 mg/L. Hour to hour variability of the raw wastewater appears to be caused by the discharge of the cyanide batch treatment tank (containing copper) into the Waste Blending Sump, which subsequently flows into the pH Adjustment Sump, where the raw samples were collected during Run 3. The cause of zinc variability was not determined.

Metal Parameter	0830 Hrs. mg/L	0930 Hrs. mg/L	1130 Hrs. mg/L	1330 Hrs. mg/L	Range mg/L	Percent Variability
Aluminum	1.4	1.8	1.9	1.5	1.4 to 1.9	26.32
Cadmium	<0.005	<0.005	<0.005	<0.005	NC	NC
Chromium	0.052	0.057	0.047	0.043	0.043 to 0.057	24.56
Copper	48.1	29.4	6.8	3.8	3.8 to 48.1	92.10
Manganese	0.054	0.067	0.097	0.074	0.054 to 0.097	44.33
Molybdenum	<0.10	<0.10	<0.10	<0.10	NC	NC
Nickel	0.023	0.031	0.042	0.035	0.023 to 0.042	41.86
Lead	0.93	2.8	4.5	5.3	0.93 to 5.3	82.45
Tin	3.6	4.7	6.8	7.3	3.6 to 7.3	50.68
Zinc	25.2	33.1	47.2	44.8	25.2 to 47.2	46.61

NC = Not Calculated

Table 14. Variability of Metals in Raw Wastewater During Run 3, Sampling Period 3

The raw wastewater pollutant concentration variability may have impacted pollutant removal. The polymer and ferric chloride treatment reagents were added at constant rates previously determined from bench scale testing. The sudden and unexpected raw wastewater concentration variability may have resulted in non-optimal dosages being applied. In addition, as described in section 5.2, the pH was not controlled to a level that provides optimum metals removal. Note that the pollutants that varied the most (copper, lead and zinc) were the most difficult to remove below their respective target levels 1 and 2 (**Tables 9** and **10**).

5.5 Waste Generation Analysis

Oily and metal sludges (see **Figure 6**) were collected into drums during Test Runs 2 and 3. On a daily basis, the drums were weighed and the net weight of the sludge was calculated.[3] The volume of sludge generated was also measured and recorded. Samples of the metal sludge were analyzed for percent solids and metal content. Samples of the oily sludge were analyzed for percent solids, percent water, and metal content. Sludge generation data and the results of the percent solids analyses are shown in **Table 15**. Sludge analytical data (metals) are shown in **Tables 2** and **3**.

Figure 6. Photograph of Oily and Metal Sludges Generated During Verification Test, Run 3

[3] Run 3 was conducted for a time period of 32 hours. The quantity of sludge generated was measured only once for that test run, after completion of the test run.

Type of Sludge	Run 2				Run 3			
	Volume, Liters	Weight, kg	% Solids	Dry Wt, kg	Volume, Liters	Weight, kg	% Solids	Dry Wt, kg
Oily Sludge	1,310	1,436	5.6%	80.4	196	216	39%	84.2
Metal Sludge	2,328	2,456	3.5%	86.0	701	740	1.8%	13.3

Table 15. Sludge Generation During Runs 2 and 3

The sludge generation rate, on a dry weight basis, during Run 2 was:

- 0.18 kg of oily sludge/1000 L of wastewater treated
- 0.19 kg of metal sludge/1000 L of wastewater treated
- 0.37 kg of oily and metal sludge/1000 L of wastewater treated

The sludge generation rate, on a dry weight basis, during Run 3 was:

- 0.45 kg of oily sludge/1000 L of wastewater treated
- 0.07 kg of metal sludge/1000 L of wastewater treated
- 0.52 kg of oily and metal sludge/1000 L of wastewater treated

5.6 Oil Removal/Recovery Efficiency

During Run 3, the oil concentration of the raw wastewater was increased by metering in a liquid that was equivalent to a spent degreasing bath used at Federal-Mogul. The liquid was prepared by combining 318 L of fresh degreasing solution and 61 L of a common rust preventative oil used at Federal-Mogul to coat parts while they are in temporary storage, waiting further processing. The oil was thoroughly mixed in a container until no floating oil was visible. All of the emulsified oil waste was then metered into the raw wastewater at an average rate of 32 mL/min. During the third sampling period of Run 3, the metering pump was inadvertently switched off for part of that period, requiring that a dosage rate higher than 32 mL/min be added for the remainder of the test.

Oil removal is accomplished in the first process step of the IWTP. This process consists of three stages. In the first stage of oil recovery, the hydrocarbon (oil) is cracked via a pH adjustment with HCl. The second stage is flocculation, where a proprietary polymer is added that captures the hydrocarbons in a floc. In the third stage, dissolved air is injected into the wastewater, forcing the flocculated material to the surface, where it is skimmed off and pumped to a collection tank (see **Figure 7**). Prior to testing, it was expected that the oil would be removed in a recoverable form as "free oil." However, during testing, the solid material collected from the first process more closely resembled an oily sludge than free oil. The analytical results of material show that it contains a high concentration of zinc and copper (see **Table 11**). The usability of this material as recovered oil was not verified during the test.

Grab samples of the raw and treated wastewaters were collected approximately every 4 hours and analyzed for O&G (HEM). These analytical results are shown in **Table 3**. Assuming the specific gravity of oil is 1.0, the expected average concentration of oil in the raw wastewater would be 324 mg/L. This is based on adding 61 L of oil to the volume of raw wastewater treated during Run 3 (188,084 L). The O&G analytical measurements of the raw wastewater are lower than the expected concentration of oil (highest measured O&G concentration was 306 mg/L). This may have been caused by the difficulty of collecting a representative grab sample from the point where the waste oil was mixed with the raw wastewater.

The analytical results in **Table 8** indicate that the IWTP effectively removed the O&G down to the analytical method reporting limit of 1.0 mg/L.

Figure 7. Photograph of Oily Sludge Skimmer

5.7 Energy Use

The only form of energy used by the IWTP is electricity. Electricity requirements were calculated by summing the total quantity of horsepower (HP) hours and dividing by 1.341 HP-hr/kWh to arrive at electricity needs (**Table 16**).

The power consumption of the IWTP is about 23.55 kW under full load at maximum throughput capacity.

IWTP Component	Power
DAF Pumps 2 @10 HP each	20 HP
Mixers 4 @ ½ HP each	2 HP
Pumps 3 @ 1 HP each	3 HP
Skimmer Motor 1 @ 1 HP	1 HP
Metering Pumps 3 @ 0.13 HP each	0.39 HP
Metering Pump 1 @ ½ HP	1/2 HP
Sludge Pumps 2 @ ½ HP each	1 HP
Polymer Unit 1 HP	1 HP
Lighting 2000 Watts Max (746 watts per HP)	2.68 HP
Total Power Load	31.57 HP
Total Power in Kilowatts	23.55 kW

Table 16. Power Consumption of the IWTP at Maximum Load

Also, electricity use was measured using an electrical instrument over a time period of 22.25 hours on April 9, 2001. The power monitoring showed an average of 29 amps. This is equivalent to 24.4 kVA:

(480 VAC 3-Phase x 29 amps x 1.73)/1000 = 24.4 kVA

5.8 Cost Analysis

This analysis determines the operating cost of the IWTP system considering the following cost parameters: chemical reagents, other materials (e.g., filters), electricity, sludge disposal, and oil disposal. Costs were calculated separately for each cost parameter for each 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 each test run were calculated by summing the individual cost elements. The calculation of treatment cost for Run 2 is shown in **Table 17**.

Cost Parameter	Unit Cost	Run 2		Run 3	
		Cost per 1000 L Treated	Cost for Test Run 2	Cost per 1000 L Treated	Cost for Test Run 3
Chemical Reagents					
hydrochloric acid	$0.27/lb	$0.00	$0.00	$0.194	$36.56
ferric chloride	$0.24/lb	$0.400	$177.46	$0.455	$85.77
sodium hydroxide	$0.28/lb	$0.00	$0.00	$0.473	$89.16
polymer	$3.00/lb	$0.036	$15.97	$0.014	$2.64
Electricity	$0.034/kWh	$0.17	$76.87	$0.17	$32.05
Sludge Disposal*	$275/ton	$0.144	$63.88	$0.053	$9.99
Oil Disposal	$275/ton	$0.129	$57.04	$0.340	$64.15
Totals		$0.879	$391.22	$2.209	$320.32

* Cost based on dewatering to 40 percent using a filter press.

Table 17. IWTP Cost Analysis

5.9 Environmental Benefit

The results of the environmental benefit analysis are presented in **Table 18**. This analysis quantifies the environmental benefit of the IWTP technology for Run 3.[4] Using historical data provided by Federal-Mogul, the concentration of pollutants in the effluent from the existing Federal-Mogul treatment system was calculated (average of seven months of data). These values were converted to kilograms per year discharged for each pollutant parameter using historical flow rate data. These values have been compared to the projected performance of the IWTP by using the analytical results of verification testing[5] and the same historical flow rate data.

This analysis indicates that the extrapolated IWTP results are lower than current discharges for O&G, nickel, and lead, higher for chromium, copper, and zinc, and unchanged for cadmium.

Parameter	Historical Federal-Mogul Results		Projected IWTP Results		Projected IWTP Reduction, kg*
	Avg. Conc., mg/L	Avg. Mass Discharge, kg*	Avg. Conc., mg/L	Avg. Mass Discharge, kg*	
O&G(Freon)	82.14	5,011	<1.0	264	4,747
Cadmium	0.004	1	<0.005	1	0
Chromium	0.045	12	<0.068	18	-6
Copper	0.699	184	1.0	264	-80
Nickel	0.07	18	<0.04	11	7
Lead	0.466	123	<0.05	13	110
Zinc	1.05	277	8.0	2,110	-1,833
Total Projected Reduction					2,945

*Based on annual volume of 263,747,000 liters.

Table 18. Projected Reduction of Pollutants at Federal-Mogul Using IWTP

Another aspect of the environmental benefit analysis is the determination of the percentage of oil recovered during Run 3. Oil recovery percentage was calculated to be greater than 97.2 percent (see section 5.6).

[4] The influent wastewater during Run 3 closely resembles the actual treatment system influent at Federal-Mogul. Runs 1 and 2 are not representative of the influent at Federal-Mogul and therefore will not be evaluated under this particular analysis.

[5] Historical effluent data are only available for certain parameters. Therefore, this environmental benefit analysis is limited to a comparison of those parameters only.

6.0 REFERENCES

1. Concurrent Technologies Corporation, "*Environmental Technology Verification Program for Metal Finishing Pollution Prevention Technologies Verification Test Plan, Evaluation of Davis Technologies International Corp. Industrial Wastewater Treatment Plant for the Metal Finishing Industry*," March 1, 2001.

2. Concurrent Technologies Corporation, "*Environmental Technology Verification Program Metal Finishing Technologies Quality Management Plan*," Revision 1, March 26, 2001.

3. EPA, *"Development Document for the Final Effluent Limitations Guidelines and Standards for the Landfills Point Source Category,"* 2000.

APPENDIX A

PRECISION CALCULATIONS

PRECISION CALCULATIONS

Laboratory ID	*CTC Id*	Parameter	Units	Sample + Spike Value	Duplicate + Spike Value	RPD %	RPD % Limits	RPD Met ? Y/N
B1D060158-008	R2-D1-R-C	pH	NA	11.4	11.4	0.0	<20	Y
B1D280109-002	R3-D2-T-C	pH	NA	6.9	6.9	0.0	<20	Y
B1D030121-011	R3-D3-T-C-Dup	pH	NA	6.9	6.9	0.0	<20	Y
B1D060158-014	R2-D1-T-C	TDS	mg/L	2820	2800	1.0	<10	Y
B1D110112-012	R2-D4-R-C	TDS	mg/L	4290	4209	0.1	<10	Y
B1D280109-018	R3-D1-R-C	TDS	mg/L	4130	4110	0.7	<10	Y
B1D030121-007	R3-D3-T-C	TDS	mg/L	2690	2680	0.2	<10	Y
B1D060158-014	R2-D1-T-C	TSS	mg/L	15.0	16.0	6.5	<15	Y
B1D110112-012	R2-D4-R-C	TSS	mg/L	53.0	51.0	3.8	<15	Y
B1D280109-022	R3-D3-R-C	TSS	mg/L	54.0	58.0	7.1	<15	Y
B1D030121-007	R3-D3-T-C	TSS	mg/L	9.0	10.	11.0	<15	Y
B1D110112-016	M1 Sludge	Sp. Gravity	NA	1.2	1.2	0.1	<20	Y
NA = Not Applicable								
Laboratory ID	***CTC Id***	**Parameter**	**Units**	**Sample + Spike Value**	**Duplicate + Spike Value**	**RPD %**	**RPD % Limits**	**RPD Met ? Y/N**
BID060158-011	R2-D2-T-G1	O&G (HEM)	mg/L	8.80	9.20	4.4	<30	Y
BID060158-011	R2-D2-T-G1	O&G (Freon)	mg/L	9.80	10.00	2.0	<30	Y
B1D110112-001	R2-D3-R-G1	O&G (HEM)	mg/L	8.40	8.20	2.4	<30	Y
B1D110112-001	R2-D3-R-G1	O&G (Freon)	mg/L	9.80	9.90	1.0	<30	Y
B1D280109-008	R3-D3-R-G2	O&G (HEM)	mg/L	9.60	9.50	1.0	<30	Y
B1D280109-008	R3-D3-R-G2	O&G (Freon)	mg/L	9.80	9.00	8.5	<30	Y
B1D280109-001	R3-D3-T-G1	O&G (HEM)	mg/L	9.60	9.50	1.0	<30	Y
B1D280109-001	R3-D3-T-G1	O&G (Freon)	mg/L	9.00	8.80	2.2	<30	Y
B1D280109-001	R3-D3-T-G1	Total Sulfide	mg/L	18.9	18.9	0.0	<10	Y
B1D280109-008	R3-D3-R-G2	Total Sulfide	mg/L	19.2	19.1	0.5	<10	Y
B1D280109-010	R3-D3-T-G2	Total Sulfide	mg/L	19.2	19.2	0.0	<10	Y
BID060158-013	R2-D2-T-C	Metal Cadmium	mg/L	0.568	0.588	1.0	<10	Y
BID060158-013	R2-D2-T-C	Metal Chromium	mg/L	0.538	0.538	0.0	<11	Y
BID060158-013	R2-D2-T-C	Metal Lead	mg/L	0.677	0.701	3.5	<10	Y
BID060158-013	R2-D2-T-C	Metal Manganese	mg/L	0.839	0.873	7.7	<10	Y
BID060158-013	R2-D2-T-C	Metal Molybdenum	mg/L	0.533	0.500	4.9	<10	Y
BID060158-013	R2-D2-T-C	Metal Nickel	mg/L	0.576	0.596	3.4	<11	Y
BID060158-013	R2-D2-T-C	Metal Tin	mg/L	0.728	0.749	2.8	<10	Y
B1D110112-005	R2-D3-R-C	Metal Cadmium	mg/L	0.557	0.553	0.7	<10	Y
B1D110112-005	R2-D3-R-C	Metal Chromium	mg/L	0.603	0.603	0.0	<11	Y
B1D110112-005	R2-D3-R-C	Metal Manganese	mg/L	0.624	0.624	0.0	<10	Y
B1D110112-005	R2-D3-R-C	Metal Molybdenum	mg/L	0.545	0.543	0.4	<10	Y
B1D110112-005	R2-D3-R-C	Metal Nickel	mg/L	0.593	0.591	0.3	<11	Y
B1D280109-002	R3-D2-T-C	Metal Aluminum	mg/L	6.85	6.79	0.9	<11	Y
B1D280109-002	R3-D2-T-C	Metal Cadmium	mg/L	0.547	0.561	2.5	<10	Y
B1D280109-002	R3-D2-T-C	Metal Chromium	mg/L	0.536	0.548	2.2	<11	Y
B1D280109-002	R3-D2-T-C	Metal Copper	mg/L	1.69	1.60	1.9	<12	Y
B1D280109-002	R3-D2-T-C	Metal Lead	mg/L	0.605	0.621	2.6	<10	Y
B1D280109-002	R3-D2-T-C	Metal Manganese	mg/L	0.659	0.670	1.7	<10	Y
B1D280109-002	R3-D2-T-C	Metal	mg/L	0.557	0.563	1.1	<10	Y

		Molybdenum						

PRECISION CALCULATIONS

Laboratory ID	*CTC* ID	Parameter	Units	Sample + Spike Value	Duplicate + Spike Value	RPD %	RPD % Limits	RPD Met ? Y/N
B1D280109-002	R3-D2-T-C	Metal Nickel	mg/L	0.576	0.587	1.9	<11	Y
B1D280109-002	R3-D2-T-C	Metal Tin	mg/L	0564	0.556	1.4	<10	Y
B1D030121-003	R3-D4-T-C	Metal Aluminum	mg/L	5.47	5.45	0.4	<11	Y
B1D030121-003	R3-D4-T-C	Metal Cadmium	mg/L	0.545	0.545	0.0	<10	Y
B1D030121-003	R3-D4-T-C	Metal Chromium	mg/L	0527	0.526	0.2	<11	Y
B1D030121-003	R3-D4-T-C	Metal Copper	mg/L	1.53	1.53	0.0	<12	Y
B1D030121-003	R3-D4-T-C	Metal Lead	mg/L	0.578	0.577	0.2	<10	Y
B1D030121-003	R3-D4-T-C	Metal Manganese	mg/L	0.857	0.855	0.2	<10	Y
B1D030121-003	R3-D4-T-C	Metal Molybdenum	mg/L	0568	0.563	0.9	<10	Y
B1D030121-003	R3-D4-T-C	Metal Nickel	mg/L	0.564	0.564	0.0	<11	Y
B1D030121-003	R3-D4-T-C	Metal Tin	mg/L	0.560	0.560	0.0	<10	Y
B1D110112-013	R2-SLUDGE	Metal Cadmium	mg/kg	464	476	0.3	<10	Y
B1D110112-013	R2-SLUDGE	Metal Chromium	mg/kg	574	563	0.2	<10	Y
B1D110112-013	R2-SLUDGE	Metal Manganese	mg/kg	1073	936	13.4	<14	Y
B1D110112-013	R2-SLUDGE	Metal Molybdenum	mg/kg	415	428	3.1	<10	Y
B1D110112-013	R2-SLUDGE	Metal Nickel	mg/kg	800	727	10.7	<10	N
B1D030121-008	R3-SLUDGE	Metal Aluminum	mg/kg	1370	1420	0.4	<24	Y
B1D030121-008	R3-SLUDGE	Metal Cadmium	mg/kg	63.9	64.8	1.4	<10	Y
B1D030121-008	R3-SLUDGE	Metal Chromium	mg/kg	125	133	6.2	<10	Y
B1D030121-008	R3-SLUDGE	Metal Manganese	mg/kg	114	120	5.2	<14	Y
B1D030121-008	R3-SLUDGE	Metal Molybdenum	mg/kg	61.1	62.0	1.4	<10	Y
B1D030121-008	R3-SLUDGE	Metal Nickel	mg/kg	81.3	83.5	2.7	<10	Y

APPENDIX B

ACCURACY CALCULATIONS

ACCURACY CALCULATIONS

CTC Sample ID	Parameter	Units	Sample Value	Sample +Spike Value	Spike Value	Recovery %	Target % Recovery	Accuracy Met? Y/N
R2-D2-T-G1	O&G (HEM)	mg/L	<1.0	8.80	10.00	88	70 – 130	Y
R2-D2-T-G1	O&G (HEM)	mg/L	<1.0	9.20	10.00	92	70 – 130	Y
R2-D2-T-G1	O&G (Freon)	mg/L	<1.0	9.80	10.00	98	70 – 130	Y
R2-D2-T-G1	O&G (Freon)	mg/L	<1.0	10.0	10.00	100	70 – 130	Y
R2-D3-R-G1	O&G (HEM)	mg/L	<1.0	8.40	10.00	84	70 – 130	Y
R2-D3-R-G1	O&G (HEM)	mg/L	<1.0	8.20	10.00	82	70 – 130	Y
R2-D3-R-G1	O&G (Freon)	mg/L	<1.0	9.80	10.00	98	70 – 130	Y
R2-D3-R-G1	O&G (Freon)	mg/L	<1.0	9.90	10.00	99	70 – 130	Y
R3-D3-R-G2	O&G (HEM)	mg/L	<1.0	9.60	10.00	96	70 – 130	Y
R3-D3-R-G2	O&G (HEM)	mg/L	<1.0	9.50	10.00	95	70 – 130	Y
R3-D3-R-G2	O&G (Freon)	mg/L	<1.0	9.80	10.00	98	70 – 130	Y
R3-D3-R-G2	O&G (Freon)	mg/L	<1.0	9.00	10.00	90	70 – 130	Y
R3-D3-T-G1	O&G (HEM)	mg/L	<1.0	9.60	10.00	96	70 – 130	Y
R3-D3-T-G1	O&G (HEM)	mg/L	<1.0	9.50	10.00	95	70 – 130	Y
R3-D3-T-G1	O&G (Freon)	mg/L	<1.0	9.00	10.00	90	70 – 130	Y
R3-D3-T-G1	O&G (Freon)	mg/L	<1.0	8.80	10.00	88	70 – 130	Y
R3-D3-T-G1	Total Sulfide	mg/L	<1.0	18.9	20.0	94	90 – 110	Y
R3-D3-T-G1	Total Sulfide	mg/L	<1.0	18.9	20.0	94	90 – 110	Y
R3-D3-R-G2	Total Sulfide	mg/L	<1.0	19.2	20.0	96	90 – 110	Y
R3-D3-R-G2	Total Sulfide	mg/L	<1.0	19.1	20.0	96	90 – 110	Y
R3-D3-T-G2	Total Sulfide	mg/L	<1.0	19.2	20.0	96	90 – 110	Y
R3-D3-T-G2	Total Sulfide	mg/L	<1.0	19.2	20.0	96	90 – 110	Y
R2-D2-T-C	Metal Cadmium	mg/L	0.012	0.568	0.500	111	85 – 115	Y
R2-D2-T-C	Metal Cadmium	mg/L	0.012	0.588	0.500	115	85 – 115	Y
R2-D2-T-C	Metal Chromium	mg/L	0.014	0.538	0.500	105	85 – 115	Y
R2-D2-T-C	Metal Chromium	mg/L	0.014	0.538	0.500	105	85 – 115	Y
R2-D2-T-C	Metal Copper	mg/L	7.9	MSB	0.500	NC	85 – 115	NC
R2-D2-T-C	Metal Copper	mg/L	7.9	MSB	0.500	NC	85 – 115	NC
R2-D2-T-C	Metal Lead	mg/L	0.13	0.677	0.500	109	85 – 115	Y
R2-D2-T-C	Metal Lead	mg/L	0.13	0.701	0.500	114	85 – 115	Y
R2-D2-T-C	Metal Manganese	mg/L	0.32	0.839	0.500	104	85 – 115	Y
R2-D2-T-C	Metal Manganese	mg/L	0.32	0.873	0.500	111	85 – 115	Y
R2-D2-T-C	Metal Molybdenum	mg/L	<0.1	0.533	0.500	107	85 – 115	Y
R2-D2-T-C	Metal Molybdenum	mg/L	<0.1	0.560	0.500	112	85 – 115	Y
R2-D2-T-C	Metal Nickel	mg/L	0.45	0.576	0.500	106	85 – 115	Y
R2-D2-T-C	Metal Nickel	mg/L	0.45	0.596	0.500	110	85 – 115	Y
R2-D2-T-C	Metal Tin	mg/L	0.20	0.728	0.500	105	85 – 115	Y
R2-D2-T-C	Metal Tin	mg/L	0.20	0.749	0.500	109	85 – 115	Y
R2-D2-T-C	Metal Zinc	mg/L	24.1	MSB	0.500	NC	85 – 115	NC
R2-D2-T-C	Metal Zinc	mg/L	24.1	MSB	0.500	NC	85 – 115	NC
R2-D3-R-C	Metal Cadmium	mg/L	0.053	0.557	0.500	110	85 – 115	Y
R2-D3-R-C	Metal Cadmium	mg/L	0.053	0.553	0.500	110	85 – 115	Y
R2-D3-R-C	Metal Chromium	mg/L	0.066	0.603	0.500	107	85 – 115	Y
R2-D3-R-C	Metal Chromium	mg/L	0.066	0.603	0.500	108	85 – 115	Y
R2-D3-R-C	Metal Copper	mg/L	28.6	MSB	0.500	NC	85 – 115	NC
R2-D3-R-C	Metal Copper	mg/L	28.6	MSB	0.500	NC	85 – 115	NC
R2-D3-R-C	Metal Lead	mg/L	10.6	MSB	0.500	NC	85 – 115	NC
R2-D3-R-C	Metal Lead	mg/L	10.6	MSB	0.500	NC	85 – 115	NC
R2-D3-R-C	Metal Manganese	mg/L	0.089	0.624	0.500	107	85 – 115	Y
R2-D3-R-C	Metal Manganese	mg/L	0.089	0.624	0.500	107	85 – 115	Y
R2-D3-R-C	Metal Molybdenum	mg/L	<0.1	0.545	0.500	109	85 – 115	Y
R2-D3-R-C	Metal Molybdenum	mg/L	<0.1	0.543	0.500	109	85 – 115	Y
R2-D3-R-C	Metal Nickel	mg/L	0.067	0.593	0.500	105	85 – 115	Y
R2-D3-R-C	Metal Nickel	mg/L	0.067	0.591	0.500	105	85 – 115	Y
R2-D3-R-C	Metal Tin	mg/L	14.5	MSB	0.500	NC	85 – 115	NC
R2-D3-R-C	Metal Tin	mg/L	14.5	MSB	0.500	NC	85 – 115	NC
R2-D3-R-C	Metal Zinc	mg/L	84.4	MSB	0.500	NC	85 – 115	NC
R2-D3-R-C	Metal Zinc	mg/L	84.4	MSB	0.500	NC	85 – 115	NC

ACCURACY CALCULATIONS

CTC Sample ID	Parameter	Units	Sample Value	Sample +Spike Value	Spike Value	Recovery %	Target % Recovery	Accuracy Met? Y/N
R3-D2-T-C	Metal Aluminum	mg/L	1.4	6.85	5.0	108	85 – 115	Y
R3-D2-T-C	Metal Aluminum	mg/L	1.4	6.79	5.0	107	85 – 115	Y
R3-D2-T-C	Metal Cadmium	mg/L	<0.005	0.547	0.500	109	85 – 115	Y
R3-D2-T-C	Metal Cadmium	mg/L	<0.005	0.561	0.500	112	85 – 115	Y
R3-D2-T-C	Metal Chromium	mg/L	0.022	0.536	0.500	103	85 – 115	Y
R3-D2-T-C	Metal Chromium	mg/L	0.022	0.548	0.500	105	85 – 115	Y
R3-D2-T-C	Metal Copper	mg/L	1.1	1.63	0.500	112	85 – 115	Y
R3-D2-T-C	Metal Copper	mg/L	1.1	1.60	0.500	105	85 – 115	Y
R3-D2-T-C	Metal Lead	mg/L	0.067	0.605	0.500	108	85 – 115	Y
R3-D2-T-C	Metal Lead	mg/L	0.067	0.621	0.500	111	85 – 115	Y
R3-D2-T-C	Metal Manganese	mg/L	0.13	0.659	0.500	105	85 – 115	Y
R3-D2-T-C	Metal Manganese	mg/L	0.13	0.670	0.500	107	85 – 115	Y
R3-D2-T-C	Metal Molybdenum	mg/L	<0.1	0.557	0.500	111	85 – 115	Y
R3-D2-T-C	Metal Molybdenum	mg/L	<0.1	0.563	0.500	113	85 – 115	Y
R3-D2-T-C	Metal Nickel	mg/L	0.038	0.576	0.500	107	85 – 115	Y
R3-D2-T-C	Metal Nickel	mg/L	0.038	0.587	0.500	110	85 – 115	Y
R3-D2-T-C	Metal Tin	mg/L	0.036	0.564	0.500	106	85 – 115	Y
R3-D2-T-C	Metal Tin	mg/L	0.036	0.556	0.500	104	85 – 115	Y
R3-D2-T-C	Metal Zinc	mg/L	9.0	MSB	0.500	NC	85 – 115	NC
R3-D2-T-C	Metal Zinc	mg/L	9.0	MSB	0.500	NC	85 – 115	NC
R3-D4-T-C	Metal Aluminum	mg/L	0.16	5.47	5.0	106	85 – 115	Y
R3-D4-T-C	Metal Aluminum	mg/L	0.16	5.45	5.0	106	85 – 115	Y
R3-D4-T-C	Metal Cadmium	mg/L	<0.005	0.545	0.500	109	85 – 115	Y
R3-D4-T-C	Metal Cadmium	mg/L	<0.005	0.545	0.500	109	85 – 115	Y
R3-D4-T-C	Metal Chromium	mg/L	<0.01	0.527	0.500	105	85 – 115	Y
R3-D4-T-C	Metal Chromium	mg/L	<0.01	0.526	0.500	105	85 – 115	Y
R3-D4-T-C	Metal Copper	mg/L	0.98	1.53	0.500	110	85 – 115	Y
R3-D4-T-C	Metal Copper	mg/L	0.98	1.53	0.500	109	85 – 115	Y
R3-D4-T-C	Metal Lead	mg/L	0.026	0.578	0.500	110	85 – 115	Y
R3-D4-T-C	Metal Lead	mg/L	0.026	0.577	0.500	110	85 – 115	Y
R3-D4-T-C	Metal Manganese	mg/L	0.32	0.857	0.500	107	85 – 115	Y
R3-D4-T-C	Metal Manganese	mg/L	0.32	0.855	0.500	107	85 – 115	Y
R3-D4-T-C	Metal Molybdenum	mg/L	<0.1	0.568	0.500	114	85 – 115	Y
R3-D4-T-C	Metal Molybdenum	mg/L	<0.1	0.563	0.500	113	85 – 115	Y
R3-D4-T-C	Metal Nickel	mg/L	0.032	0.564	0.500	106	85 – 115	Y
R3-D4-T-C	Metal Nickel	mg/L	0.032	0.564	0.500	106	85 – 115	Y
R3-D4-T-C	Metal Tin	mg/L	0.030	0.560	0.500	106	85 – 115	Y
R3-D4-T-C	Metal Tin	mg/L	0.030	0.560	0.500	106	85 – 115	Y
R3-D4-T-C	Metal Zinc	mg/L	13.7	MSB	0.500	NC	85 – 115	NC
R3-D4-T-C	Metal Zinc	mg/L	13.7	MSB	0.500	NC	85 – 115	NC
R2-SLUDGE	Metal Cadmium	mg/kg	16.6	464	449	100	85 – 115	Y
R2-SLUDGE	Metal Cadmium	mg/kg	16.6	476	449	102	85 – 115	Y
R2-SLUDGE	Metal Chromium	mg/kg	141	574	449	97	85 – 115	Y
R2-SLUDGE	Metal Chromium	mg/kg	141	563	449	94	85 – 115	Y
R2-SLUDGE	Metal Copper	mg/kg	111,000	MSB	449	NC	85 – 115	NC
R2-SLUDGE	Metal Copper	mg/kg	111,000	MSB	449	NC	85 – 115	NC
R2-SLUDGE	Metal Lead	mg/kg	42,200	MSB	449	NC	85 – 115	NC
R2-SLUDGE	Metal Lead	mg/kg	42,200	MSB	449	NC	85 – 115	NC
R2-SLUDGE	Metal Manganese	mg/kg	593	1070	449	107	85 – 115	Y
R2-SLUDGE	Metal Manganese	mg/kg	593	936	449	76	85 – 115	N
R2-SLUDGE	Metal Molybdenum	mg/kg	<89.8	415	449	92	85 – 115	Y
R2-SLUDGE	Metal Molybdenum	mg/kg	<89.8	428	449	95	85 – 115	Y
R2-SLUDGE	Metal Nickel	mg/kg	369	809	449	98	85 – 115	Y
R2-SLUDGE	Metal Nickel	mg/kg	369	727	449	80	85 – 115	N
R2-SLUDGE	Metal Tin	mg/kg	49,400	MSB	449	NC	85 – 115	NC
R2-SLUDGE	Metal Tin	mg/kg	49,400	MSB	449	NC	85 – 115	NC
R2-SLUDGE	Metal Zinc	mg/kg	251,000	MSB	449	NC	85 – 115	NC
R2-SLUDGE	Metal Zinc	mg/kg	251,000	MSB	449	NC	85 – 115	NC

ACCURACY CALCULATIONS

CTC Sample ID	Parameter	Units	Sample Value	Sample +Spike Value	Spike Value	Recovery %	Target % Recovery	Accuracy Met? Y/N
R3-SLUDGE	Metal Aluminum	mg/kg	833	1370	641	84	85 – 115	N
R3-SLUDGE	Metal Aluminum	mg/kg	833	1420	641	91	85 – 115	Y
R3-SLUDGE	Metal Cadmium	mg/kg	<6.4	63.9	64.1	100	85 – 115	Y
R3-SLUDGE	Metal Cadmium	mg/kg	<6.4	64.8	64.1	101	85 – 115	Y
R3-SLUDGE	Metal Chromium	mg/kg	70.4	125	64.1	85	85 – 115	Y
R3-SLUDGE	Metal Chromium	mg/kg	70.4	133	64.1	98	85 – 115	Y
R3-SLUDGE	Metal Copper	mg/kg	34300	MSB	64.1	NC	85 – 115	NC
R3-SLUDGE	Metal Copper	mg/kg	34300	MSB	64.1	NC	85 – 115	NC
R3-SLUDGE	Metal Lead	mg/kg	4550	MSB	64.1	NC	85 – 115	NC
R3-SLUDGE	Metal Lead	mg/kg	4550	MSB	64.1	NC	85 – 115	NC
R3-SLUDGE	Metal Manganese	mg/kg	55.0	114	64.1	92	85 – 115	Y
R3-SLUDGE	Metal Manganese	mg/kg	55.0	120	64.1	101	85 – 115	Y
R3-SLUDGE	Metal Molybdenum	mg/kg	<64.1	61.1	64.1	95	85 – 115	Y
R3-SLUDGE	Metal Molybdenum	mg/kg	<64.1	62.0	64.1	97	85 – 115	Y
R3-SLUDGE	Metal Nickel	mg/kg	19.5	81.3	64.1	96	85 – 115	Y
R3-SLUDGE	Metal Nickel	mg/kg	19.5	83.5	64.1	100	85 – 115	Y
R3-SLUDGE	Metal Tin	mg/kg	4390	MSB	64.1	NC	85 – 115	NC
R3-SLUDGE	Metal Tin	mg/kg	4390	MSB	64.1	NC	85 – 115	NC
R3-SLUDGE	Metal Zinc	mg/kg	1380	MSB	64.1	NC	85 – 115	NC
R3-SLUDGE	Metal Zinc	mg/kg	1380	MSB	64.1	NC	85 – 115	NC

MSB = The recovery and RPD were not calculated because the sample amount was greater than four times the spike amount.
NC = The recovery and/or RPD were not calculated.

APPENDIX C

REPRESENTATIVENESS CALCULATIONS

REPRESENTATIVENESS CALCULATIONS

CTC ID	Parameter	Units	Sample Value	Duplicate *CTC* ID	Duplicate Value	% Difference	RPD % Limits	RPD Met ? Y/N
R2-D2-T-G1	O&G (HEM)	mg/L	<1.0	R2-D2-T-G1-D	<1.0	0.0	30	Y
R2-D2-T-G1	O&G (Freon)	mg/L	<1.0	R2-D2-T-G1-D	<1.0	0.0	30	Y
R2-D2-T-G2	O&G (HEM)	mg/L	<1.0	R2-D2-T-G2-D	<1.0	0.0	30	Y
R3-D3-R-G2	O&G (Freon)	mg/L	<1.0	R2-D2-T-G2-D	<1.0	0.0	30	Y
R3-D3-R-G2	O&G (HEM)	mg/L	16.7	R3-D3-R-G2-D	19.2	13.9	30	Y
R2-D2-T-G2	O&G (Freon)	mg/L	16.0	R3-D3-R-G2-D	39.4	84.5	30	N
R3-D3-T-G1	O&G (HEM)	mg/L	<1.0	R3-D3-T-G1-D	<1.0	0.0	30	Y
R3-D3-T-G1	O&G (Freon)	mg/L	<1.0	R3-D3-T-G1-D	<1.0	0.0	30	Y
R2-D2-T-C	pH	NA	6.6	R2-D2-T-C-D	6.4	3.1	20	Y
R3-D3-R-C	pH	NA	6.4	R3-D3-R-C-D	6.4	0.0	20	Y
R3-D3-T-C	pH	NA	6.8	R3-D3-T-C-D	6.9	1.4	20	Y
R2-D2-T-C	TDS	mg/L	2840	R2-D2-T-C-D	2820	0.7	10	Y
R3-D3-R-C	TDS	mg/L	2060	R3-D3-R-C-D	2040	1.0	10	Y
R3-D3-T-C	TDS	mg/L	2690	R3-D3-T-C-D	2670	0.7	10	Y
R2-D2-T-C	TSS	mg/L	14.0	R2-D2-T-C-D	15.0	6.9	15	Y
R3-D3-R-C	TSS	mg/L	56.0	R3-D3-R-C-D	54.0	3.6	10	Y
R2-D2-T-C	TOC	mg/L	4.5	R2-D2-T-C-D	4.5	2.2	10	Y
R3-D3-R-C	TOC	mg/L	10.7	R3-D3-R-C-D	10.8	0.1	10	Y
R3-D3-T-C	TOC	mg/L	8.7	R3-D3-T-C-D	8.1	7.1	10	Y
R2-D2-T-C	Cadmium	mg/L	0.012	R2-D2-T-C-D	0.012	0.0	10	Y
R2-D2-T-C	Chromium	mg/L	0.014	R2-D2-T-C-D	0.012	15.4	11	N
R2-D2-T-C	Copper	mg/L	7.9	R2-D2-T-C-D	7.9	0.0	12	Y
R2-D2-T-C	Manganese	mg/L	0.32	R2-D2-T-C-D	0.32	0.0	10	Y
R2-D2-T-C	Molybdenum	mg/L	<0.1	R2-D2-T-C-D	<0.1	0.0	10	Y
R2-D2-T-C	Nickel	mg/L	0.045	R2-D2-T-C-D	0.044	2.2	10	Y
R2-D2-T-C	Lead	mg/L	0.13	R2-D2-T-C-D	0.13	0.0	10	Y
R2-D2-T-C	Tin	mg/L	0.20	R2-D2-T-C-D	0.21	4.6	10	Y
R2-D2-T-C	Zinc	mg/L	24.1	R2-D2-T-C-D	23.8	1.3	10	Y
R3-D3-R-C	Aluminum	mg/L	1.6	R3-D3-R-C-D	1.6	0.0	15	Y
R3-D3-R-C	Cadmium	mg/L	<0.005	R3-D3-R-C-D	<0.005	0.0	10	Y
R3-D3-R-C	Chromium	mg/L	0.042	R3-D3-R-C-D	0.043	2.4	11	Y
R3-D3-R-C	Copper	mg/L	25.5	R3-D3-R-C-D	25.1	1.6	12	Y
R3-D3-R-C	Manganese	mg/L	0.071	R3-D3-R-C-D	0.070	1.4	10	Y
R3-D3-R-C	Molybdenum	mg/L	<0.1	R3-D3-R-C-D	<0.1	0.0	10	Y
R3-D3-R-C	Nickel	mg/L	<0.04	R3-D3-R-C-D	<0.04	0.0	10	Y
R3-D3-R-C	Lead	mg/L	2.9	R3-D3-R-C-D	2.9	0.0	10	Y
R3-D3-R-C	Tin	mg/L	3.0	R3-D3-R-C-D	3.1	3.3	10	Y
R3-D3-R-C	Zinc	mg/L	36.2	R3-D3-R-C-D	35.6	1.7	10	Y
R3-D3-T-C	Aluminum	mg/L	0.39	R3-D3-T-C-D	0.35	10.8	15	Y
R3-D3-T-C	Cadmium	mg/L	<0.005	R3-D3-T-C-D	<0.005	0.0	10	Y
R3-D3-T-C	Chromium	mg/L	0.013	R3-D3-T-C-D	0.012	8.0	11	Y
R3-D3-T-C	Copper	mg/L	1.3	R3-D3-T-C-D	1.3	0.0	12	Y
R3-D3-T-C	Manganese	mg/L	0.20	R3-D3-T-C-D	0.20	0.0	10	Y
R3-D3-T-C	Molybdenum	mg/L	<0.1	R3-D3-T-C-D	<0.1	0.0	10	Y
R3-D3-T-C	Nickel	mg/L	<0.04	R3-D3-T-C-D	<0.04	0.0	10	Y
R3-D3-T-C	Lead	mg/L	<0.05	R3-D3-T-C-D	<0.05	0.0	10	Y

CTC ID	Parameter	Units	Sample Value	Duplicate *CTC* ID	Duplicate Value	% Difference	RPD % Limits	RPD Met ? Y/N
R3-D3-T-C	Tin	mg/L	<0.1	R3-D3-T-C-D	<0.1	0.0	10	Y
R3-D3-T-C	Zinc	mg/L	8.6	R3-D3-T-C-D	7.9	8.5	10	Y
R2-Sludge	Cadmium	mg/kg	<44.9	R2-Sludge-D	<46.5	0.0	10	Y
R2-Sludge	Chromium	mg/kg	141	R2-Sludge-D	120	16.0	10	N
R2-Sludge	Copper	mg/kg	11000	R2-Sludge-D	10600	3.7	15	Y
R2-Sludge	Manganese	mg/kg	593	R2-Sludge-D	552	7.2	14	Y
R2-Sludge	Molybdenum	mg/kg	<89.8	R2-Sludge-D	<92.9	0.0	10	Y
R2-Sludge	Nickel	mg/kg	369	R2-Sludge-D	334	10.0	10	Y
R2-Sludge	Lead	mg/kg	42200	R2-Sludge-D	38800	8.4	25	Y
R2-Sludge	Tin	mg/kg	49400	R2-Sludge-D	43900	11.8	10	N
R2-Sludge	Zinc	mg/kg	51000	R2-Sludge-D	37000	31.8	36	Y
R2-Sludge	Sulfide	mg/L	<1.0	R2-Sludge-D	<1.0	0.0	10	Y
R2-Sludge	Sp. Gravity	NA	1.1	R2-Sludge-D	1.1	0.0	20	Y
R2-Sludge	% Solid	%	5.6	R2-Sludge-D	5.4	3.6	20	Y
R2-Sludge	% Water	%	77	R2-Sludge-D	91.5	17.5	20	Y
M1-Sludge	Cadmium	mg/kg	<70.8	M1-Sludge-D	<46.5	0.0	10	Y
M1-Sludge	Chromium	mg/kg	198	M1-Sludge-D	323	48.0	10	N
M1-Sludge	Copper	mg/kg	53000	M1-Sludge-D	44700	17.0	15	N
M1-Sludge	Manganese	mg/kg	870	M1-Sludge-D	1410	47.4	14	N
M1-Sludge	Molybdenum	mg/kg	<142	M1-Sludge-D	<123	0.0	10	Y
M1-Sludge	Nickel	mg/kg	518	M1-Sludge-D	231	76.6	10	N
M1-Sludge	Lead	mg/kg	64000	M1-Sludge-D	20900	101.5	25	N
M1-Sludge	Tin	mg/kg	72300	M1-Sludge-D	26800	91.8	10	N
M1-Sludge	Zinc	mg/kg	370000	M1-Sludge-D	105000	111.6	36	N
M1-Sludge	Sulfide	mg/L	<7080	M1-Sludge-D	<6130	0.0	10	Y
M1-Sludge	Sp. Gravity	NA	1.1	M1-Sludge-D	1.0	9.5	20	Y
M1-Sludge	% Solid	%	3.5	M1-Sludge-D	3.6	14.1	20	Y

NA = Not Applicable